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Motivating students to perform an experiment in technological design contexts

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In a teaching-learning sequence on the subject of energy we have tried technological design contexts to motivate students by using only context-based reasons to perform experiments on the subject of energy. We use these experiments to have the students reinvent practical laws of energy conservation from their data. We expected students to see the need for an experiment to test their designs but in our first try-out we encountered some problems with this, basically blocking the intended path to understanding energy conservation. In our second try-out we have improved the learning materials effectively hereby finding several contextual reasons for students to perform an experiment but also an unexpected reason for students not to perform an experiment.

Introduction

In the Netherlands curriculum innovation committees for the exact sciences have chosen a context-based approach to education (Eijkelhof et al., 2006). Pilot (Pilot et al., 2006) says further investigation is needed on attaining abstract concepts in context-based education. As it is one of the more abstract concepts in physics we chose energy conservation as a concept that we will try to attain in a context based teaching-learning sequence. In order to achieve our goal we chose to use the guided reinvention approach (Freudenthal, 1991) and have the students discover their own conservation laws from their own experiments.

For using contexts in education Gilbert describes four models, of which he regards “contexts as the social circumstances” as the most promising (Gilbert, 2006). We will adhere to this model, because it avoids putting the concept in the center of attention too early for students to be able to reinvent it[1]. Gilbert describes a number of criteria for the use of contexts based on this model:

i. Contexts must arise from the students themselves, from actual social issues or industrial settings and must address the zone of nearest development in students.
ii. The assignments need to clarify a certain way of operating and must consist of clear examples of major concepts.
iii. The context needs to give rise to a coherent jargon for students to use. The context decides which concepts are useful to achieve this.
iv. Every important subject needs to be related to background knowledge. Students need to be able to recontextualize.

In our case we are looking for contexts in which practical laws involving energy conservation can be reinvented by performing experiments. Practices in which physical laws are discovered are the practices of either technological designers or scientists (ii). Staying as close to real life experiences as possible (i) we decided to start with technological design practices. To clarify the technological design way of operating we decided to use designing principles from the Techniek15+ approach (ii) developed by a project group involving five Dutch universities, regional engineering companies, and engineering societies (i) (Techniek15+, 2002). In the problem orientation phase Techniek15+ connects the context to the background knowledge of

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[1] The other extreme is to regard contexts as illustrations of concepts. Gilbert mentions some intermediate possibilities too.

the students (iv). To see whether our contexts comprise a clear need for the desired practical laws involving energy conservation, we will try out whether it is possible to motivate the students through the whole process with only hints, questions, and reasons stemming from the context (ii & iii) as opposed to guidance stemming from the law to be discovered. This way both the purpose of the law as well as its utility to the context should become straightforward to the students (iii). With our choices we aim to satisfy all of Gilbert's conditions (i-iv).

The first indispensable step to be taken in our teaching-learning sequence towards the concept of energy conservation is to motivate the students to perform an experiment based on contextual reasons only. In our first try-out some students did not want to perform an experiment because among others (i) they were not used to testing their ideas with experiments, and (ii) they relied on established techniques like electrical engines (Logman et al., 2010). For the second try-out one of our research questions therefore was: *While using a guided reinvention approach, how can we motivate students by contextual reasons only to perform experiments on energy?*

Method

Research approach

To develop the teaching-learning sequence we use the method of design research (Van den Akker et al., 2006) which makes use of subsequent test cycles. We have finished our second try-out and we will have a third and last try-out in the next school year. Following this method, we aim at uncovering the major difficulties for students to overcome in our approach by critically analyzing the reactions of students (and teachers) to the created material and are working on solutions to the difficulties. To answer our research question we have designed a teaching-learning sequence which is expected to help the students through the desired learning process. For every step in the learning process a worksheet has been designed along with specifications of desired outcomes. In the worksheets we only use context-based questions.

Designing the educational materials

The path from contexts to experiments

To motivate the students to perform an experiment the problem posed within the context must make an experiment inevitable. An example of a context that we used is lifting a cap stone (of about 1000 kg) on top of the pillars of an ancient Greek temple. To give this a setting more appealing to students we used a documentary maker who wants to shoot a reconstruction of a Greek temple building process but does not know how to go about that. Therefore he hires a technological design company to come up with a possible realistic solution to lifting the cap stones on top of the pillars. The students are supposed to be employees of that company. Technological design contexts involve constructing an apparatus that needs to be tested, to see whether it meets the requirements posed by the client. However such experiments do not necessarily result in generalizable knowledge: if the apparatus just works, then all arguments about why it works may remain tacit.

The path from experiments to practical laws involving energy conservation

Because we want the context to lead the students this means that students have to feel the need for a new concept before they arrive at it. To achieve this we need to narrow down the problem situation to one in which a particular practical law of energy conservation plays an inevitable role. To make the practical law not too difficult to reinvent we chose experiments that involve only one or two forms of energy. In the case of the reconstruction of the Greek temple the desired practical[2] law of energy conservation is $\sum(m\cdot h)_{before} = \sum(m\cdot h)_{after}$ or any equivalent notation. This law has as preconditions that it is only valid when the objects concerned are balanced and that there is little friction. To make sure students need such a solution we require the lifting of the cap stone to be safe and we hoped (and hinted) that students would see the safety benefit of a balanced solution. Also, to lift the stone as easily as possible there must be as little friction as possible. Besides all that we expected the students choosing the balancing counterweight to be a factor lighter than the cap stone because otherwise lifting the counterweight would pose the same problem as lifting the cap stone.

Generalization of the practical laws of energy conservation

In a discussion with the students on their findings in three different contexts (lifting a heavy object, designing a thermostatic water tap, and designing a rollercoaster), we aim to generalize the various reinvented practical laws of energy conservation by combining them into one. Because such a generalization of physical laws is not a part of the job that a technological designer does we chose a scientific context to perform these generalizations but this is beyond the scope of this paper.

In the end we expect the students to be able to combine practical laws of energy conservation themselves. Combining more and more laws of energy conservation we expect the students to come up with the idea that for any situation one can create a law of energy conservation particular to that situation. We will report more on our results concerning these generalizations in a future paper.

Data collection

Our first try-out involved one teacher teaching 8 couples of students. The second try-out involved three teachers (including the teacher from the first try-out) teaching respectively 11, 15, and 12 couples of students. We have designed several technological design contexts in which the requirements were varied to see how they affect the learning process. Faced with a few unforeseen obstacles for the students in the second try-out the teachers spontaneously added some requirements to guide the students in overcoming these obstacles.

To see whether the context-based questions work as expected we look at students' notes and verbal reactions to the questions and compare them to our expectations. To this end we make audio recordings and collect students' notes. To make sure to what extent only context-based questions, hints, or reasonings are used by the teachers we analyze their conversations with the students. If any unexpected questions are used we analyze the effect on the students: do the students acknowledge the question as connected to the context and does the question help them along in their progress towards the energy concept.

Results

Below we report our progress on the reasons for students not to perform an experiment found in the first try-out.

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[2] In this case practical means it is as easy as possible to apply the law to the case at hand. So all constants that cancel out will not play a role in the solution to the contextual problem and can therefore not be discovered.

Students are not used to testing their ideas experimentally

From the first try-out we created a list of context-based hints to motivate the students to perform an experiment in order to find an answer to the contextual problem. The provided hints seem to have diminished the problems in having students test their ideas experimentally: in the first try-out only 6 out of the 8 groups saw the point of performing an experiment and in the second try-out and the same teacher all 11 of the 11 groups did. The other two teachers were not involved in the first try-out therefore a comparison is impossible but out of their 27 groups in total only 1 group did not see the need for an experiment. To illustrate the workings of these hints and their origin from the context we list some examples of these hints in Table 1.

Table 1 Context-based hints

Context-based hints to guide students to perform an experiment
Are you sure it will work in the real situation?
How can we be sure it will work in the real situation?
Technological designers normally create a prototype to test their ideas.
If it goes wrong in the real situation a lot of cost/effort will be lost.
Can you explain your solution to the client?

Seeing that these hints diminished the problems from the first try-out effectively it may have been that it was not the students' unfamiliarity with testing their ideas experimentally that was causing the problem but that it was that the students did not properly see the need to test their ideas experimentally. By providing the context-based hints we seem to have resolved this issue.

Students rely on established techniques like electrical engines

In the first try-out in trying to find solutions to a contextual problem in which the students needed to give advice on lifting a heavy optical table, several students relied on electrical engines to lift the table. As using electricity would interfere with our aim to reinvent the law $\sum(m \cdot h)_{before} = \sum(m \cdot h)_{after}$ from the experiments we decided to redesign this context in such a way that electrical engines were not possible by setting it in a time in which electricity was not yet available: lifting a cap stone on top of pillars in ancient Greece. Knowing these considerations one of the teachers wanted to adapt this context of lifting a heavy object in the second try-out by setting it in a more recognizable and modern school setting (lifting a very heavy stage perfectly balanced during a theater show). He eliminated the engine-driven solutions by stating that engines generate too much noise during a theater show. This time two groups of students came up with the ready-made solution of a jack to lift the stage. Even though these students were not unwilling they found it difficult to perform any experiment on the apparatus mainly because they did not see the need for testing the apparatus as clearly it would work as shown in the following excerpt:

"[The last item for the jack has been retrieved]
T: Ok. ***Are you able to measure something now?***
S2: Well.. No.
T: No?
S2: ***We know that it can lift the stage*** *and that the thicker this one is, the more force it can supply.*
T: Ok.
S3: And that the longer you make this, the easier it is.
T: What needs to get longer?
S2: This.
S1: Behind here.

T: Oh that one ! And how much does this thing go up when you let that piece go up once, twice or ten times?
S1: Yes, we can measure that.
T: Is this important for our problem or am I asking stupid questions?
S1: Well, in itself.. Then you know how much this one goes up but then we would need another one (another jack) with a different size.
T: Yes, you would need one more with a different size. Yes. ***Can you reconstruct the principle?***
S1: As soon as you know those proportions one can calculate the other proportions as well, one could say.
T: Ok. Is that height also important for the problem itself? For the real stage?
S2: Yes.
S1: It has to come up 50 cm."

The excerpt shows the teacher asking what physical law explains the working principle of a jack. This is not a context-based question as there is no need for the students to answer this question to come to a solution to the contextual problem. Through this we realized that in the engine-driven solutions to the lifting assignment in the first try-out the problem was that engines are a ready-made technique which take away the students' need to perform an experiment to find out whether their solution will work. Of course eliminating this need for an experiment also takes away the chance to reinvent the desired practical law of energy conservation.

Another small number of groups decided to use manual laborers or animals to lift the heavy cap stone. One could argue that these solutions are ready-made 'techniques' of the ancient Greeks. In a group discussion about all the investigated solutions, the students in general agreed that these solutions involving manual laborers or animals would still benefit from the knowledge behind other solutions that did make it easier to lift heavy material. To the desired learning process it is therefore essential that at least a few groups in a class find solutions that make lifting easier.

On the problem with established techniques we can conclude that it would be best to choose the context in such a way that ready-made techniques are excluded as a possible solution to the context (e.g. by setting it in a time or place where the ready-made techniques are not available) but this may reveal other, most likely simpler, ready-made techniques in the new setting. In our case for example the problem of using many people or animals to lift the heavy material is still to be addressed.

For the other two contexts we found similar results where it has to be noted that these contexts were already set before the time of the appropriate invention. In the case of the water tap manufacturer it was easy to motivate the students to perform an experiment by telling them that this particular manufacturer did know how to make water taps but did not yet know how to manufacture a thermostatic water tap. In the case of the rollercoaster it was not hard at all to motivate students to do an experiment even though on the internet in the rollercoaster database (www.rcdb.com) there is a lot of data available on height and maximum speed of many rollercoasters around the world. With this data students could have easily evaded performing an experiment but none did. It is however remarkable that in the lifting assignment we observed students looking on the internet for solutions whereas in this context they did not look for it or did not find it. The reasons these contexts showed less problems in motivating students to perform an experiment may also lie in the fact that the students had already solved a similar contextual problem in the lifting assignment and now knew better what was expected by the teacher or were simply more attracted by experiments with hot water and rollercoasters.

Discussion and conclusion

Technological design contexts appear to be useful if one wants to create context-based educational materials in which one desires the students to perform experiments. However to technological designers, educational designers, and teachers it may be obvious to perform an experiment to test one's ideas but for students this idea is not immediately self-evident. To help teachers to make the students see the need for an experiment the created list of context-based hints is helpful.

If one desires to have students reinvent a certain physical principle from an experiment in a context-based approach one has to be aware that ready-made techniques available in the context can obstruct students to see the need for the physical principle behind such a technique. To make sure students perform experiments in which the desired physical principle will become clear, contextual problems can be chosen such that the solution to students is yet unknown or can be set in a time in which the solution was unknown. Roth (Roth, 2001) has used technological design contexts in many situations as well and has set a similar lifting problem in the arctic where power supply may go faulty but the need for lifting heavy objects is ever present (i.e. he set the contextual problem in a *place* where a ready-made solution is not available).

Completely avoiding ready-made techniques however is impossible because in any new setting other ready-made techniques will be available. Contextual problems should therefore be chosen such that solving them can not be done with a ready-made technique that obscures the physical principle we are aiming at. This can be done by the right choice of context or else by setting the context in a time or place in which the undesired ready-made technique is unavailable. By setting extra requirements on the contextual problems (e.g. asking for a rollercoaster with the highest speed suggesting as little friction as possible) it is possible to motivate students to perform experiments suitable to reinvent desired physical laws.

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