Students' meaning making in science: solving energy resource problems in virtual worlds combined with spreadsheets to develop graphs

Ingeborg Krange · Hans Christian Arnseth

Abstract The aim of this study is to scrutinize the characteristics of conceptual meaning making when students engage with virtual worlds in combination with a spreadsheet with the aim to develop graphs. We study how these tools and the representations they contain or enable students to construct serve to influence their understanding of energy resource consumption. The data were gathered in 1st grade upper-secondary science classes and they constitute the basis for the interaction analysis of students' meaning making with representations. Our analyses demonstrate the difficulties involved in developing students' orientation toward more conceptual orientations to representations of the knowledge domain. Virtual worlds do not in themselves represent a solution to this problem.

Research demonstrates that issues associated with changing students' conceptual meaning making in science continue to be problematic when virtual worlds[1] are used for learning. As part of this complex problem, reasoning with representations constitutes one of the most important topics. The purpose of this study is to scrutinize how conceptual meaning

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[1] Virtual worlds are understood as 3D web based knowledge environments where students and teachers are represented by avatars and where they can interact, combine, and change different representations. The virtual world can be combined with other relevant technologies such as spreadsheets as this study reports on, or other multimodal solutions.

I. Krange (✉)
InterMedia, University of Oslo, Oslo, Norway
e-mail: ingeborg.krange@intermedia.uio.no

H. C. Arnseth
Department of Educational Research, University of Oslo, Oslo, Norway

making is realized when students engage with different representations to develop their understanding of energy resource consumption. Here, we are thinking about representations such as different components in a virtual world or a spreadsheet with the aim to develop graphs. During a 6-week period, we collected data (taped interactions, observational notes, and student written reports) in three 1st grade upper-secondary science classes where students solved problems with regard to energy resources. In this article, we describe how two students interacted with different representations, both conceptually and procedurally, and how representations of energy and energy consumption embedded in a virtual world and a spreadsheet influenced these interactions.

Our main finding is that students, for the most part, demonstrated a procedural orientation in their meaning making processes and that it was demanding for them to combine reasoning in science with the more technical mastery of the virtual world and the spreadsheet. This means that conceptual kinds of meaning making suffered throughout their learning trajectory. That being said, it is also important to mention that the students, in their written report, managed to explicitly formulate a more systematic understanding of certain issues with regard to energy resource consumption.

In our analysis, we focus on the tensions and opportunities that occur between what we call a procedural and a conceptual orientation in students' work. These two issues are not necessarily interconnected. As we will argue, it is perfectly possible and reasonable from the students' point of view to ignore the conceptual issues and simply focus on procedural performance. Our analytical interest is also to describe in detail why a conceptual orientation does not occur, including a discussion of how it might have been facilitated in the students' work.

The use of representations for meaning making

There is a considerable body of research on the use of different types of technology in science education. Several studies, across different disciplinary backgrounds, report that students manage to solve given tasks while at the same time demonstrate difficulties with applying conceptual knowledge to their understanding of scientific phenomena (Furberg 2010). This means that students are primarily led to solve and complete the problems they are exposed to. An unfortunate consequence is that they approach concepts as separate units and do not consider them to be part of larger conceptual systems unless this is explicitly asked for. In our previous work, this approach to meaning making has been labeled *procedural* (e.g., Krange and Ludvigsen 2008). We argue that this form of procedural learning is inadequate and we find support in Vygotsky's (1978) idea about *scientific concepts*. According to him, a concept is not scientific before it is considered in relation to, or as part of, a larger conceptual system. The orientation to meaning making, where concepts are considered as part of a greater whole, has in our previous work been labeled *conceptual*. We are interested in how, when doing school science, students shift between procedural and conceptual orientations, including how these shifts are responsive to features of the context in which they operate. In addition, we focus explicitly on the meanings and functions of representations in students' meaning making, including how their interpretations and use of representations are characterized by procedural and conceptual orientations.

Reasoning in science is interconnected with students' abilities to interpret, construct and make use of representations and models. When students gradually appropriate these artifacts, a conceptual orientation can slowly be replaced by a procedural orientation. In any

case, our argument is that in order to learn a complex scientific domain, a conceptual orientation is crucial. Research in this area attempts to understand the meanings and functions of representations for cognition, including how students learn to interpret and manipulate representations and symbols, and how these representations might be designed to facilitate learning. Research indicates that students have difficulties with understanding relevant meanings from visual and spatial representations of science (Schnotz and Lowe 2008). Säljö and Bergqvist (1997), for example, show how students engaged in a practical demonstration of refraction of light in a science lab have difficulties in interpreting what they see because they do not know what to look for. Their study shows how seeing is dependent on prior knowledge and that processes of seeing are mediated by cultural knowledge that teachers somehow need to make available to students. Krange (2007) demonstrates in another study how making representations more complex, realistic and dynamic does not necessarily make reasoning with representations easier. How students are able to use representations productively is dependent on a wide range of issues where the nature of the task and type of teacher support appear to be the most critical.

The purpose of this study is to understand how students make meaning of energy resource consumption when they work in a virtual world and how they develop their accounts further using other kinds of tools, namely spreadsheets. Against this background, we have formulated two research questions:

- How does a procedural orientation towards the task influence students' meaning making with representations of energy resources?
- How do different tools and representations relate to and complement each other and how do students shift from one representation to the other?

In our analysis we focus on how the students interacted with the representations of energy resources and, in particular, we scrutinize how conceptual aspects are made relevant in and through their interactions. Procedural aspects of meaning making will also play a central part in the analysis. We are concerned with how a disciplinary domain, or parts of it, is represented as models and concepts specific to a discipline. The use of various technological solutions provides different possibilities and limitations with regard to how these models can be represented. It will be a central aim to study how representations of the subject matter impact students' meaning making processes and how different tools and representations relate to and complement each other.

Theoretical and methodological background: a sociocultural approach to meaning making

Most of the research on the effects of representations on learning science is framed by an information processing perspective, which emphasizes amodal problem solving. From this perspective, learning is primarily treated as resulting from the mental manipulation of symbols. The problem with this approach is that it tends to black box the processes of how conceptual learning is derived, in this case, how students make meaning with representations in situ, including how features of the context structure their interaction (see e.g. Furberg and Arnseth 2009). It is exactly this process of shared conceptual meaning making that is the point of departure for our research. This is by no means a unique approach, but this interpretation has not been very visible in studies of students' learning in science (Tobin 2008). We argue that a sociocultural approach focusing on how thinking and conceptual artifacts come together and are constituted in social interaction enable us to

study how students' conceptual understanding in science emerges, including how students shift between a conceptual and a procedural orientation towards the subject matter.

The methodological implication of our theoretical stance is that the analysis is set within a sociocultural frame, but is empirically driven. The focus is on how the different cultural tools, such as representations in science, come into play, and how the students translate their knowledge from one such representation to another one.

Design and research methodology

In educational research, it is an important goal to not only describe how things are, but also how they can be (Schonfield 1990). It is vital to generate models of how students' conceptual learning using different digital tools can be organized in ways that enable learners to use these more productively. This is particularly important in areas where we know that students often encounter problems with understanding conceptual knowledge. More generally, it is an important goal for research to help finding solutions to problems teachers and students encounter. This approach is often termed design experiments or design-based research (Barab and Squire 2004). We are sympathetic to this goal, and even though we do not at this point engage in any redesign of the social and material organization of the learning environment, we attempt to describe in detail what works and what does not, the conditions for why it does or does not work, and identify some possible implications for the pedagogical design of virtual worlds in combination with other learning tools. Doing this kind of research is usually a cyclical process where analysis of the interplay between the learning design and how teachers and learners actually orient to it feeds back into re-design (Brown 1992). It should also be mentioned that even though we aim to find solutions to problems that teachers and students encounter, we do not believe in a final, controlled and complete version of a design that can be controlled independent of the situation of which it becomes a part.

Our data were collected during a test trial where a newly developed and specifically designed virtual world called World Beside was tested in several schools. Participants in the project accessed World Beside through the Internet using specific client software. We followed teachers recruited at three upper secondary schools. Together, the design company World Beside Inc. and the teachers had developed and designed an energy resource application inside a virtual world and a didactical approach for using the application in the classroom. In total, 79 students and three teachers participated. In line with our research position focusing on interactions in detail, we videotaped six dyads. In this article, we present findings from our analysis of one specific dyad and their teacher as they are solving a problem related to consumption of energy resources. The reason for focusing specifically on this dyad is that their orientations towards representations are representative of what we have termed a procedural orientation. In addition, they are rather explicit about what they found difficult and the teacher's interventions followed this up. Therefore, this enables us to study in detail how this orientation is constituted and maintained in interaction including the challenges involved in developing students' conceptual orientations. During their activity, students are expected to describe the correlation between speed and fuel consumption. They do this by monitoring the variation in CO_2 emission. To do this, they needed to build a car in the virtual world and drive two test races, one at high speed and one at low speed, respectively. In the virtual world, data of their CO_2 emission was automatically logged and these data were transported into a spreadsheet through which the students were to make a graph. In our analysis we stay close to the particularities and

concrete details of humans interacting with one another, with tools and their environment. We attempt to anchor our claims in the orientations and actions of the participants engaged in activity. Even though we remain close to the details, this does not mean that our findings are specific to this case (Lindwall and Ivarsson 2010). In and through our analysis, we will identify patterns that generalize, not in a concrete and empirical sense, but as patterns that can be oriented to, reproduced and made relevant in similar activities and settings. Furthermore, as mentioned above, it is an aim to contribute to constructing generalizable models that can inspire and inform future learning designs (Schonfield 1990).

The learning resources

The students were located in their usual classroom settings. Students worked together in pairs, both in the virtual world and in the classroom. Each student had access to the virtual world through his or her own computer. The teachers introduced the problems that the students were meant to solve, they were available throughout the students' work, and they summed up and discussed some conceptual issues at the end of the lesson. The goals were also made available in the form of a worksheet.

The energy application is embedded in a virtual world where the students can construct cars from ready-made parts with different affordances and constraints. When they have built their car, they can drive it through a particular racecourse and compare their time to that of the other students. Furthermore, they can process their data and compare the results with regard to principles of energy resource consumption. The students are represented by avatars that are able to move around and interact with the environment. In Fig. 1, we can see the energy resource application where the students can build different cars and change their characteristics.

The spreadsheet is based on the log data of the car's movement in the energy resource application. These are made available through files that the students can pick up and employ as a basis for developing conceptual knowledge of graphs with regard to speed and variation in CO_2 emission (Fig. 2).
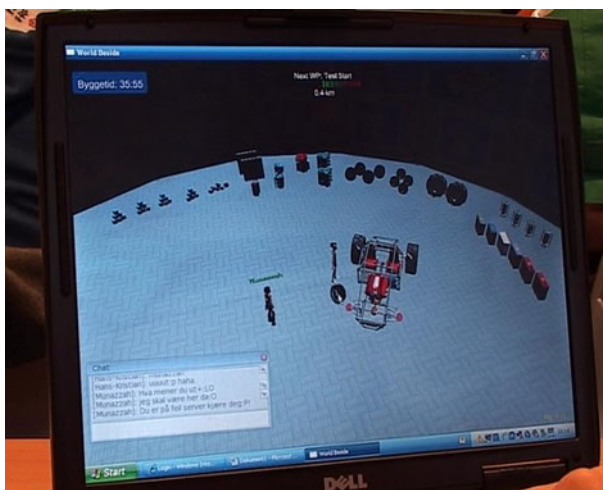

Fig. 1 This is the virtual world. Here illustrated by the platform where the students built cars with different engines, batteries, tires, and fuels. The *white square* in the *left corner* is an integrated chat solution

Fig. 2 This is the spreadsheet with values of speed and variation of CO2 emission. This is gathered from the students' interface. The values are based on their test races in the virtual world and transferred into the spreadsheet

The problems the students were asked to solve

Previously, students had built different types of cars. They had combined various kinds of engines, fuels, and tires and tested them on a specific racecourse. The task procedure was very strictly formulated and the students had been asked to fill in different values based on the vehicles they built and the results from the races that followed into a ready-made table.

They had also been asked to consider which of the cars was the most eco-friendly and which of the cars they expected to be the fastest in combination with low CO_2 emission. This means that when we enter the students' interactions during the second part of their work in the energy resource application, we know that they had some experiences with the virtual world and with how the different parameters influenced the level of CO_2 emission.

In the episode we analyze, the students are asked to find out how speed influences how eco-friendly a car drives according to the level of CO_2 emission. They are given the following task (this is taken from their worksheet):

1. Choose exactly the same car as in Test 1 from the previous task (gasoline engine, V8 power with gasoline fuel), and drive this with low speed. Fill in the missing values in the Table 1 [this table is both available in paper format and in Fronter].[2]
2. In the folder C:\WorldBeside\data\log you will find log files from the test races. Sort these according to when these were modified. Open the two log files from the test races in Excel, and make a diagram that illustrates the total CO_2 emission (column T)[3] and combine these with the driven distance (column B). Choose a scatter plot (XY). Write the axis documents and make the heading "low speed". Do the similar test again, but this time, at a higher speed. Justify the scale on the y-axis to make the two diagrams comparable. Paste both diagrams (low and high speed) into the results as part of Task 2.

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[2] Fronter is a Learning Management System that all schools in the area use.

[3] The letters refer to different parametres that have been logged during the students' test races. The teacher gives them this explicit specification to delimit what is relevant for them.

Table 1 This is the ready-made table the students had to fill in based on the results from test race 1 (high speed) and test race 2 (low speed)

Test-race	Motor	Type spec	Fuel	Tires	Weight	Distance	CO_2 emission	Time (real time)	Additional time	Total time
1 High speed	Gasoline	V8, powerful	Gasoline	*						
2 Low speed	Gasoline	V8, powerful	Gasoline	*						

These tasks imply that the students need to understand how to:

- Build a car in the virtual world, drive it, and vary the speed.
- Identify the relevant knowledge about CO_2 emission in the virtual world and fill it into a ready-made table in the worksheet (see Table 1).
- Create two scatter plots using Excel that are based on the values collected in the virtual world and justify the axis in the plot to make these understandable and comparable.

It is worth mentioning that there is nothing in these tasks that prompt the students to engage with the concepts in a conceptual manner. The task formulations do not require them to explain variation in emissions or understand why characteristics of their cars have certain effects. Even though it cannot be expected that students can explain the relations between emissions and energy consumption in chemistry terms or explain their results using Newton's laws or in Work and Energy considerations, something that would be difficult since the experiment did not offer the opportunity to isolate variables, we might expect that they would engage with some of the conceptual resources found in the learning resource to interpret the variation in emissions. When writing up their report, students are required to summarize their knowledge about CO_2 emission and conclude about how speed influences this. More specifically, the students are asked to (this is gathered from their worksheet):

- Provide a description of how speed influences the total CO_2 emission. What can be the reasons for this?

This description should be written in the ready-made worksheet together with the scatter plots. The students' texts and plots will be assessed by the teacher. There is nothing in the formulation of the task that requires students to engage more conceptually with the correlations between emissions and speed. Even though they are asked to come up with reasons for the variation, they are not provided with any clear guidance in terms of what kind of reasons or accounts are considered appropriate. This is important to bear in mind when we analyze students' meaning making.

Data sources

Three data sources have been used in this study. These are video recordings of students working with the energy application, observational notes, and the students' written reports answering the questions proposed in the worksheet. The first kind of data constitutes the basis for the analysis, while observational notes have been used to fill in gestures and interactions between the two students where we have considered it necessary. The students' written reports have been used to illustrate how they make different kinds of knowledge in the energy application relevant in their work.

The video recordings gave us the possibility to follow the students' and their teacher's interactions, what they did in the energy application and how this was taken up when working with the spreadsheet to elaborate on some disciplinary issues. A camera on a tripod was placed behind a dyad and we filmed quite actively by zooming in and out on their computer interfaces to document what they did and to record details with regard to, for example, disciplinary hints. The recordings gave us the possibility to look through the students' interactions as these unfolded in our video analysis laboratory.

In total, the dyad worked for approximately four and a half hours. About 74 min were used in a plenum introduction and a test trial with different cars. About 120 min were used to perform the task we are going to look at, focusing on the relation between varying speed and CO_2 emission, and finally they spent about 75 min on an eco-friendly race and a disciplinary oriented debriefing session. During the 120 min, the students spent about 30 min listening to the teacher's introduction and presentation of the task, about 10 min building the car, doing the test trials in the energy resource installation and registering the relevant values, and finally about 90 min making this knowledge relevant and presentable as graphs in a spreadsheet. We have selected this particular part of the students' and their teacher's interactions because it makes evident how they made meaning with the representations of the energy resources, and how the virtual world and the spreadsheet with possibilities to make graphs had impacted their meaning making.

Data selection, analysis and transcription method

We have looked through the data several times, both alone and together. We transcribed longer passages that we found particularly relevant for the study of how conceptual learning about energy resources comes into play. Gradually, the contours of how the computer representations structured the students' conceptual meaning making became apparent. We finished by analyzing three extracts in detail. Common to these are the shifting conditions for meaning making, both with regard to changing learning tools and the representations of the subject matter. These are also chosen because they illustrate how the students translated their knowledge from one representational setting to another. Each of the extracts have been labeled with regard to each of the representations they refer to; to build the car, driving the test race and making it disciplinary relevant, and creating a graph. The two first extracts are gathered from activities in the virtual world; one focusing on decisions made with regard to building a car and the other with regard to using this car to collect data on the relationship between different variables and CO_2 emission. The third extract is collected from their problem solving using the spreadsheet to develop graphs. We will argue that the totality of the extracts provides a valid selection of data for analyzing students' meaning making with different types of representations and the translations between representational forms.

We used interaction analysis as a method for analyzing the video data (Jordan and Henderson 1995). Conducting interaction analysis implies that we have been concerned with the sequentiality of action; that is, how actions are responded to, taken up and made sense of by interlocutors. Furthermore, we have been concerned with how the participants orient to, use and make relevant specific tools or other features of their environment and their uptake by fellow participants in the activities. Interaction analysis is particularly useful for studying details in interactions and meaning making in and between settings. Moreover, it is particularly useful to study the interactions between students and the representations that in different ways come into play by paying close attention to what they say and do. Interaction analysis is useful for studying students' meaning making in the

virtual world, in the classroom using spreadsheets, and how this meaning making was translated from one representational setting into another.

The transcripts were written up according to our analytic interest in understanding students' conceptual learning when new representations or combinations of these were used. The practice according to the level of detail included in these kinds of transcripts varies between researchers and their analytical interpretations. We have made the transcripts as plain as possible to make them accessible to a broader audience. We have included talk, shorter pauses, overlapping speech, and non-verbal aspects related to the students' movements and other visualizations in the energy application, the students' orientation to the spreadsheet and the possibilities that this offers to creating representations of graphs, and finally gestures like pointing at a particular aspect of the interface. All non-verbal interactions are written in *italics*. In addition, we have given each utterance a number for use in the analyses. All names are pseudonyms.

Students' conceptual learning of energy resources using a virtual world supported by a spreadsheet

The analyses aim to illustrate how conceptual learning comes into play when a virtual world supported by a spreadsheet is used as a tool to develop conceptual knowledge regarding energy resources. This type of analysis demonstrates how different cultural tools are made relevant in students' problem solving and how their knowledge is translated from one representation to another, which is from a virtual world to a graph. In the following three excerpts, we focus on how the students' built a car in the virtual world, how they were driving a test race and made it disciplinary relevant, and finally how they made graphs to represent the results from their races in a spreadsheet. The role of a highly structured worksheet and the teacher's interventions towards the students' problem solving processes will be a common theme throughout the analysis.

To build the car

In this extract we analyze how the students made conceptual knowledge in the virtual world relevant in their talk and actions when building a car. We also scrutinize how the students made use of, and became oriented to, the worksheet and their requests for support from their teacher.

When we enter the data, it appears as though the teacher has given a detailed introduction to the tasks and the worksheet describing them. She asks the students to keep the parameters (engines, batteries, tires, and fuels) as constant as they can in order to make it possible to study the relation between speed and CO_2 emission. In line with the description on the worksheet, she encourages them to choose the same car as the first one they had built during the previous lesson, namely maintaining the V8 gasoline engine. Henry and Mary have logged on to the virtual world and are ready to work. Henry suggests that they should start to solve task number 2. He starts to move the cursor over different engines and Mary follows his moves.

Extract 1: to build a car

1. Henry: What were we going to have? A powerful gasoline engine?

> Henry refers back to the teacher's introduction about choice of car and/or the task worksheet where it is also written. He starts to move the cursor over different engines. He looks quickly at a V8 gasoline engine, then at a V8 effect reduced gasoline engine, and then back to the V8 gasoline engine. He chooses the V8 gasoline engine. He picks off-road tires and places these on the car's rear axle. He picks up formula 1 tire and places these on the front axle. (…) Henry drives towards the racecourse and suggests that they should drive with high speed first. Mary does not hesitate, jumps into the car, and Henry starts driving.

The teacher's thorough introduction to the problem, together with the detailed worksheet identifying each step the students need to take to perform the task, give the students a clear direction for how to begin working. When Henry says, "What were we going to have? A powerful gasoline engine?" (1) This is a way to initiate their problem solving abilities. It is also an effort to include Mary, and a confirmation of following up on the teacher's introduction and starting to solve the detailed formulated problems to be found in the worksheet (see page 7). Next, Henry picks out a V8 gasoline engine, different kinds of tires and completes building the car before he starts driving. This does not appear to be problematic for him, but it does not seem to stimulate any kind of conceptual reflection either. The conceptual knowledge that is made available for the students when they move the cursor and place it over various objects is not made relevant in the sense that this knowledge is needed to build the car (see Fig. 3). Henry is doing what he has been asked to and this does not, at least at this stage, require any conceptual considerations of the disciplinary knowledge. Mary does not intervene when Henry builds the car.
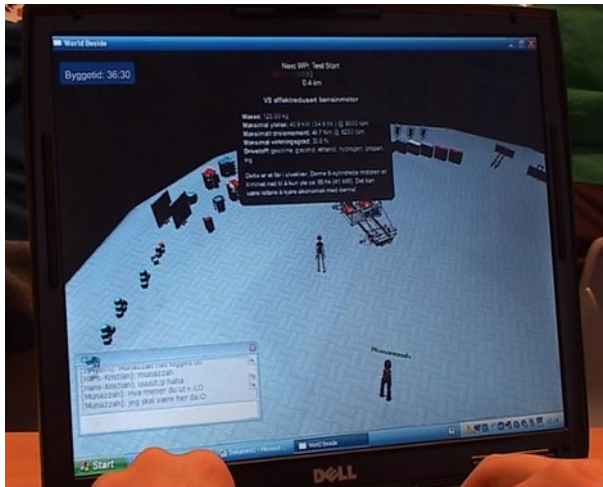

Fig. 3 This illustration visualizes how different conceptual knowledge about the students' choices pops up when they move their cursor and place it over various objects, so-called representations (the *black square with white text* in the *middle*). This means that the students can, for example, find out more about the power of different engines and the emission they produce either as a consequence of use or in term of how they were produced. In this particular illustration, the students can read more about V8 effect reduced gasoline engines

In this very short extract, it is evident that the teacher's thorough introduction and the strictly formulated worksheet direct the students' interactions in a procedural direction. Neither talk nor their actions provide evidence of any active orientation to conceptual resources. This is probably not the goal for this part of the task, and therefore, the virtual world is used as a kind of laboratory where students build cars from ready-made parts. However, it is worth mentioning that when Henry moves the cursor and picks up objects, disciplinary information (see Fig. 3, the black square with white text) is available to the students. This is likely because an orientation to the conceptual content is not explicitly asked for in the worksheet, therefore, it is not made relevant in and through their talk. Moreover, the chat functionality that is available for all the students in the class and can be used to express more informal kinds of expressions than any procedurally, conceptually, or socially kinds of interactions. This tool, in this co-located setting, is therefore more distracting than productive for the students' meaning making. Furthermore, since this group work is arranged in a classroom where the students are divided into fifteen dyads, the teacher is most of the time somewhere else in the room and neither of the students seem to have any need for teacher support, or at least their need was not visible in their talk or in their actions. At this point in time, the virtual world is more of a stepping stone for the students' further interactions than a conceptually oriented learning environment—the students have been told what to do and they understand how to do it. It also becomes apparent that it is the student who controls the mouse that decides what to do, and that the virtual world invites action more than talk at this point of the students' learning trajectories. This kind of orientation is likely linked to how the students are arranged in pairs in front of a shared computer.

The students' work in the virtual world coincides with previous research on conceptual learning in science (e.g., Krange and Ludvigsen 2008). In line with what we could expect with regard to the task formulations (see p. 7), it is not equally important for the students to achieve conceptual learning as it is for them to perform procedural activities. Moreover, the students manage to use the representations adequately to build a car. This was expected, since they had trained to do this in a previous exercise. However, they do not discuss what it means with regard to CO_2 emission and this can be explained by the lack of this kind of question in the worksheet, that the teacher does not intervene, or that the students are not particularly trained for this kind of talk (e.g., Mercer and Wegerif 1999). This means that although potential issues in terms of the disciplinary domain are present, as in the case above, students are most likely to leave these aspects out if these are not explicitly asked for. Following up on Säljö and Bergqvist (1997), it makes sense to ask if the students would know what to look for in "the black square with white text" (see Fig. 3). Do the students' have the necessary knowledge to consider the disciplinary oriented information and make this part of their argument? Similarly, it is also worth questioning, as Krange and Ludvigsen (2008) have done, whether the information is too extensive in the sense that all the disciplinary information given is presented as equally important. As such, there are no particular features in the representation and how it is organized that point to specific aspects that would be more or less crucial for the students' conceptual understanding.

Driving the test race and making it disciplinary relevant

Again, we will investigate how the students make conceptual knowledge in the virtual world relevant in their talk and actions when driving the two test races. We also scrutinize how the students follow up with the highly structured worksheet.
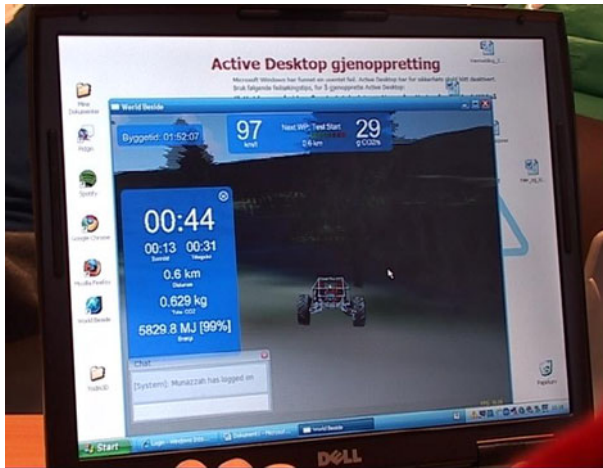
Fig. 4 Results from the high-speed test race

Henry and Mary have just passed the start of the test race. Another window pops up to the right in the interface (see Fig. 4). Within this window, the total time used based on a sum of real time spent driving and additional penalty time is registered based on the emission (CO_2) of this particular car. When we enter the episode, Henry and Mary have already driven the test high-speed race.

Extract 2: driving the test race and making it disciplinary relevant

2.   Henry: Yes, okay. I got lots of additional time.

Henry refers to the 31 s we can read as additional time in the blue square to the right in interface (see Fig. 4).

3.   Mary: Yes, I know.

Henry fills in the ready-made table and notes the different values that are asked for based on the high-speed race. Then Henry and Mary perform the second test race and this time Mary takes notes of the values when they pass the finish line (see Fig. 4). The students used the paper format of the ready-made table.

The connection is strong between the energy resource application and the table the students are asked to fill in (see Tables 2 and 3). The three first values: "Engine", "Type of engine", "Fuel and battery", are all given in the worksheet. The rest of the values the students are asked to identify can be determined based on the values in the blue square on the left hand side of the interface (see Figs. 4 and 5). The Tires column is marked with a star and the students are not asked to fill this in.

Immediately after Henry and Mary have passed the goal of the test race, Henry starts commenting on the conceptual resources built into the virtual world by saying "Yes, okay. I got lots of additional time" (Turn 2). By looking at Fig. 4, it is evident that he refers to the values in the blue square on the interface. Mary confirms that she has also registered

Table 2 An overview of the data material in each dyad

Total time for the learning trajectory	Main activities	Sub activities
Approx 4 ½ h	Plenum introduction 74 min	
	Performing the task 120 min	Teacher introduction 30 min
		Build car + test trial 10 min
		Presentation of graph 90 min
	Test race 75 min	

Table 3 This is the readymade table where the students have filled in the missing values

Test-race number	Engine	Type of engine	Fuel and battery	Tires	Weight	Distance	CO_2 emission	Time (real)	Extra time	Total time
1	Gasoline engine	V8, powerful	Gasoline	*	492	0.6 km	0.629	13	31	44
2	Gasoline engine	V8, powerful	Gasoline	*	492	0.6 km	0.327	45	18	1.03

Race number 1 refers to high-speed and race number 2 refers to low-speed
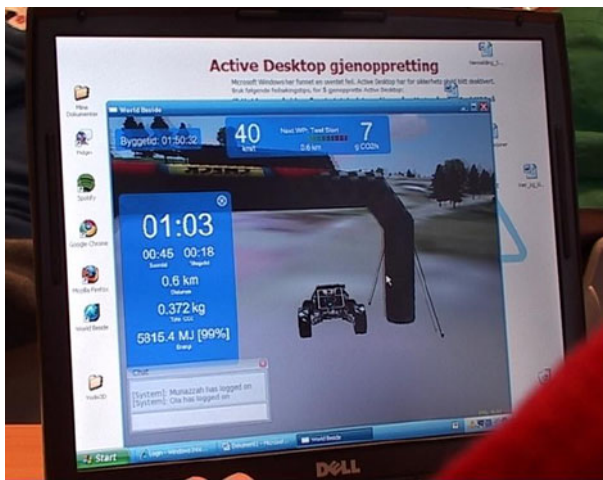

Fig. 5 Results from the low-speed test race

that they have used quite a lot of additional time (Turn 3). This engagement from both of the students is followed up by their effort to fill in the table with default values, first Henry after the first test-race, then Mary after the second one. This implies that the relevant conceptual resources are understood and oriented to in interaction, but are not a topic for negotiation or discussion.

Again, it is obvious that it is quite easy for the students to make meaning of the virtual world. This becomes evident in that they do not have a problem driving through the test race with high and low speed, nor to they find issue in picking up relevant information and filling it into the ready-made table. If we compare the numbers in the blue squares in Figs. 4 and 5 with the numbers in Table 3, respectively test race 1 and 2, all of these are

correct. This means that the students are able to translate their knowledge from one representational setting, the virtual world, to another, the ready-made table. In this occasion, it is important to mention that the blue squares with their categories and numbers in the virtual world and the categories and numbers in the ready-made table are the same and should be fairly easy to fill in. According to one perspective, this is productive in the sense that the students manage to pick out relevant disciplinary information from the blue square and fill it into the ready-made table. In another, however, this process likely contributes to the lack of comments that point in a more conceptual direction together with the strongly procedurally formulated task. Again, the virtual world supports actions and procedural problem solving more than conceptually oriented activities. Moreover, it is also worth mentioning that there are no hints built into the virtual world or the other support tools, such as the worksheet, that stimulate and aim to regulate the students' talk. Therefore, it is easy for the students to leave any (conceptual) discussions out.

This is a session where the students work together in dyads, and in the data we are analyzing, the teacher is somewhere else in the classroom. Neither of the students appear to have any need for teacher support as far as this does not become visible in their talk nor in their actions. It is simultaneously evident that the students' conceptual meaning making would have benefited from being challenged to make some explicit formulations with regard to comparing the two test-races and the values they have filled into the ready-made table. However, the conceptually oriented problem solving is neither asked for in the detailed formulated worksheet nor triggered by example of any visual representations in the virtual world. Moreover, the teacher neither asks for this kind of conceptually-oriented problem solving nor do available authoring tools in the virtual world prepare it. Nevertheless, from the students' point of view, at this point they do not seem to have any need for teacher intervention or technology support to complete the task.

Again, we can see that the students' problem solving using the virtual world tends to be procedurally oriented, although it highlights conceptual issues as well. Relevant conceptual data are identified within the frame of the students' interface. However, these are more or less copied from the virtual world into their work sheet. This procedural orientation fits in with previous research on conceptual learning in science. Moreover, the students do not seem to have any problems with action oriented activities like driving the car at respectively high and low speed, which in this sense creates a foundation for more conceptually oriented work later. Following up on Säljö and Bergqvist (1997), it is clear that the students know what to look for in the blue square (see Figs. 4 and 5 and how this is noted down in Table 3). We know that this has been explicitly presented by the teacher in her introduction to the task. Further, the amount of information in the students' interface seems to work fine (refer: Krange and Ludvigsen 2008). They make it relevant in their interactions and there are reasons to believe that it could make a solid foundation for further conceptual work.

Making a graph

In this third extract, we analyze how the values from the test races with high and low speed in the virtual world were brought forward in developing graphs using scatterplots based on values in a spreadsheet. We investigate how they interacted with the representations in relation to the scatterplot functionalities, how they followed up the instructions in the worksheet, what needs they had for teacher interventions, and finally how they summed up their conceptual knowledge as part of the tasks they were asked to solve in the worksheet.

The teacher was very explicit about where to find the Excel logfiles with low and high speed when she introduced the tasks in the beginning of the lesson. Henry and Mary
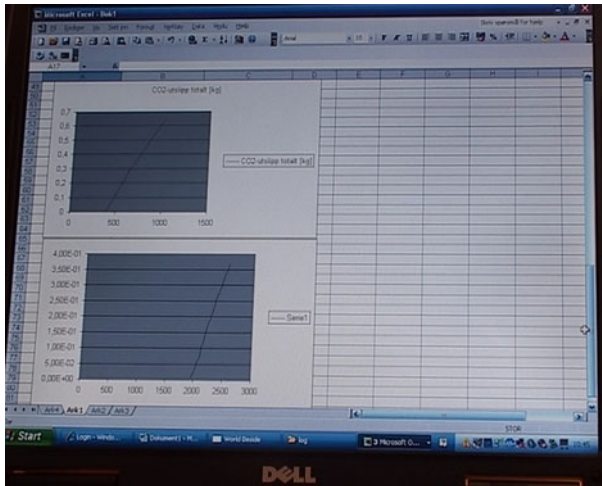
Fig. 6 The two graphs representing total CO_2 emission depending on high and low speed with different values on the y-axis

opened the two relevant logfiles where the results from their two test races by design have been logged into two spreadsheets. Each of these consists of several values. In line with the task formulation in the worksheet, they had opened a new spreadsheet and copied column T, total CO_2 emission, and column B, driven distance. When we enter the data Henry and Mary have made two relevant graphs but they have problems to understand what the graphs mean and therefore also difficulties to compare them (see Fig. 6). Henry and Mary agree to ask the teacher for help, and Mary begins by saying that they have major problems with Excel.

Extract 3: making a graph

4. Teacher: What are you struggling with?
5. Mary: Yes, well. The diagram doesn't look right. What is this? *Mary points to the y-axis on the upper graph* (see Fig. 6). The unit is probably kilo, but 0,7 and so on…
6. Henry: Yes, that one is okay, but the one below… *Henry refers to the graph they have pasted further down on the page* (see Fig. 6). Here we have got some kind of standard formulae.
7. Teacher: Yes, it is a standard formula, yes. And what you can do then is—you can change these very easily by pushing the x–y-axis or the right button on the mouse. *The teacher pushes the y-axis. By doing this, a new diagram pops up and she can format the axis.* Format axis. *A new window pops up.* "Format axis". And then you turn to… If you like standard numbers, ordinary numbers, push Numbers.
8. Henry: Yes, ordinary numbers.
9. Teacher: It is now on Exponential. Then you push on "Standard". *She chooses standard and thereafter OK.* And then …
10. Henry: Yes, there it becomes good.
11. Teacher: Yes, there it becomes good. Then …
12. Henry: Yes, how to get them equal? *Henry refers to the y-axis on the other graph.*

13. Teacher: When you are going to get them equal, you turn to the same place and then scale.
14. Henry: Yes, yes. *Pushes the y-axis and chooses scale.*

Based on the teacher's question about what they are struggling with (Turn 4), Mary brings the teacher's attention towards the first of the two diagrams that they are working with (Turn 5). It is obvious that they have problems with creating conceptual knowledge due to their limited familiarity with using graphs in Excel. In the worksheet they have been asked to justify the y-axis to make the diagrams comparable, but when it is not explained in detail, the students have problems interacting with the graphs as computer representations. They experience issues with making the graphs adequate according to present variations in CO_2 emission depending on the speed of cars. This also implies that they have problems with transferring their knowledge from the virtual world and the ready-made table over to a graphical representation of the same disciplinary phenomenon. The conceptual resources linked to conceptual issues are therefore not taken up, negotiated or discussed. Thus, the potential to support the students' conceptual learning by using multiple representations of the same phenomenon becomes undermined.

If we look at the next turns (Turn 5 and Turn 6) where they identify their problem to the teacher, it also becomes evident that Mary has difficulties with even understanding what their problem is. While she refers to the y-axis in the upper graph that operates with standard numbers (see the upper graph in Fig. 7), Henry closes this as a problem by saying "that one is okay". Instead, he turns the focus towards the second of the graphs and suggests that the values on the y-axis are likely presented in some kind of standard formulae. The teacher confirms that this is correct (Turn 7) and she gives the students a highly procedural explanation for how to change the values on the y-axis from standard formulae to standard numbers. Henry replies by saying "Yes, ordinary numbers" (Turn 8), but it is not very clear if he just follows the teacher's explanations or if he actually understands what it means. The teacher is now fairly deep into the presentation of graphs and when she has changed Exponential to Standard and pushes OK (Turn 9), the graph seems to be much more in line with how Henry wanted it to be and more similar to the
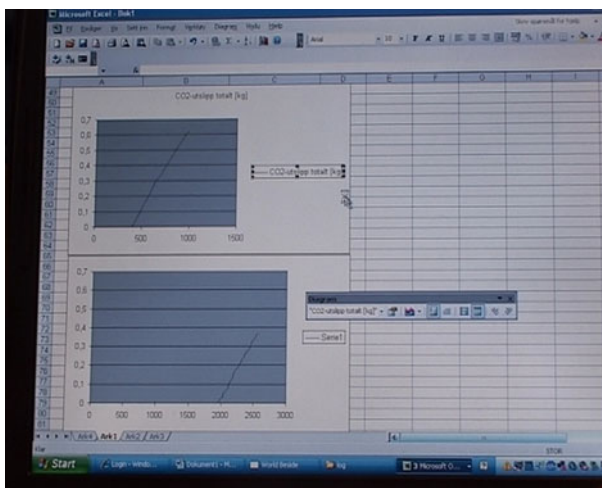

Fig. 7 The diagrams with similar values on the y-axis

upper graph in Fig. 7 (Turn 10). However, Henry is not completely satisfied, because although the y-axis on the two graphs have the same values, they do not start at the same one, and Henry wants them to be similar to make them comparable (Turn 12). Again, the teacher explains how to change the presentation of the graph (Turn 13), but this time, it is Henry that pushes the buttons (Turn 14). This indicates that he is about to make meaning of the graph as a computer representation and he becomes familiar with how he, with a certain purpose, can change it (make the graphs comparable).

Although the students managed to make two fairly comparable graphs (they have not made the two x-axis similar), these were not dealt with as conceptual resources either by the teacher or by any of the two students. At this stage, their work with the graphs is about handling these as computer representations and making improvements of these for later to make conceptual knowledge of the graphical presentation of variations in CO_2 emission, depending on the speed of the cars. When we look into the students' reports, they are making this conceptually oriented link both in the form of written text and by an improvement of the presentation of the graphs (see Fig. 8). According to their written text, this means that they are explicitly summing up their knowledge about the relation between CO_2 emission and speed as they try to explain why high speed causes more emissions than low speed (see the description of the students' worksheet in the paragraph "The problems the students were asked to solve"):

> When we drive fast, the emission of CO_2 is very high. If we reduce the speed, the emission is reduced to a certain point. The reason for this might be that it burns and uses more gasoline faster when the speed increase, therefore the CO_2 emission also becomes greater (gathered from Henry's and Mary's written report).

This quote illustrates that the students have managed to take up the most relevant conceptual knowledge and that they are able to formulate this in a fairly precise manner. Moreover, the presentation of the graphs has also improved:

Looking at Fig. 8, it is obvious that the students have changed the x-axis, likely to make the two test-races more comparable and their conceptual conclusion more explicit.

In Extract 3, the students have problems handling the computer representation, and they acknowledge that they cannot make any comparisons and conclusions regarding the relation between speed and CO_2 emission without managing Excel as a tool. Again, it is interesting to see how the worksheet requires the students to do step-wise activities and the teacher contributes with procedurally oriented interventions, thereby helping the students to handle the graphs. What the graphs are actually an expression for is not taken up as an
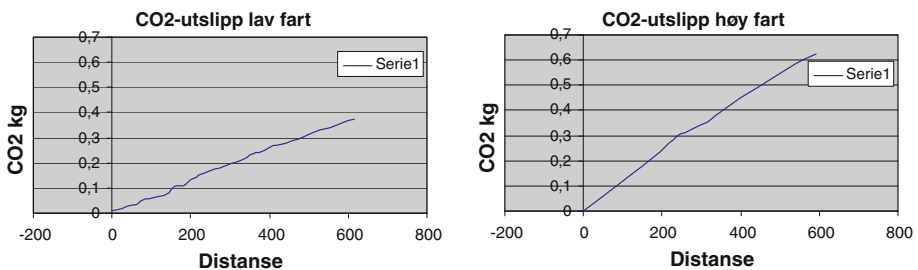

Fig. 8 The final graphs were handed in as part of the students' written report. The one to the *left* refers to low speed and the one to the *right* to high speed. The x-axis refers to distance and the y-axis to CO_2 emission per kilo

explicit issue. The students are left on their own to make an interpretation of it. However, these conceptual connections are not explicitly asked for in the worksheet but first after the graphs are made. However, the conceptual link between CO_2 emission and speed is dependent on the procedurally oriented groundwork of preparing the graphs for comparison. Again, we can see that the students have problems with making conceptual knowledge part of their work process (e.g., Clark and Sampson 2007). Their discussions are only related to procedural issues concerning the presentation of the graphs and do not touch upon more conceptually oriented interpretations of what the two graphs represent. It would have been an additional advantage if they had managed to keep up these kinds of discussion with regard to conceptual issues (Mercer and Wegerif 1999). Nevertheless, they make conceptually oriented conclusions at the end of their learning trajectories, and the students know what to look for to improve the graphs and make these useful to develop conceptual claims (e.g., Säljö and Bergqvist 1997).

How three kinds of cultural tools come into play during students' meaning making

The aim of this study has been to scrutinize how conceptual meaning making is realized when students engage with different representations to develop their understanding of energy resources. We have done this by studying how the students made meaning with representations of energy resources and we have particularly focused on how virtual world and other learning tools impacted these meaning making processes. In our analysis, we have been concerned with a perspective of learning that treats it as being about coordinating and applying a conceptual and procedural orientation towards the tasks and representations that students encounter. By selecting three extracts, we have had the possibility to examine these shifting conditions for meaning making both in terms of learning tools and what disciplinary content that has been highlighted. Moreover, this selection has also provides us with the ability to analyze how students translate their knowledge from one representational setting to another.

Based on this study, it becomes evident that students gather conceptual meaning of energy resources when engaged with different representations. When summing up their knowledge at the end of their learning trajectories, they make an explicit link between speed and CO_2 emission. In line with our sociocultural stance to meaning making, we argue that such knowledge is something that emerges during problem solving processes. However, there are no signs of such knowledge appropriation in the students' talk before it is expressed in their written report at the very end of their learning trajectories. Most of the time, the students' meaning making processes are procedurally oriented, and the ways they speak and make meaning of conceptual issues are not made explicit. In this context, it is important to mention that the students might have made conceptual meaning of energy consumption earlier in their trajectories, but there are no tools that bring this up front and summarize conceptual issues consecutively. An implication of this is that the students become less aware of their knowledge appropriation, and teachers and researchers have no basis to evaluate what the students have learned at different points in their trajectories. The virtual world, as it appears now, invites action. This may be productive as a basis for conceptual meaning making but it is not sufficient to make it likely that the students will make meaning of scientific concepts (Vygotsky 1978). Moreover, it becomes evident that students manage to identify relevant disciplinary information and partly link this to other learning resources such as the ready-made table. However, there is nothing in our findings that indicates that they draw any conclusions based on the values aggregated from the two

test races in the virtual world or that they manage to translate this knowledge further into the understanding of the graphical representation of the same phenomenon. This means that the abundance of a combination of multimodal representations—read virtual worlds, ready-made tables, and spreadsheets—still has not found its optimal pedagogical use in this situation.

As a first step towards an improved design of virtual worlds in combinations with other learning resources, we will identify some *scaffolding tools* that support conceptual and procedural aspects of the students' meaning making processes. As part of this, we will also briefly comment on possible *teacher tools* that can make it easier for teachers to moderate the students' meaning making processes in a productive direction. We will do this by emphasizing three challenges with regard to further designs of virtual worlds in combinations with other learning resources:

1. *If conceptually oriented meaning making is not asked for, it will not become explicit in the students' talk.* This is the case, although disciplinary resources are made relevant in the students' actions, and it seems to be independent of what representations are used. Therefore, there is a need for a better integration of the relation between conceptual and procedural scaffolding tools that can improve the quality of the students' talk and collaborations. With regard to conceptual tools, it could be possible to design for a visual model of the relation between CO_2 emission and speed after the second test race in the virtual world is completed. This relation could be supported by procedural scaffolds, thereby challenging the students to discuss the results of the visualization or simply the values they have added to the ready-made table. The visual model and what to look for in it could be made relevant by being clearly mentioned in the students' worksheet. Moreover, this could be followed up by explicitly challenging the students to discuss what they see in the model and how they understand it conceptually. It would also be beneficial for the teacher to have some teaching tools available, particularly in situations during learning trajectories that we know are often critical in terms of improving the students' conceptual meaning making. A typical situation is the one mentioned after the second test race in the virtual world. Potential tools could be a bar diagram or an interactive simulation model where CO_2 emission and speed could be manipulated and presumptions for correlations could constitute a basis for teacher-guided summation discussions.

2. *The potential of multimodality where different representations of the domain contribute to comparing models across settings is small if not asked for explicitly.* If students' conceptual meaning making is not summarized during their learning trajectories, comparing models across settings becomes difficult for them. The potential in using multiple representations is not realized. Strengthening the conceptual and procedural scaffolds to support students' possibility to translate their knowledge across different representations would address this challenge. To actually have something to compare the graphs to would require a summing-up activity after the test races in the virtual world had been completed (see challenge 1). If this was also explicitly asked for in the worksheet, and if the students where stimulated to compare and discuss, the abundance of the representations would appear more obvious. Some teaching tools would also improve the multimodal potential. This could, for example, be prepared groups of representations that the students had worked with, which could function as a basis to compare the various presentations.

3. *The representations in the virtual world are nearly too easy to deal with in the sense that students tend to work procedurally and not conceptually.* This means that students

manage to make the representations relevant in their meaning making processes, yet they do not discuss what these mean conceptually if they are not explicitly asked to do so. We conclude that the virtual world gives a solid basis for changing students' conceptual meaning making in science through its action oriented trajectories. However, these actions need to be framed in a manner that to a larger degree also stimulates conceptual issues through tasks in worksheets, certain types of talk and collaborations, and teacher interventions that contribute to make conceptual relations more explicit. A last but important point concerns the design of representations. Even though their task was quite simple, the representations relevant for providing explanations and accounts was not sufficiently tied to students' activities. Additionally, the information provided was too difficult for them and they did not have sufficient knowledge to interpret the representations and make them relevant in their meaning making.

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Author Biographies

Ingeborg Krange has in more than a decade been working with issues in regard to design of virtual worlds and she has performed several studies of how these worlds can be used for an educational purpose. She emphasis the importance of knowledge representations and dialogical aspects between peers and their teachers. Dr. Krange has several publication in international journals particularly linked to science education. Dr. Krange is now affiliated with InterMedia, University of Oslo, Norway, and is the project leader of the MIRACLE project.

Hans Christian Arnseth has in more than a decade been working with ICT and learning in science education. He stresses the importance of knowledge representations and dialogical aspects between pupils and their teachers. Associate professor Arnseth has several publication in international journals particularly linked to science education and game-based learning. Associate professor Arnseth is now affiliated with Institute for Educational Research, University of Oslo, Norway, and is involved in the projects Local literacies and community spaces and MIRACLE.