From kinetic energy to climate change: Design of technology to link school science to personal energy consumption

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ABSTRACT
Energy sustainability is prevalent in political and popular rhetoric and yet energy consumption is rising. Teenagers are an important category of future energy consumers, but little is known of their conceptions about energy, energy saving, and energy related problems. We report on a study with a group of teenagers that explored their conceptions about energy and their skills in finding information about their personal energy consumption. In this paper we focus our discussion on the challenges in using Web technologies to support learning about complex real world issues like energy consumption. An initial analysis of the data indicates that teenagers struggle to grasp the complexity of problems around energy and to search for information on examples of their personal energy consumption. We highlight that, to fulfil the learning potential of Web technologies, educators must provide support both in terms of learners' initial conceptual understanding of the learning topic and the process of searching for information. Motivation is also critical if learners are to engage in the time intense process of searching for information and creating content. These findings have implications for the design of technology enhanced learning experiences that build on young people's Web technology skills to support learning about complex real world issues.

Categories and Subject Descriptors
K.3.1 [Computers and Education]: Computer Uses in Education

General Terms
Design.

Keywords
Learner-centred design, informal learning, scaffolding, science learning, energy.

1. INTRODUCTION
Climate change and resource scarcity have brought energy sustainability to the forefront of environmental concerns. An important factor in shaping future patterns of energy consumption is the understanding of the problem and the willingness to address it by younger generations. Teenagers are not the principal decision-makers within the household, but they are well placed to have an impact, both by changing their individual behaviour and by acting to influence others within the family, their social network and the public sphere [1]. We know little about teenagers' understanding and behaviours in relation to energy consumption. We can, however, observe that energy consumption has been increasing over recent years [2]. Also studies with adults suggest widespread lack of awareness of the energy intensity of different behaviours, indirect energy consumption (through products and services, as opposed to direct use of electricity and fuel), and lack of willingness to adopt changes in behaviour that have high impacts but are inconvenient [3,4]. Some studies that have involved teenagers have presented a negative picture of their contribution to energy consumption [5,6].

Energy is a topic in the secondary school science curriculum in the UK. The curriculum includes learning about different forms of energy and different ways of generating energy, as well as associated environmental and economic issues, such as climate change and scarcity of non-renewable sources of energy. However, students have difficulty applying their understanding of formal science learning to their personal circumstances. These issues are complex and teenagers must be supported in order to understand them to be in a position to make informed decisions. In particular, complex real world issues such as energy consumption need to be understood not as isolated, abstract problems, but linked to personal choices and behaviours so that learners can understand their personal role in addressing them.

Learning about energy consumption and how people can act to mitigate the problems arising from it must, therefore, be embedded as information in the everyday contexts in which energy related behaviours and choices are made. The information must be personalised and presented in such a way that teenagers are motivated to engage with it. Emerging Web technologies are portable, flexible and adaptable and, therefore, have the potential to create learning experiences that bridge the gap between formal learning and everyday contexts. Many of today's youth are skilled in using Web technologies to search for and share knowledge, and to create and annotate content. However, the challenge of employing these technology skills in learning about complex issues, such as the problems arising from energy consumption, requires close consideration. In this paper we discuss some of the challenges of using Web technologies to learn about personal energy consumption and the associated environmental and economic issues. We report on a study that explored teenagers' understanding of energy in the context of their everyday lives, their sources of information about energy, and their skills in finding information about their personal energy consumption. This work informs our understanding of the challenges we need to

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overcome in order to use the potential of new technologies to support learning about complex real-world problems.

2. THE PROJECT AND METHODOLOGY

The study reported here is part of an ongoing project that aims to design technology based interventions to engage teenagers' curiosity to find out more about their energy consumption and to support them to learn about and save on their energy consumption. These objectives encompass both direct (electricity and fuel) and indirect (products and services) energy consumption. It is important that the learning experience is personalised and embedded in teenagers' everyday contexts. To achieve this we employ a design methodology that identifies teenagers' circumstances, including their knowledge, concerns and motivations, and models the connections between the multiple influences within teenagers' contexts. The Ecology of Resources design framework [7] offers a process for working with participants that models and takes account of their context.

The EoR framework is inspired by a sociocultural philosophy of understanding and supporting learning [8,9] and the notion of scaffolding, which defines the process of providing support that is closely contingent on the learner's current understanding and skills [10,11,12]. The EoR provides a method for designing learning technology and/or learning technology use that considers the important relationship between the learner in their context and the learning that arises out of their interactions with their context. The EoR conceptualizes a person's context in terms of their interactions with the many resources of their world, for example, with the people, places, books, knowledge concepts and technologies they encounter; and in terms of their personal resources, such as their motivation and existing understanding. In order to support learning, the EoR design process seeks to effectively link the world resources that are most appropriate for a specific learning goal and to scaffold interactions between these resources and the learner, taking into account the learner's own personal resources.

The EoR provides a method through which we first identify the world resources available to the learner and the processes and relationships that shape the learner's access to these. We also build an understanding of the learner and what they bring to the learning experience: their personal resources. The EoR also introduces the notion of *filters* to describe the artefacts that constrain a learner's access to resources, such as rules, regulations or physical and social boundaries or expectations. Having mapped out the learner's context, we begin an iterative, participatory process of design with the aim of developing technology that facilitates access to appropriate resources at appropriate times during the learning process. The EoR has been used with learners and teachers across a range of subjects, including science and language learning to design technology rich learning activities and technology applications, such as smart phone applications [13].

2.1 The Design Framework

The EoR design process is structured in three phases that take a learner's wider context into account (see [7] for framework detail). These are:

Phase 1: Creating an Ecology of Resources Model to identify and organize potential resources for learning. Six iterative steps support the modelling process, in which some steps will require several iterations. Step 2 is of particular importance and can necessitate several iterations through other steps. The steps in Phase 1 of the EoR and the associated driving research questions regarding teenagers' conceptions of energy use are:

Step 1 – Brainstorming Potential World Resources

a. What are the circumstances in which teenagers use energy?
b. What energy uses are most relevant to them?
c. What are their sources of information about energy use and energy sustainability?

Step 2 – Specifying the Focus of Attention

This is informed by three elements: a) the current body of knowledge about energy consumption and energy sustainability issues, derived from the literature, b) the energy consumption that is relevant to teenagers (Step 1 of Phase 1), and c) teenage learners' current understanding about energy consumption and energy sustainability (Step 5 of Phase 1). The EoR design process is iterative. Step 2 emerges gradually through the entirety of empirical work in Phase 1.

Step 3 – Categorizing World Resource Elements from Step 1 into: Knowledge and Skills, People and Tools, Environment.

Step 4 – Identify potential Resource Filters

Constraints on:
a. Information available to teenagers about energy use and energy sustainability?
b. The choices teenagers have on the energy they use?
c. How visible is energy use to teenagers?

Step 5 – Identify the Learner's Personal Resources

a. How do teenagers understand energy use and energy sustainability in their everyday life?
b. How aware are they of their energy use?
c. How much knowledge do they have about the energy intensity of their behaviour and choices?
d. Are teenagers concerned about energy sustainability?
e. What are their attitudes towards energy saving?
f. What motivates them to save energy?

Step 6 – Identify potential More Able Partners (MAPs).

a. Who are the potential more able partners in relation to understanding energy use and energy sustainability?
b. Who are the potential more able partners in relation to motivating to learn about energy use and energy sustainability?

Phase 2: Identifying the relationships within and between the resources produced in Phase 1. Identify the extent to which these relationships meet a learner's needs and how they might be optimized.

Phase 3: Developing the Scaffolds and Adjustments to support learning and enable the negotiation of a Zone of Proximal Adjustment (ZPA) for a learner [7]. Phase 3 of the framework is about identifying the possible ways in which the relationships identified in Phase 2 might best be supported or scaffolded. This support might, for example, be offered through the manner in which technology is introduced, used or designed.

3. STUDY

The study reported here is part of ongoing research into designing technology enhanced learning experiences to support teenagers learning about their personal energy consumption. Previous studies on this project focused on Phase 1 of the EoR process: identifying teenagers' personal resources (their conceptions,

concerns and motivations about energy consumption and associated problems) and world resources (the resources in their everyday lives that make up their learning context about energy). The findings from these studies suggested a focus on the following aspects of energy consumption: indirect energy use (through products and services) and the link between personal energy consumption and energy related environmental problems [14]. Building upon these findings, this work focused on Phase 2 of the EoR with particular attention to indirect energy use and to teenagers' conceptions of how energy problems are affected by their choices (and, conversely, how energy problems affect them). Specifically, we explored teenagers' understanding of their indirect energy use, their sources of information, how they assembled information from various sources, and how they would use these sources to find out information about their personal indirect energy use.

3.1 Participants

Two secondary school science classes (teenagers aged 14 years) participated in the study. The students taking the class had chosen to focus on science (UK triple-science GCSEs). Twenty one students participated from class 1 (14 male and 8 female) and seventeen from class 2 (9 male and 10 female).

3.2 Overview of Study Design

The study ran over two sessions, one week apart. Before the first session, the participants were asked to complete a questionnaire about their views on energy-related problems and their consequences, and on their personal energy consumption. The first session focused on discussing energy consumption, energy related problems, and sources of information on energy. During the week between the first and second sessions, the participants were asked to do an activity in which they captured an example of energy use and found out more about it. The second session focused on an activity to design technology that would support the participants and other similarly aged teenagers to learn about the indirect energy involved in products.

3.3 Procedure

Consent forms and questionnaires were completed during a prior science lesson. The questionnaire included eleven questions on the participants' views and understanding of energy problems, their awareness of their personal energy consumption, their concern about energy problems, and their motivation to save energy. The two one-hour sessions took place during school hours. For all sessions the participants were split into 3 groups. One of the participants was given the role of writing the answers the group agreed upon, and a researcher or the class teacher was present in each group to facilitate. Each group's discussion was audio recorded.

3.3.1 Session 1 (one hour)

The aim of Session 1 was to find out more about the students personal contexts through identifying the people, places and things in their everyday lives, and to discuss ideas around how we consume energy. Participants also tried to identify the problems arising from energy consumption, how much they understand about these problems, how concerned they are about them, and how they believe they will be affected by energy related problems. Participants were asked to complete the following

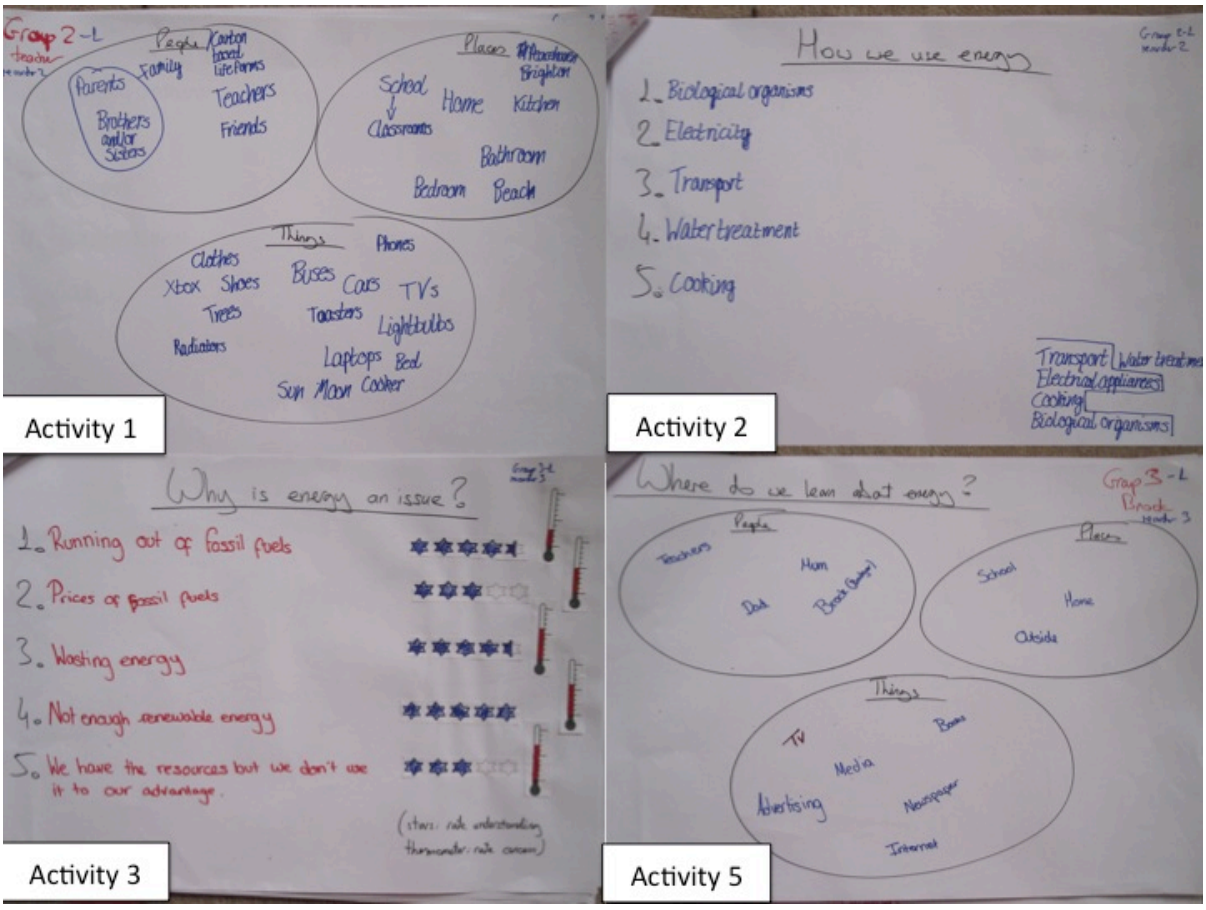

Figure 1: Activities in Design Session 1

activities:

Activity 1: List the people, places, things in your everyday life

Participants were asked to brainstorm the people, places and things in their everyday life, without any reference to energy consumption (see Figure 1).

Activity 2: How do we use energy (top 5 ways)?

Participants identified the 5 top ways in which we (as individuals) use energy (see Figure 1). After initial brainstorming, the group moderator (teacher or researcher) prompted the group to discuss indirect energy use using pictures of food, packaging materials, etc., as prompts to discuss production, packaging, transport and disposal of various products.

Activity 3: Why is energy an issue? (5 reasons, with rating of understanding and concern)

Participants identified 5 reasons why energy consumption is considered a problem by society, in general. For each reason, participants were asked to rate their own understanding of the problem (using a scale from 1 to 5) and their own level of concern about it (using a thermometer scaled from 1 to 10, see Figure 1).

Activity 4: How will people, places, things in everyday life be affected by energy issues?

Using the sheet from activity 1, the participants were asked to note which people, places and things in their everyday life would be affected by energy problems, marking them in red.

Activity 5: Where do we learn about energy: people, places, things?

Given the rating of their understanding of energy problems, the participants were asked to discuss the source of their information. They identified the people they learn about energy from, the places in which they learn about energy, and the things that inform them about energy (see Figure 1).

Home Activity

The participants were asked to identify an example of personal indirect energy use and find out what energy use it required and what alternatives there are that require less energy. They were given an activity sheet on which to (a) rate their understanding of energy used in the example, (b) rate their understanding of alternatives that use less energy, and (c) write some notes on their search for information as well as a list of the sources from which they learn about energy. All participants in class 1 were given cameras to capture their examples of energy use. Five participants in class 2 were given a Smartphone with an app that enabled them to capture photos or video of examples of energy use and to rate their understanding (see Figure 2).

3.3.2 Session 2 (one hour)

The focus of session 2 was on elucidating how the participants learn about energy consumption, specifically about indirect energy use, building on their experiences of trying to find out about indirect energy consumption during the Home Activity. A volunteer in each group was enlisted to take notes during the session. The participants answered several questions that guided them to reflect on indirect energy use and to develop a scenario in which they (or a teenager their age) finds out about indirect energy use related to a consumer product. They were prompted to identify:

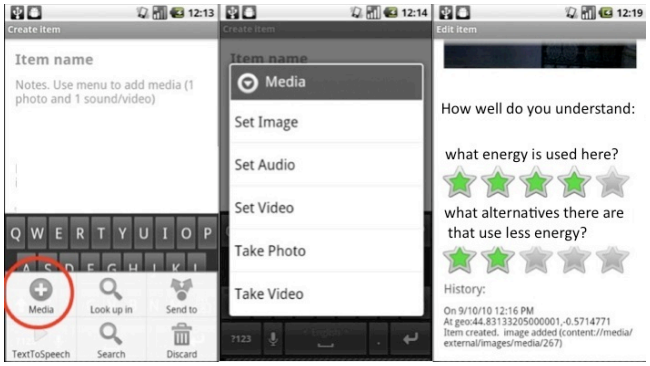

Figure 2. The app for capturing examples of energy use

a. a product that would be relevant to teenagers,
b. when and where teenagers might want to find out about the indirect energy use involved in that product.
c. what would prompt a teenager to consider this product,
d. what (if anything) might motivate them to find out about more about the energy involved and what less energy intensive alternatives there are.

Based on this scenario, each group designed a technology to support other teenagers their age to find out about their indirect energy use.

4. RESULTS

Our main focus in this work has been to identify the challenges of using the potential of Web technologies to support learning about complex issues around energy consumption, in the context of Phase 2 of the EoR design framework. A first cycle of analysis has been performed on the questionnaires, activity sheets and audio recordings. Several further cycles of analysis are needed, however, and so we report on an initial analysis of the results. We highlight three topics: (a) teenagers' understanding of energy consumption in the real world, (b) the sources of energy information that teenagers report to be available to them and how these are accessed to find information on examples of personal energy consumption, and (c) their motivation to engage in learning about energy consumption. Further analysis will identify in more detail the relationships between the resources available to teenagers and how technology can support these relationships to scaffold learning about personal energy consumption. In particular, to link energy information to teenagers' personal circumstances and the people places and things that are meaningful to them.

4.1 Energy consumption in the real world

All groups identified problems around climate change, resource scarcity, non-renewable vs. renewable sources of energy, and energy prices. They rated their understanding of these problems as relatively high (mostly 4s and 5s on a scale from 1 to 5). Over the course of the sessions it emerged that although these issues were understood at a high level, the nuances of how the issues arise and the resultant consequences appeared difficult for the participants to grasp. For example, the impact of limited resources was understood as a straightforward trajectory towards a future in which we run out of energy and must deal with energy rationing, rather than the complex interplay of social and economic factors that determine what energy sources are used and developed. The efficiency of different sources of energy and the broader social issues on, for example, choosing sites for wind farms were not

discussed. This finding is not surprising and it serves to highlight the complexity of the issues around energy consumption and the difficulty teenagers experience in understanding them. The participants had studied energy production and energy problems in their science classes and were clearly informed about them. Yet, the complexity of the issues was not immediately obvious to them. This points to a gap between learning about different sources of energy and the issues around energy consumption as isolated issues in the classroom, and understanding these in the context of the complex factors that shape problems in the real world.

Most energy consumption occurs directly through use of electricity and fuel, but it is estimated that about 40% of UK household energy consumption is indirect [15]. The participants readily identified direct energy consumption, as well as energy needed to fuel living organisms. However, they found the idea of indirect energy consumption more difficult to understand. The Home Activity between Sessions 1 and 2 specified that they should find examples of indirect energy use (and indirect use was discussed explicitly during activity 2 in Session 1). Yet only a few participants captured examples of indirect energy use, with most capturing energy use of electronic devices and appliances. The idea that energy is required to produce, package, transport and dispose of products such as food, clothes and make-up appeared to be very abstract to them. This was especially the case when they considered the consequences of these energy requirements. For example, during the design activity in Session 2, in which the participants were asked to design technology to support teenagers to learn about indirect energy use, one group decided they could motivate teenagers by showing the consequences of buying a product, in terms of the energy use required to produce it. However, this group struggled to understand the consequences in terms of energy use and tended to focus instead on issues around child labour. One participant proposed showing "some place in China where they have the rough conditions of making a phone". Another group proposed a labelling system to illustrate and rank the energy involved in the manufacture of a garment, but were unable to articulate the ranking criteria.

These findings again point to the complexity of real world issues and the necessity of supporting learners to gain an understanding of this complexity. Learning about isolated parts of the problem, for example, the different ways in which energy can be produced and their advantages and disadvantages will not automatically translate into an understanding of the real world processes of energy production and the many factors that determine current policy. Above all, if teenagers are to be in a position to make informed choices both in terms of public actions and private actions they must have an understanding of how their personal choices and behaviour impact on complex issues.

4.2 Sources of information about energy

The sources of information about energy that the participants identified were teachers, school, parents, the internet, campaigns on TV and through leafleting, the media, and energy companies. It was obvious from the participants' discussions that they were relatively well informed about energy-related problems and different sources of energy. Some also discussed the different forms of energy (heat, kinetic, light) in the context of energy use. However, an initial analysis of the data indicate that (a) the teenagers are passive receptors of information about energy and these sources have not been used to actively seek information about their personal or other energy consumption, and (b) the participants lacked the necessary understanding and skills to use these sources to construct understanding about personal energy consumption.

During the Home Activity, many participants did not fill-in the section on their activity sheet related to finding out about the energy required in their example of energy. It is, of course, likely that they did not want to put in the effort. However, from the group discussions it appeared that they genuinely were uncertain of how to go about finding information on the energy intensity of different activities and products (the participants who did search for information used Google or Wikipedia and reported information from a single source). For an example of direct energy use, searching for information would involve finding out about the energy consumed by the device per unit of time and a consideration of how long the device is used. For products this would be more complicated and might involve, for example, identifying packaging materials, location of production, transport, recycling of packaging and product components. Thus it is not surprising that the participants found this activity challenging. The difficulties the participants encountered highlight that an essential skill in searching for information and constructing knowledge is the ability to break down the problem into component parts around which to structure the search and create the content with respect to specific examples of energy consumption.

4.3 Motivation to learn

Searching for information and creating and annotating online content requires cognitive effort and is time intensive. Motivation is, therefore, a key factor in teenagers' engagement in such activities. Not all real world issues are of equal interest to teenagers and energy consumption and the resulting problems are quite abstract. The environmental problems arising from energy production do not have the immediate sentimental valence that other environmental issues have, such as animal welfare. A consistent and clear case for the link between energy consumption and the resulting effects of climate change is not made in the media, and the connection is not directly observable. In economic terms, consumers are directly affected by price but the process by which that price is determined, as well as the short vs. long-term economic factors related to different sources of energy production are less clear. It would be expected, therefore, that energy consumption is not something that teenagers would think of as an immediate problem, nor something that they believe they should be acting upon.

The findings from the present study suggest that many of the participants are concerned about energy problems (4 out of the 6 groups had concern ratings above 5 out of 10 on most energy-related problems they identified). During activity 4 in Session 1, the participants were asked to discuss how they thought they would be affected by energy problems. Many were concerned about the prices of energy, running out of energy in the future, and pollution. Some considered these issues quite serious. However, this concern did not translate into motivation to act, nor engagement to learn about their personal energy consumption. It is possible, of course, that part of the difficulty is in seeing the relevance and potential impact of individual actions, given the magnitude of the problem. However, this was not given as one of the reasons for their lack of motivation to learn about energy consumption. During the Session 2 design activity, one of the points that participants were asked to consider was whether teenagers their same age would be motivated to learn about their energy use and, if not, how they might be motivated to care. The consensus was that teenagers would not be interested and the only thing that might motivate them would be cost.

Irrespective of the reasons behind the lack of motivation, which we will explore in more detail during further analysis of the data, motivation remains important. If we are to engage teenagers in learning through the use of Web technologies that they are skilful in using to create social networks and share knowledge about their interests (e.g., games and music), we need to consider how we can motivate them to engage in these activities around subjects that are of lesser interest.

5. CONCLUSIONS

This paper reports a study that explored teenagers' understanding of energy consumption and problems arising from it, and on their skills in finding out about their personal energy consumption. It is part of ongoing work on the development of technology enhanced learning experiences to support teenagers learn about energy in the context of their personal energy consumption. A preliminary analysis of the results highlighted three important issues in using Web technologies to support learning about complex real world issues.

First, the real world problems that young people will have to address, such as energy consumption, are complex and the link with individual actions that give rise to these problems is not directly observable. Web technologies are an important medium through which young people can co-construct knowledge. However, cultivating skills in using these technologies for accessing information are only the first step. Educators need to provide appropriate support for learners to construct the necessary conceptual understanding of problems in order to be in a position to build on that understanding through their use of Web technologies. Concepts, such as climate change that arise from energy consumption, need to be grounded in the complexity of the real world, such as the social and economic factors that impact on them, and not conceptualised as isolated problems.

Second, our findings highlight that although the skills to use Web technologies to search for information are important, the skills to determine what information to search for and how to link the different elements of this information together are critical. Although many sources of information may be available and visible to learners, this does not mean that they are able to use these effectively to find out the information they need.

Third, young people do have the skills to create, annotate, and share content online around subjects of interest. But applying those skills in the context of learning about complex problems requires sufficient motivation, effort and time to engage with content in sufficient depth. This may be lacking in relation to many topics. A key factor, therefore, in the design of learning experiences is fostering that motivation through the subject matter or the technology.

Future work will continue to explore teenagers' conceptions around energy consumption. Follow up studies will draw on these findings to design technology supports that can assist learners in developing the conceptual basis and skills necessary to construct understanding of their personal energy consumption and how this relates to the complex issues around energy.

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