



Students' knowledge of emerging technology and sustainability through a design activity in technology education

Johan Lind¹ · Susanne Pelger² · Anders Jakobsson³

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Abstract

The purpose of this study is to explore whether, and if so how, a design activity could encourage students to express and develop knowledge on emerging technology in relation to issues about sustainability. Several researchers have asserted that, in today's technologically dependent society, it is important to be able to control technology and make informed decisions connected to technology. Design activities could make a significant contribution to technology education while students are developing their knowledge about technology. Thus, the present study aims to analyze students' verbal interactions as they work in a design project, which includes designing a model of a house, regarding their ability to develop technological literacy with the support of a physical model. The study is based on several small-group interactions that were recorded, transcribed, analyzed, and discussed. This research project was conducted as an observation of technology education in a Swedish compulsory school. The students (aged 13–14) negotiated and shared knowledge about technology as they interacted with their fellow students. The results indicate that, in a relatively large number of situations, the students expressed knowledge about emerging technology and adopted a sustainability perspective while working in a design activity, and thereby, successively developed technological literacy. This meant that the students were able to integrate knowledge on emerging technology like graphene, nanotechnology, and algae batteries in their models. Furthermore, the results indicate that, during technical development work, students were able to develop reasoning, communication, and collaboration skills.

Keywords Technology education · Design activity · Emerging technology · Sustainability · Technological literacy · SOLO taxonomy

✉ Johan Lind
johan.lind@uvel.lu.se

¹ Department of Educational Sciences, Lund University, Lund, Sweden

² Faculty of Science, Lund University, Lund, Sweden

³ Faculty of Education and Society, Malmö University, Malmö, Sweden

Introduction

In Western societies, most educational curricula assert that technology education should aim to help students develop an interest in technology and an ability to meet technical challenges in a conscious and innovative way. In Sweden, for example, technology education is characterized as a subject that aims to develop students' technical skills and technological awareness in order to prepare them to be part of and act in a technology-intensive world (Swedish National Agency for Education 2017). According to this curriculum, technology education is largely about communicating ideas through creating models and drawings and using support from technological concepts and symbols. This could include explaining ideas behind a model or clarifying underlying thoughts about a self-made construction or design idea. In recent years, several researchers (e.g., Ingerman and Collier-Reed 2011) have referred to this type of knowledge or generic skills as *technological literacy*. This view highlights students' ability to communicate technology in different situations and to develop their abilities in this area as a central part of technology education. Thus, teachers should aim to create opportunities for interactions in the classroom, such as group interactions along with practical work related to issues about technology. Moreover, technological literacy could be viewed as a combination of technological awareness, an ability to work with problem-solving activities and to work in projects, as well as the ability to communicate ideas supported by drawings, models, or design work (Custer et al. 2001; Blomdahl and Rogala 2008). According to McCormick (2006) and Keirl (2006), technology literacy is also a matter of enabling students to reflect on their technological lives, to develop critical awareness about how to live in a technological world, and to learn to discern the benefits and disadvantages of technology (Dakers 2006).

However, Middleton (2009) argued that an important part of technology education is an explicit focus on problem-solving in relation to issues about sustainability. Further, Winthrop et al. (2016) and Lind et al. (2019) claimed that educational activities become relevant and engaging when students are involved in doing things while reflecting and responding to real-world challenges. They also argued that we can expect societies to work well with emerging technologies if young people are equipped with abilities regarding literacy, numeracy, and science, as well as flexibility, creativity, and collaborative work. This implies that technology education may be presented as problem-solving activities in which students develop ideas and technological solutions collaboratively. According to Wells (2013), technology education has the potential to support design thinking that enables students to identify and develop solutions to potential technological achievements. He also indicated that *design activities* constitute an essential part of technological literacy and that education should improve design and creative thinking rather than limit creativity and risk-taking. Therefore, design activities could also be part of education from an early age, especially within the learning of technological literacy. Moreover, Archer and Roberts (2009) claimed that a design activity concerns individuals in relation to artifacts and systems and estimations of the effects of human activities such as sustainability issues.

However, among the important issues in this context are determining which activities constitute a design process in compulsory technology education and what specific abilities these activities require of students. For example, Middleton (2005) emphasized that a design process usually requires students to be able to identify a technical problem, undertaking research and technological investigations, and developing, producing and evaluating different solutions. Vande Zande et al. (2014) stressed that the design process requires students to be able to generate and try out new ideas, make prototypes and models, and

present solutions. Other researchers (Blomdahl and Rogala 2008) have pointed out that several different types of skills need to be developed in order to participate in a design process together with others. They suggest that the activities should focus on the students' abilities to communicate the language of technology with support from various techniques, such as drawings and models. In these contexts, de Vries (2005) emphasized that contemporary and emerging technology needs to be studied through visualizations, often without access to a physical model, which also places new and challenging demands on students.

Thus, in view of all these studies, the purpose of the present study is to examine what specific abilities and skills design activities in technology education require of students and explore the extent to which the students express and develop conceptual knowledge about emerging technology. However, there is a lack of studies in technology education literature related to these issues. This implies a lack of studies that empirically focus on students carrying out design activities in action, and studies that describe the opportunities and problems this specific situation creates. In the present study, the design activity the students are engaged in requires them to be independently able to produce a drawing and construct a physical model of a future house or apartment that includes emerging technology and, more specifically, sustainable solutions to environmental problems. This involves presentations and reflective dialogues in which the students' ideas are tested with other participants' ideas. The purpose of this approach is to explore the ways in which a design activity can promote students to communicate knowledge on technology and how, in doing this, they successively develop technological literacy.

Notwithstanding all these above-mentioned studies, there is a lack of studies in technology education literature related to the specific abilities and skills that design activities in technology education require of students and that explore the extent to which the students express and develop conceptual knowledge about emerging technology. This implies a lack of studies that empirically focus on students carrying out design activities in action, and studies that describe the opportunities and problems this specific situation creates.

The study and research questions

The purpose of the study is to explore the ability of students to express and develop knowledge on emerging technology through a design activity in technology education. An underlying aim is to explore what kind of abilities the students in this situation require and which abilities they develop during their work. Thus, the research questions in this study are as follows:

1. In what ways do students express and develop knowledge about emerging technology through a design activity?
2. In what ways could a design activity promote students' progress development of technological literacy?

In the present study, the design activity the students are engaged in requires them to be independently able to produce a drawing and construct a physical model of a future house or apartment that includes emerging technology and, more specifically, sustainable solutions to environmental problems. This involves presentations and reflective dialogues in which the students' ideas are tested with other participants' ideas. The purpose of this approach is to explore the ways in which a design activity can promote students to

communicate knowledge on technology and how, in doing this, they successively develop technological literacy.

Theoretical background

Technological literacy

The International Technology Education Association [ITEA] (2007) defines technological literacy as the ability to manage, use, evaluate, and develop problem-solving abilities, as well as the ability to understand technological systems and artifacts. Further, to be technologically literate one must have hands-on abilities, such as making a drawing, using tools, and constructing a model (Frederik et al. 2011). Additionally, a technologically literate individual must be able to communicate knowledge in a specific situation (Blomdahl and Rogala 2008; Frederik et al. 2011). For example, Lind et al. (2019) investigated students' ideas about technological concepts in relation to technological systems. However, that study also focused on students' reasoning and collaboration in small-group interactions and concluded that the students' joint discussions were crucial for their individual knowledge development and their ability to express themselves about technology. The process of explaining and justifying a choice of a solution seems to support the development of technological knowledge, as well as thoughts on technology. According to the authors (Lind et al. 2019), the students in that study expressed and developed knowledge about technological concepts within a specific situation—something that Blomdahl and Rogala (2008) considered to be part of technological literacy.

Ingerman and Collier-Reed (2011) also emphasized that actions and competences used in specific situations are essential parts of technology and technological literacy and that literacy occurs within the relation between individuals and technology. They also considered that *competences in action* (Ingerman and Collier-Reed 2011) were an essential part of technological literacy and defined them as recognizing needs, articulating problems, contributing towards the technological process, and analyzing consequences. This implies that the enactment of technological literacy involves competences in action and could be described as the way in which technical knowledge is used through social commitment. For example, students recognize the need for electricity in apartments and discuss how to solve the emerging problem with fellow students. The context requires students to use their knowledge on how technological systems of electricity supply work in order to be able to articulate the problem and to solve the problem, thus contributing towards a technological process. This requires competences in action, which together create a context in which students could possibly solve the problem. According to this view, technological literacy becomes the relationship between the articulated problem and the recognized need. In other words, the ways in which the solution solves the identified problem and satisfies the expressed human need (Ingerman and Collier-Reed 2011).

The design process as a design activity in school

Vande Zande et al. (2014) argued that the design process is integrated in technology education because students are expected to be able to identify problems, think problems through and explore new approaches if the first one did not work. They also proposed six aspects of the design process: *defining a problem, investigating and researching, generating ideas,*

making the prototype, presenting, and evaluating and revising. This is close to Middleton's (2005) five aspects of the design process: *identifying a problem, undertaking research, developing solutions, producing solutions and evaluating solutions.* Moreover, Mioduser (1998) suggested that students are involved in four aspects while designing technological solutions: *identifying problems, exploring ideas of solutions, constructing, and evaluating.* In accordance with the Swedish curriculum, these aspects are similar to a technology development work: *identifying needs, investigating, developing solutions, designing, and evaluating a product* (Swedish National Agency for Education 2017). Although the different definitions appear to be similar, there are differences in word choice and emphasis. The various aspects of the design process are summarized in Table 1.

Furthermore, Blomdahl and Rogala (2008) pointed out that students, in design activities, should be given opportunities to develop their abilities to communicate the language of technology with support from various presentation techniques, such as drawings and models. In addition, Martin (2017) emphasized that one way of expressing knowledge and explaining and clarifying an idea is by sketching. Hence, the technical drawings and models could be viewed as visible evidence of the understanding achieved during a project. According to Buxton (2007), the drawings and models, in interaction between students, may be developed and revised while they simultaneously achieve new knowledge. However, some technical knowledge has to be visualized; for example, in a technical drawing where emerging technology can be imagined without physical material (de Vries 2005). Accordingly, de Vries (2005) assumed that drawings contain a large amount of knowledge that may not be articulated in words, while Medway (1994) argued that drawings might express perspective on the design that cannot be constructed practically, as well as promote interaction in the work process. Thus, design activities are often characterized as technological problem-solving activities in which students could learn to think innovatively and become creative problem-solvers, both as individuals and as members of a group (e.g., Barlex 2006). From this view, problem-solving requires people to come up with solutions to their everyday challenges (Wakefield 2017), which includes both thinking and doing (Svensson and Johansen 2019).

In the present study, for example, creating a drawing of a future house or an apartment requires students to have both practical and theoretical skills to know how to construct technical drawings. This reasoning works well in conjunction with McCormick's (2004) statement that technological knowledge is procedural, conceptual, and context-dependent. He considers procedural knowledge as managing to take on a problem and solve it in a practical way. Conceptual knowledge adds understanding of how things are connected and

Table 1 Overview of the aspects in the design process based on the authors' different perspectives

Vande Zande et al. (2014)	Middleton (2005)	Mioduser (1998)	Swedish National Agency for Education
Defining a problem	Identifying a problem	Identifying a problem	Identifying needs
Investigating and researching	Undertaking research	Exploring ideas of solutions	Investigating
Generating ideas	Developing solutions	Constructing	Developing solutions
Making the prototype	Producing solutions	Evaluating	Designing a product
Presenting	Evaluating solutions		Evaluating a product
Evaluating and revising			

related to each other and enables humans to think out solutions and link knowledge from different areas (McCormick 2006). According to this view, procedural knowledge and conceptual knowledge are integrated and included in practical problem-solving (Svensson and Johansen 2019) and design processes (McCormick 2004).

Williams (2000) also highlighted the importance of considering technology activities as being thoroughly integrated and not divided into procedural and conceptual knowledge or practice and theory. Working with technological systems in a known context—for example, technological systems related to an apartment—gives students opportunities to develop understanding of the technical environment they live in (cf. Lind et al. 2019). Hence, students could develop technological awareness of how society is constructed in systems (Blomdahl and Rogala 2008). During a design activity, for example, sketching helps designers handle different levels of abstraction (Cross 1999), think problems through (Buxton 2007), extend short-term memory for problem-solving (Lane 2018), support communication and analysis (Hennessy and Murphy 1999; Schütze et al. 2003), and develop design in teams (Goldschmidt 2007). Thus, sketching becomes an important part of the design process, as in identifying needs, developing solutions, and analyzing consequences based on current knowledge (cf. Cross 1999; Goldschmidt 2007; Schütze et al. 2003). Nielsen (2017) stated that students also need to develop their understanding of the design process in order to take part in decision making in the nearby future regarding technology. This implies that designing is an intellectual process that involves reasoning, and that this reasoning is facilitated by visual representations of knowledge such as images and physical models, as well as tinkering with tangible material. Representations could provide students with support in a problem-solving design activity (Larkin and Simon 1987), such as the making of technical drawings. Martin (2017) also pointed out that the drawings and models express both theory and practice, thus bringing students' ideas to a tangible form and visualizing specific properties. Thereby, technical drawings can visualize and communicate ideas and concepts on emerging technological solutions.

Further, Söderling (2018) argued that it is important to give students opportunities to use different ways of expressing themselves, to get access to abilities that are required to describe, for example, technical drawings. Technical drawings may help students specify the problem and create common ground for dialogue and discussion within the problem-solving process (Blomdahl and Rogala 2008). According to Nielsen (2017), visual representations can communicate complex technological solutions better than words. A study by Yliveronen et al. (2018) explored six-year-old students' collaboration during a craft design assignment from the perspective of verbal and embodied interactions. The assignment was to collaboratively design and sketch the nests of forest animals. The researchers' focus was on students' verbal interactions depending on the use of language and embodied interactions. The results indicate that six-year-olds can work collaboratively and solve a design task verbally. According to the conclusions, the students also developed sufficient abilities to express their thoughts, consider and listen to the other participants, and find a way to collaborate as a group. Rowell (2002) also studied students' interactions as they participated in a shared task of building a robot. She focused on problem-solving through technology, where each student participated in a group by jointly creating a robot. Her results indicate that language skills are central to solving problems collaboratively. Hennessy and Murphy (1999) explained this situation as a close relationship between verbal language and underlying thoughts, and concluded that discussions develop thinking as ideas are shared and evaluated, feedback received and interpreted, new issues resolved, and joint decisions made. According to Razzouk and Shute (2012), students' abilities to clarify and elaborate ideas develop as they put words to their ideas in small-group discussions. In another study,

Vande Zande et al. (2014) concluded that when students interact with other students who have different perspectives, knowledge, and skills, they develop abilities to express knowledge in various ways. All these studies show clearly that if students develop an understanding for the design process, they are likely to be able to achieve abilities to expand their technological literacy.

Methodical considerations and analytic perspectives

Setting, participants, and data collection

The empirical part of this study was conducted in a municipal school in southern Sweden and followed the technology education over a period of 4 weeks in one class of 36 students in a year 8 class (13–14 years old). During this period, the students worked on a design process concerning housing of the future and were divided into groups of three or four participants. The organization gave the researchers opportunity to more closely observe and document the students' conversations and their practical work in action. This focus in the data collection phase made it possible to get close to the research questions in the analytical part of the study. In order to collect data, the researchers used video recordings of students' interactions, which supports a sociocultural perspective of learning and human development (Jakobsson and Davidsson 2012; Mercer 2000). Video recordings capture material that is useful when analyzing, for example, how students interact with each other and a model (cf. Cohen et al. 2011; Goldman et al. 2014). Furthermore, Ash (2007) stressed that video material enables researchers to capture detailed dialogues and non-verbal communication. The video data is important because the students' interactions often focused on their models of apartments and details therein. It is possible to look at the models as an important cognitive tool that could promote students' ideas on emerging technology and sustainability.

A purposive data sampling procedure could provide the researchers with students who are interested in taking part in a research study as well as talkative, cooperative and articulate informants (Cohen et al. 2011; Shenton 2004). Accordingly, the school and the students were chosen deliberately. Instead of seeking generalizable results, our aim was to collect in-depth information of students thought and ideas about emerging technology and sustainability issues. Hence, as recommended by Shenton (2004), it was important that the participating students could contribute without fear of failing. Therefore, the results were not assessed by their teacher, and the students were thoroughly informed about this fact.

In accordance with the ethical principles of the Swedish Research Council, the students and their guardians were told the purpose of the study and informed about their participation. Students also had the option to refuse to participate or end their participation without any explanation, meaning that only students who were genuinely willing to take part in the research study were involved (Cohen et al. 2011; Shenton 2004). The information mainly focused on the researcher's interest in investigating how students express and develop knowledge about emerging technology through a design activity and how they manage to develop technological literacy. As mentioned, it was considered important to record the interactions in order to come as close as possible to the students' ideas. However, some factors were difficult to control, such as how the groups were composed and how the students respond to the video camera. Parkinson (1999) asserted that the setting of a study can potentially influence and limit the language-related outcomes in a discussion.

Furthermore, the presence of researchers in the classroom is likely to affect the students' interaction because some students want to perform better, while others become quieter and less likely to share their thoughts (Tracy 2010). We assumed that students' understanding of technology may become obvious and explicit when they present and discuss in small groups alongside practical work and the theoretical input.

The conducted case study is a study of ongoing technology work and students' interactions in technological design processes, which seem likely to lead to learning. We argue that knowledge is socially constructed and we therefore present carefully selected examples of how students communicate and discuss emerging technology through a design process. As a case study, we make no claims that the surveyed students' thoughts and ideas are representative of all students of the same age. However, we believe that the study can contribute to increased knowledge, since even limited amounts of data can make a valuable contribution to the shared knowledge (Tracy 2010).

The classroom in the current study

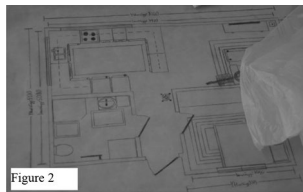
The students were introduced to the design activity assignment, where they were individually asked to construct a drawing and a model. The drawings were made on a scale of 1:20 and the relationship between the drawing and the model was 1:1. The students worked simultaneously with theoretical inputs and practical design work. The theoretical input was especially about contemporary technology, such as graphene, algae batteries, or passive houses and how these products could be used in the near future. We assumed that the physical model referred to the knowledge the students have acquired in the input and possibly built into their model during the project (cf. Schoultz et al. 2001). The activity of making a model supports abilities in the design process, which, according to Johnsey (1998), include planning, evaluating, suggesting how to proceed, and identifying strengths and weaknesses in the design and thus improving the design.

Twice a week, the students were divided into small groups to present their models and solutions. A group of students could possibly extend the range of experience and be able to further develop their experience, which is more difficult to do individually (Buxton 2007). According to Brown (1997), small groups can create meeting places for reflection and collaborative learning. In the small groups, the students presented and discussed the use of emerging technology in their models. In this way, the models were utilized as memory support and something to focus on in the interactions. Blomdahl and Rogala (2008) considered that communication with the support of a model is a way of establishing a language of technology that can visualize students' understanding and clarify their ideas. Further, Barlex (2006) found that students are more likely to develop co-constructed knowledge in socially shared activities, such as group interactions, where students carry out peer reviews while working on a project. Designing a house or apartment is context-dependent, which means that students' current knowledge will probably be integrated in the design process and thereby developed during the construction process. The design activity can be described as incorporating five aspects: planning (including considerations of constraints), designing, making, reflecting, and presenting a physical model. Alongside practical work, input from teachers encourages students to express and develop knowledge on the use of emerging technology. The inputs included a television show featuring a scientist, literature studies, teacher's lectures, and group interactions about emerging technology (such as graphene, nanotechnology, and algae batteries). Figures 1 to 5 describe the working order during the technology project.

1. *Planning* of the apartment (Fig. 1). The students plan by identifying needs and collecting ideas, which are translated into a technical drawing.



2. *Designing* a technical drawing (Fig. 2). This aspect is a process by which the students examine ideas and then produce a solution in a technical drawing.



3. *Making* of models (Fig. 3). At this stage, interaction with the model could be described as interaction through tinkering, which provides engagement to develop the model (Collier-Reed 2006).



4. *Reflecting* on drawings and models (Fig. 4). According to Wells (2013), reflection may be a way to structure knowledge and develop understanding.



5. *Presenting* drawings and models (Fig. 5). The students give and receive verbal responses, and express knowledge about emerging technology.



In this context, the design activity involves the design process aspects stated by Middleton (2005): identifying a problem (aspects 1–2), undertaking research (aspects 2–4), developing a solution (aspects 2–5), evaluating the solution (aspects 4–5), and finally producing a solution (aspects 2–4). In the present study, we investigated classroom activities in which the design process is given implicit attention.

The analytical process

As mentioned, our analysis adopts a sociocultural perspective on learning and human development, which implies that students are socialized through technology education into scientific ways of reasoning and acting (Vygotsky 1986; Säljö 2012). The analytic procedure in the study is separated into four separable but interrelated phases, which are described in detail in paragraphs 1–4 below.

1. We carefully reviewed all of the collected material, and content-related situations related to the research questions were selected for further analysis (approximately 15 h of video recording).
2. We focused on specific situations where the students explicitly expressed their knowledge about emerging technology for the purpose of sustainable development in relation to their models. All of these specific situations were carefully transcribed and constitute the material for the in-depth analysis of the students' reasoning (approximately 4 h). The analysis in this phase implies that we could explicitly focus on our research questions in more detail. However, we interpret all transcriptions as adaptations of digital recordings, which makes these the primary material (Burges 2010). The transcriptions focus on the students' interactions and how they express themselves in relation to content. According to Mercer (2000), discussions between students could be valuable for the construction of knowledge, and students' social identities affect how they act and talk and how their fellow students act in the classroom.
3. We adopted Middleton's (2005) aspects of the design process and a part of Ingerman's and Collier-Reed's (2011) model to investigate technological literacy. The process of studying students' knowledge and understanding in technology becomes a process of studying students' ability to use the subject specific language in relevant ways while engaged in a design activity; that is, analyzing how students are able to formulate when reasoning, arguing, and learning in situated activities (Jakobsson et al. 2009). By studying how students discuss and reflect while engaged in a design activity, it is possible to find and describe examples of how students use competences in action.
4. We used the SOLO taxonomy (Structure of the Observed Learning Outcome) in order

to analyze the students' levels of understanding in technology (Biggs and Collis 1982). The SOLO taxonomy is divided into different levels, in terms of various characteristics, from the concrete to the abstract (Hattie and Purdie 2019). Additionally, Hook (2019) asserted that in order to be able to classify learning outcomes in terms of the complexity, we must look at the students' work in relation to the quality and not in terms of how much information they put into their work. Biggs and Collis (1982) described the levels of understanding as prestructural, unistructural, multistructural, relational, and extended abstract. In the prestructural level of understanding, students have missed the point with the task and need help to start working. The unistructural and multistructural levels of understanding

are related and bring in the information (surface understanding). Students' understanding of the task is limited in the unistructural level of understanding, but their understanding of how different aspects relate to each other is not demonstrated at the multistructural level. In the relational level of understanding, however, the aspects of the task are integrated and linked and contribute to a deeper and coherent understanding of the whole. At the highest level of understanding, the understanding is looked at in a new way and used as the basis for generalizing, predicting, reflecting, and creating new understanding. Hattie and Purdie (2019) asserted that students at the relational level must be able to generalize within a given context and, at the extended abstract level, be able to generalize in situations that are not experienced.

Results

This section presents the results of the empirical study that focus on students' ideas on emerging technology. The following excerpts illustrate the ways in which students express knowledge in a design activity. We selected these extracts because we find them to be representative examples of the entire material. In the following excerpt, Robyn, Kanye, Kim, and Olof are discussing how they would use graphene and algae batteries in their apartments.

Excerpt A

- | | |
|------|---|
| A1. | Robyn: I would've built in graphene and then I would've used ... algae batteries ... (Fig. 6) |
| A2. | Kanye: Graphene? |
| A3. | Robyn: ... as walls ... as algae are ruining the oceans ... |
| A4. | Kanye: You can use graphene as windows |
| A5. | Robyn: Yeah but then the rain will get in |
| A6. | Kanye: Aha that's right because it's ... yeah that's right |
| A7. | Robyn: You mix it with something else |
| A8. | Kim: But of course it does if you have walls of graphene |
| A9. | Robyn: Yeah I have a roof that will ... |
| A10. | Kim: It rains in? |
| A11. | Robyn: Yeah but then I can get water when it rains on graphene and then we have ... Let's say that here is the roof ... yeah normal like and then the graphene and it can go through the graphene and so I have filtered away the bad water |
| A12. | Olof: Ah |
| A13. | Robyn: So you can drink the water |



Figure 6

Robyn initiates the discussion on emerging technology by stating I would've built in graphene and then I would've used ... algae batteries ... (A1). Robyn shares her thoughts on how she would use the algae batteries as material for constructing her walls and articulates a problem with algae in the oceans (A3). However, the algae batteries receive no attention from the other participants. Instead, Kanye's utterance—You can use graphene as windows (A4)—seems to show that he wants to deepen the discussion on graphene and how it can be used in technological solutions, which indicates that he recognizes the need for graphene. Robyn analyzes a consequence and evaluates the solution of choosing graphene as windows: Yeah but then the rain will get in (A5). Kanye confirms Robyn's idea on the properties of graphene (A6) and Robyn and Kanye use the model to point out and reinforce their reasoning.

Thus, one possible interpretation is that the model could be seen as a kind of external support and memory system that students can utilize to clarify, visualize, or reinforce reasoning in technology (cf. Schoultz et al. 2001; Säljö 2005). Robyn also tries to expand her thinking on graphene as a constructing material by presenting a refined solution. This may reflect her developing technological awareness. With the statement But of course it does if you have walls of graphene (A8), Kim contributes by identifying the problem of rainwater passing through, which is a consequence of having walls built of graphene. Kim also questions Robyn's idea of building roofs out of graphene and asks for clarification as she articulates a question about the choice of material: It rains in? (A10). However, Robyn explains how she gets drinking water out of rain water: Yeah but then I can get water when it rains on graphene and then we have ... Let's say that here is the roof ... yeah normal like and then the graphene and it can go through the graphene and so I have filtered away the bad water (A11). This constitutes an example of Robyn's reasoning about the possible use of emerging technology in her model, which implies that she recognizes a need and contributes towards a proposal of a technological process. Thereby, she also highlights that graphene could be used as a water filter system, which could possibly provide apartments with drinking water (cf. Bird 2018). The latter becomes obvious in the following part of the interaction, where Robyn states that [...] you can drink the water (A13). Thus, Robyn adds a functional property of graphene and formulates arguments for choosing graphene in her construction.

The discussion constitutes an example of students' growing ability to discuss and integrating emerging technologies into their models, while the discussion as such may support their understanding of new concepts. Robyn's utterance (A11) is an example of how such understanding may be demonstrated. In this statement, she clearly indicates that she has reached an understanding that one of graphene's applications is to clean water while having other properties (cf. Bird 2018). Another example of this process is Kanye's suggestion to use graphene for windows, and Robyn and Kim's argument that the rainwater will leak through. We understand this type of discussion as typical for productive design and construction processes, where the advantages and disadvantages of different materials are considered in relation to an expressed need. Further, in the discussion, Robyn returns to the leaking problem by suggesting that graphene filters away "bad" water and may provide drinking water to the apartment. In this way, the group's questioning of Kanye's claim leads to a reflective dialogue on how to solve sustainability issues using emerging technology in technological solutions.

However, the sustainability perspective is implicitly expressed in the subsequent excerpt as Alfons, Nina, Kim, and Magnus present and discuss the concept of passive houses.

Excerpt B

- B1. Alfons: Passive houses? (Fig. 7)
- B2. Nina: They are basically self-sufficient heat-saving houses...
- B3. Kim: Self-destructing?
- B4. Nina: Self-sufficient
- B5. Alfons: Energy-efficient so to speak.
- B6. Nina: Yep. [...] it uses all the energy that otherwise would have gone lost...like rests of body heat ...
[...] used as electricity and heat so then you don't need to use as much energy and water. Yeah.
- B7. Alfons: Houses that save... for example, people can have, you know like, kind of solar cells on the roof. That save energy. Thick walls insulate well.
- B8. Magnus: Yeah, it's like houses that get their own energy for example maybe you have solar panels
Yeah cycling in the cellar...



Nina uses her model to present the idea behind passive houses: They are basically self-sufficient heat-saving houses ... (B2). Her statement indicates that she recognizes the need for passive houses in a future perspective and in her model by arguing that these houses save heat and are self-sufficient. Alfons contributes to the discussion by widening the concept of self-sufficiency, stating that passive houses are Energy-efficient so to speak (B5). This could be interpreted as the first step towards the use of a technological process in form of a passive house in relation to their models. Nina continues: [...] it uses all the energy that otherwise would have got lost ... like the rest of body heat [...] used as electricity and heat so then you don't need to use as much energy and water (B6). Nina refers to her utterance on self-sufficiency and develops thoughts by arguing that passive houses use the heat from both people and electric devices to avoid wasting energy. She is probably referring to body heat as a consequence of taking care of rest heat. Alfons provides some additional examples on how to save energy: [...] kind of solar cells on the roof. That save energy. Thick walls insulate well (B7). Finally, Magnus summarizes by emphasizing that it's like houses that get their own energy for example maybe you have solar panels ... (B8). This could indicate that Magnus contributes to the solution of creating one's own energy and becoming self-sufficient.

The above excerpt is an example of the participants formulating arguments for a specific technological solution—passive houses—with justifications such as the use of thick insulated walls and renewable energy resources such as solar panels. This indicates that the students are thinking about how to build a house in an energy-efficient and sustainable way and thinking about how to integrate these ideas into their models. Thus, again we want to emphasize that we see this example as typical of a productive design and construction process where the advantages and disadvantages of different materials and solutions are considered in relation to an expressed need. We also argue that this seems to be a collaborative process in which several students jointly form a common understanding. For

example, Nina and Alfons seem to have reached a joint agreement that self-sufficient and energy-efficient are similar concepts. Nina's statement (B6) seems to reinforce this conclusion, as she agrees with Alfons and further explains that passive houses use energy that would otherwise have been lost. Moreover, Alfons' utterance (B7) may indicate a possible understanding of the properties of a passive house. The aspects of environmental issues are expressed more explicitly as they discuss the properties and evaluating solutions of passive houses, such as the supply of energy in relation to their models.

In the next excerpt, Chris, Ollie, Elmore and Moody also discuss the use of emerging technology in their construction of an apartment.

Excerpt C

-
- C1. Chris: How would you build your house if you had access to new technology?
 C2. Ollie: I would've chosen them batteries...
 C3. Chris: I would've used nanotechnology so that they can regulate the heating by itself
 C4. Ollie: Yeah I would've too. The batteries as walls. They create energy ... then ...
 C5. Chris: I would like the whole of my house to be built in that carbon...
 C6. Elmore: Graphene
 C7. Chris: Yeah
 C8. Ollie: Even though water runs through it
 C9. Elmore: Then you could build a part of your house so that you get all your water from ... a wall
 C10. Moody: Yeah (nods)
 C11. Elmore: Collect all the water from a stream (chuckles)
 C12. Ollie: Just like Minecraft, a never-ending source of water
 C13. Chris: You can make a hole here with just that graphene ... (Fig. 8)
-



Figure 8

It seems likely that Ollie refers to algae batteries when he says I would've chosen them batteries... (C2) and, by that, probably recognizes that he could use them in his model over the apartment. Chris continues Ollie's argument and seems to identify a property of the algae batteries by suggesting I would've used nanotechnology so that they can regulate the heating by itself (C3). This could indicate that Chris perceives nanotechnology as a heat regulator in algae batteries. However, it is not entirely clear what he means by this statement. Ollie seems to interpret the statement as a suggestion for how to integrate algae batteries into his model of an apartment when he says Yeah I would've too, the batteries as walls. They create energy (C4). This statement indicates that Ollie perceives that walls that

integrate algae batteries could provide the apartment with energy. He may be recognizing the need for algae batteries as bricks of energy-creating walls and thereby developing a solution to the energy supply system in an apartment. We interpret this situation as another example of a productive and creative design and construction process where the advantages and disadvantages of different solutions are considered in relation to an expressed need. In this case, it is about using algae batteries for the apartment's energy supply. However, it is possible to conclude that the students seem to have a preconceived notion that energy is created, which is not the case, as it is energy forms that are transformed. Ollie probably perceives the batteries as a component in two different ways: the batteries as a construction material and also as a component in the technological system of energy supply.

In the further discussion, Chris highlights another technological innovation by saying I would like the whole of my house to be built in that carbon (C5), which brings Elmore to introduce the concept of graphene. The statement leads to Ollie analyzing the consequence of choosing graphene as a construction material by questioning the statement and saying Even though water runs through it ... (C8). Elmore further contributes to the discussion by claiming: [...] you could build a part of your house so that you get all your water from ... a wall (C9). He seems to perceive a technological system in which graphene is a component in the water supply system, and he tries to contribute to the technological process by stating; collect all the water from a stream (C11). Ollie continues with Elmore's idea regarding the use of emerging technology, and points this out on Elmore's model: Just like Minecraft, a never-ending source of water (C12). Here Ollie is using his previous experience from playing the computer game Minecraft and applying it to the model. Future clean freshwater supply is presumably a problem that needs solutions; the students in this group recognize the need and try to find a solution to the problem in a playful way by using their previous knowledge from Minecraft. They use the models as support to back up their suggestions, as exemplified by the utterance on making a part of the house in graphene, to get a never-ending source of water, as a water supply system. However, the sustainability perspective on water supply is implicitly expressed, for example, creating an infinite water source. This could indicate that they have discovered a way to get water in a sustainable way. The students spontaneously integrate graphene in their model. The model also seems to facilitate the use of ideas from a different area: computer games. Although some of the students' proposals are somewhat adventurous, we argue that most elements of the discussion constitute important parts of a design process in technology education.

In the fourth example, Nina, Alfons, and Phil discuss emerging technologies in relation to the energy supply of the apartment.

Excerpt D

-
- D1. Nina: ...and electricity I get from the windows with built-in solar cells. Plants on that. Yeah live by the sea so I use water power and wind power so it there from I get the most of my electricity... (Fig. 9)
- D2. Alfons: Vättern that's a lake. How do you use water power there?
- D3. Nina: Because its water...
- D4. Alfons: Yeah but water power has to lead the water somewhere.
- D5. Nina: Yeah but...
- D6. Alfons: Tunnels or I don't know.
-

-
- D7. Nina: It's like a small water power plant. Environmentally friendly options. Solar power. My house is made of wood. The wood comes from Swedish forests. The walls have I made of algae batteries so that energy is stored therein. I had the roof so that it's solar cells. Much more energy from wind power and water power... may not buy electricity.
- D8. Alfons: If I had to build with new technology, I would have had this eeh... window so ehm... nano-technology for windows as they arrived in 2004, so an atomic layer eeh... Lead as windows and then I would have had algae like walls for it as saving energy ... then you could have been a year-consuming eeh ... years of self-consumption is kind of something like that ...
- D9. Phil: Yeah
- D10. Nina: Self-sufficient
- D11. Alfons: Self-sufficient, fully self-sufficient. It would have been very environmentally friendly, so I strive for it.
-

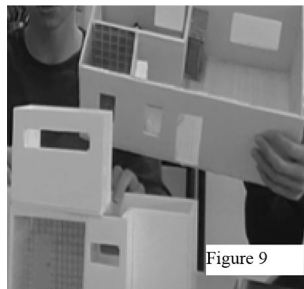


Figure 9

Nina develops an energy solution as she shows on her model and talks about solar cells being integrated in the windows: ... and electricity I get from the windows with built-in solar cells (D1). She continues by saying, [...] I use water power and wind power so it there from I get the most of my electricity (D1), clarifying that she is referring to electric energy. Further, Nina states that the electric energy sources in her apartment are solar-cells, water power, and wind power, which also indicates a sustainable solution. She identifies the need for electricity and mentions three non-fossil sources of electricity production. These are also renewable resources that are generally considered to be part of sustainable development. However, Alfons problematizes the issue of electricity from waterpower by questioning the solution [...] that's a lake. How do you use waterpower there? (D2). Thereby, Alfons evaluates Nina's proposal and raises the question of investigative character, which requires Nina to continue her reasoning about electricity from waterpower: Because it's water... (D3). She is not given the opportunity to develop this reasoning further, but is interrupted by Alfons' when he states—Yeah, but waterpower has to lead the water somewhere (D4). By this assertion, he indicates that he has developed some knowledge of technological systems, as he seems to be aware that stagnant water in a lake cannot generate any electricity. However, it is not clear how he contributes towards a technological solution because of his statement—Tunnels or I don't know (D6)—does not lead the discussion further. However, Nina answers, It's like a small water power plant. Environmentally friendly options... (D7). This indicates that she has made a thoughtful choice considering the environment, but has not really solved the problem of waterpower at all. However, she continues her reasoning by stating, My house is made of wood. The wood comes from Swedish forests. The walls have I made of algae batteries so that energy is stored therein (D7). Thus, she recognizes the need for storing energy and looks at algae batteries as a possible solution to this. It is likely that she perceives algae batteries as technological systems that store energy inside. Thus, Nina identifies the need for algae batteries and formulates

her arguments with a specific justification for choosing algae batteries as walls in the apartment.

Alfons also tries to explain how he would use emerging technology—[...] nanotechnology for windows (D8)—and thus brings the concept of nanotechnology into the conversation. Further, he articulates arguments on the environment by stating: I would have had algae like walls [...] as saving energy [...] years of self-consumption. Alfons then evaluates the use of algae batteries by arguing that he would be energy-self-sufficient. He makes a link to the sustainability perspective when he states, Self-sufficient, fully self-sufficient. It would have been very environmentally friendly, so I strive for it (D11). Together, it appears that Alfons and Nina develop an understanding of the concept of self-sufficiency. It is also clear that they articulate, from an environmental perspective, their devised solutions of their models, even though this has not been a stated perspective in the task. The analysis of the excerpt also shows that they are largely able to identify needs and evaluate solutions, which is a crucial part of the design process (Middleton 2005; Vande Zande et al. 2014; Mioduser 1998). In addition, they raise and articulate problems and try to analyze the consequences of their solutions. All of these abilities and competencies are included in the concept of *competences in action*, which is considered to be a significant part of a design process and thus part of becoming technologically literate (Ingerman and Collier-Reed 2011).

Summary of results and discussion

The main purpose of this study is to investigate how students express and develop ideas on emerging technology when they participate in a design activity. Thus, the group interactions constitute an important part of the design process as the process involves identifying a problem as well as developing and evaluating a solution to the problem (Middleton 2005). For example, when the students are discussing how to apply emerging technology in their self-made models, they reason about sustainability, as exemplified by Alfons in Excerpt D striving to make his building fully self-sufficient and environmentally friendly. Alfons' group uses several technological concepts, including nanotechnology and algae batteries (cf. Strömme 2015), and tries to explain them together. The sustainability perspective is often expressed implicitly, which can be regarded as a competence that the students bring into action and express in the joint discussion. Further, in some discussions we could discover students trying to relate their technological solutions to a larger context. In Excerpt A, for example, Robyn seems to apply her proposal in the context of a technological system when she reasons about filtering water with graphene. She uses and explains several technological concepts and, along with her fellow students, reflects on possible usage of graphene. In a joint reflective discussion, the students seem to reach a deeper quality of knowledge that approaches generalizability of the concepts. It appears likely that the students use the model to point out and clarify their views about how to use the graphene's properties, such as group A's reasoning about the process of water cleaning. Thus, they seem to be able to discuss in a more informed way whether or not a model supports their reasoning (cf. Schoultz et al. 2001).

The analysis accordingly shows that, during the design activity, the students develop knowledge about emerging technology in joint collaboration, such as when Group C discusses the issue of getting fresh water by utilizing the properties of graphene. It appears that they develop the ability to think innovatively and, in some cases, possibly replace

misunderstandings (cf. Christensen et al. 2018). One example of this is when Group C discusses the use of graphene to get a source of water. In this case, all of the group members are engaged in the discussion and it seems that they reach agreement on graphene's properties. It is therefore reasonable to assume that their misconceptions have been replaced, but this needs to be investigated further. Furthermore, the results indicate that the design process helps students to develop their ability to use competences in action, which includes recognizing needs, articulating problems, contributing towards a technological process, and analyzing consequences in the discussions (Ingerman and Collier-Reed 2011). Recognizing need is a way for the students to identify problems that they believe need to be solved, such as future supply of energy and water. When they recognize a need, they add a wider perspective, as sustainability is often included in the discussions, which could be considered as an attempt to analyze the consequences of a solution and thereby generalize new knowledge. For example, when considering the properties of passive houses, the students talk about the concept of self-sufficiency and, in so doing, identify a possible solution. The ability to analyze the consequences of a solution seems to correspond to the ability to evaluate a solution in the design process. In order to gain a more comprehensive overview of the analysis, the results are summarized in the proposed Table 2.

The analysis also indicates that most of the students emphasize sustainability through the design activity and display sufficient understanding of relevant concepts to use in the interactions. In these situations, we argue, the students' knowledge is transformed into competences in action, which signifies that they are able to express and to use knowledge in a relevant way. In particular, the students discuss water supply and energy-saving issues. This applies, for example, to Group A when they discuss graphene as a constructing material. They concluded that graphene can be part of a solution to get fresh water. In general, the students use their models as support, to clarify a thought, communicate knowledge, and to help solve a problem (Blomdahl and Rogala 2008), which has become obvious in the present study. This means that we consider competences in action as a complement to the design process that could be related to technological development work in technology education (cf. Ingerman and Collier-Reed 2011; Middleton 2005; Swedish National Agency for Education 2017). This comparison is summarized in the proposed Table 3.

In conclusion, the four excerpts we have chosen show that the students use separate pieces of information at the beginning of the interactions. They then identify, combine, and describe one or more of the concepts in relation to emerging technology and manage to integrate them into their models. Thus, it seems likely that the students were able to use the new knowledge about contemporary research in order to solve problems in their model proposals. An example of this is when the students present passive houses as self-efficient heat-saving houses (for example, B2). According to Biggs and Collis (1982) and Biggs and Tang (2007), this could be described as the students seizing increased knowledge (unistructural knowledge becoming multistructural level of understanding, [SOLO level 2 and 3]). However, we also note that most students during group interactions develop a more generalized knowledge of technology, such as when they discuss how graphene can function as a water purification filter (for example, A11). This indicates that the students see the connection between different concepts, such as recognizing the characteristics of graphene, and applying and justifying the solution to purify water. We also note that, in some situations, the students can reflect on different solutions that involve emerging technology and can discover the pros and cons of various proposals. At the same time, it becomes clear that questions from fellow students often deepen the reasoning, such as when a student questions the use of graphene in windows because water passes through graphene. According to Biggs and Tang (2007), this indicates that the student has reached the relational level

Table 2 Proposal for a table with the students' statements in relation to competences in action (Ingerman and Collier-Reed 2011)

Identify initial need/recognize need	Articulate problem	Contribute towards a technological process	Analyse consequence
A4. [...] graphene as windows	A3. [...] algae [...] ruining the oceans A8. [...] if you have walls of graphene A10. It rains in?	A7. [...] mix it with something else A9. [...] I have a roof that will	A5. [...] the rain will get in A11. [...] get water when it rains on graphene [...] filtered away bad water A13. [...] drink the water
B2. [...] basically self-sufficient heat-saving houses	B3. Self-destructing?	B4. Self-sufficient B5. Energy-efficient [...] roof [...] Thick walls insulate well B8. get their own energy [...] solar panels [...] cycling [...]	B6. [...] all the energy that otherwise would have gone lost [...] like the rest of body heat [...] used as electricity and heat [...] don't need to use as much energy and water B7. [...] save energy
C2. [...] chosen them batteries C5. [...] built in that carbon C6. Graphene	C3. [...] used nanotechnology C4. [...] create energy	C3. [...] regulate the heating C4. [...] batteries as walls C9. [...] get all your water from ... a wall C13. [...] a hole here with [...] graphene	C8. [...] water runs through it C11. Collect all the water from a stream C12. [...] like Minecraft, a never-ending source of water
D1. ... and electricity I get from [...] D8. [...] new technology [...]	D2. [...] use water power there? D3. [...] its water D4. [...] lead the water somewhere D10. Self-sufficient	D1. [...] windows with built-in solar cells [...] water power and wind power [...] D6. Tunnels [...] D7. [...] small water power plant. Environmentally friendly options. The walls [...] of algae batteries [...] energy is stored therein [...] solar cells [...] more energy from wind power and water power [...]	D7. [...] may not buy electricity D8. [...] algae like walls [...] saving energy [...] years of self-consumption [...] D11. [...] Self-sufficient, fully self-sufficient. [...] very environmentally friendly, so I strive for it.
		D8. [...] nanotechnology for windows [...]	

Table 3 Proposal for a table with the design process related to competences in action and abilities in a technology development work

Aspects of the design process	Competences in action	Abilities in a technology development work
Identify problem	Recognize need Articulate problem	Identify need
Undertake research Develop solution Produce solution	Contribute towards a technological process	Develop solution Investigate Design
Evaluate solution	Analyse consequence	Evaluate products

of understanding (SOLO level 4) and has thus deepened his or her understanding (qualitative relational understanding). However, during these interactions we have not been able to identify the extended abstract level of understanding in the interactions (SOLO level 5) where relational understanding becomes extended abstract understanding. In some situations, the students reflect on and value a solution, but do not seem able to generalize the perceived knowledge; this may indicate that students are still heading towards the fifth level of understanding.

Final remarks

The results of this study clearly indicate that the design process greatly encourages students to develop and express their knowledge on contemporary technology and sustainability issues as they add aspects of these in the group interactions. It is also obvious that most students, in these situations, are able to integrate their new knowledge of contemporary research in science and technology into their models and use them to solve problems they face. Of course, this does not imply that they have acquired all of the advanced knowledge or all aspects that nanotechnology, algae batteries, passive houses, and graphene may possibly bring to house construction in the future. However, such acquisition of knowledge has not been the aim of the present study. It has been more about whether it is possible to use today's research and development in science and technology in a project in compulsory schools with the intention that students should get something out of it and learn about emerging technology. From this perspective, we feel that the present study has shown that it is possible to integrate contemporary technology into technology education at compulsory schools in a way that enables students to develop knowledge in the subject area.

We also argue that, as the students discuss, explain, and apply different perspectives on a specific topic, they develop a wider understanding of technology. Consequently, most of the students communicate knowledge on emerging technology, which enables them to predict how they could use the new knowledge in their models. This implies that as students integrate knowledge verbally in their models, it could be associated with undertaking research on a specific topic, such as the properties of nanotechnology. It seems obvious that some of the students implement knowledge on sustainability in their self-made models and that the models support and reinforce reasoning about the relation between emerging technology and sustainability. For example, saving energy

and using renewable resources is an underlying concept that is important in sustainable development. In this context, for example, Robyn (A13) demonstrates her ability to use knowledge on emerging technology as she solves a need for fresh water. According to Middleton (2005), this is part of a design process, as Robyn is identifying a need and developing a solution. Robyn formulates arguments for a solution where graphene becomes a visible component in the technological system of cleaning rain water to get drinking water. Her solution could be viewed as a contribution to global sustainability development. Her reasoning could refer to a deeper understanding of the technological concepts, which means that the knowledge becomes generalizable and can therefore be used in new contexts.

The second purpose of this study has been to explore whether, and if so how, students can manage to develop technological literacy through a design activity. It has become clear during the analyses that most of the students, in a quite developed way, can discuss and apply knowledge about emerging technology and implement a sustainability perspective in interactions. Accordingly, students seem to develop the ability to work in a design activity in which theory and practice are intertwined in the process (Blomdahl and Rogala 2008), while also developing both procedural and conceptual knowledge (McCormick 2006). Finally, we note that a conscious teaching strategy could promote students' development of technological literacy. Firstly, students' thoughts and ideas on emerging technology and sustainability became explicit in the joint discussions and in the interactions. Secondly, it was implied that the interaction with support of a physical model forced students to react and argue. Thirdly, the interaction in a design activity and the use of competences in action led to the gradual development of a technological literacy. We understand technological literacy as more than just conceptual knowledge; it is also a question of using the knowledge in an appropriate way in new situations. This indicates that students can develop technological literacy during a carefully thought-out design activity that involves theoretical input and discussions alongside practical work.

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