

Factors that influence pupil engagement with science simulations: the role of distraction, vividness, logic, instruction and prior knowledge

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Abstract: Constructivist perspectives advocate high quality visual and auditory multimedia to simulate complex and authentic situations. However, the influence of symbolic or representational learning materials on pupil engagement or learning outcomes is not clear. This paper reports on pupil engagement with two types of simulation commonly found in school science (to illustrate practical experiments or depict microscopic chemical interactions). The project pilot phase involved three 15-16 year old male pupils and a main phase involved twenty one 14-15 year old pupils. They were presented with a digital record of their 'think aloud' behaviour with the simulation and they were asked for retrospective comment. Pre and post surveys were also used. Distraction, vividness, logic, instruction and prior knowledge played a significant role in determining the nature of engagement and the outcome of engagement. E-assessment involving multimedia or symbolic representation in science education must take great care if it is to ensure that what it is assessing is the pupil's science capability and not information processing skills that rely on shared symbol identification or on the ability to follow the designers' logic of instructions. [*Chem. Educ. Res. Pract.*, 2007, **8** (1), 1-12]

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Introduction

A review by Rodrigues (2004) documented the potential of various computer-based technologies for science education. Much of this potential is guided by a belief in their power to motivate pupils and is guided by a suggestion that goal orientation, interactivity and feedback empowers pupils and produces enhanced learning outcomes (Leach, and Moon, 2000; Rodrigues, Smith and Ainley, 2000; Wu, Krajcik and Soloway, 2001; Löhner, Van Jooligen and Savelsbergh, 2003; Mayer, 2003; Ardac and Akaygun, 2004; Lagowski, 2005). However, Cuban (2001) suggests that the potential of goal orientation, interactivity and feedback found in various multimedia has not been fully realised in science classrooms. This may be because, beyond macro design principles, little is known about the effects of micro design variables (Tabbers et al., 2004). Indeed, the influence of symbolic or representational learning materials is not clear (Betrancourt and Tversky, 2000). Given the trend for increasing reliance on computer-based teaching resources (Cuban, 2001; Lagowski, 2005), what is needed is a clearer understanding of what engages and sustains pupil interest when using multimedia in science.

Some authors suggest that what is known about the various design variables is sometimes ignored by software developers (Gee, 2003). But in reality, only a few studies in the area of formal education have investigated either pupils' perceptions of learning in computer

technology-based classrooms (Deaney et al., 2003) or pupils' roles in determining the success or failure of computer based technology use (Levin and Wadmany, 2005). Though it should be noted that researchers have studied young people's engagement with computer games (see Kennedy, 2002).

Mayer (2001) suggests that pupils build mental representations of multimedia instructions and Sweller, van Merriënboer and Pass, (1998) have argued that changing presentation format can reduce unnecessary memory load. For example, Moreno and Mayer (1999) suggest that multimedia instructions are more effective, when verbal and visual information is presented close together (the contiguity principle). Mayer (2001) suggests instructions are effective when verbal information is presented aurally rather than visually (the modality principle). Experiments show that replacing written text with speech increases test scores (Kalyuga et al., 1999; Moreno and Mayer, 1999). Often Baddeley's (1992) two modality systems, (visual/spatial information and aural information) model of working memory is used to explain findings. Many studies demonstrating modality effects claim a reduction in extraneous load as a consequence of more efficient use of available memory resource. However, results could also be explained by a reduction in visual search (Tabbers et al, 2004).

The constructivist perspective advocates high quality visual and auditory interfaces to simulate complex and authentic situations. In essence the argument centres on the potential of multimedia to help learners construct their understandings by establishing links between what they know and familiar or not so familiar situations that appear realistic because of the high quality depiction available. However, analysis of static or interactive visualisations to help pupils integrate symbolic representations suggests that not all constructivist-influenced activity improves learning outcomes (Bodemer et al., 2004). Nevertheless, much of the perceived value of multimedia lies in the notion of interactivity (Prensky, 2005). The cybernetic literature on feedback provides many definitions for interactivity, but given the nature of multimedia commonly found in schools, the project reported in this paper uses Laurillard's (1993) definition of interactivity: users receiving "*intrinsic feedback on their actions that relate to the nature of the task goal*" (page 94). A project aim was to help understand how interactivity in this broad sense can arouse and sustain pupil engagement. By closely monitoring pupil engagement and by seeking pupils' perspectives on their engagement, the project hoped to provide insight into how multimedia design features function to either enhance or restrict learning and interest.

Simulations

Two types of simulations were used in the project. They were high quality simulations aimed at introducing college chemistry (United States of America, general chemistry) that could be downloaded free from the website, providing the source was acknowledged. <http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animationsindex.htm>

This website, rather than a software package, was chosen for two reasons. First, a website would provide readers with access to the simulations evaluated, and second, the website simulations matched the types used, and the concepts and learning outcome levels advocated for secondary school science in Scotland. For example, pupils usually aged between 14-16 years, can pursue Standard Grade Chemistry or Intermediate 1 and Intermediate 2 Chemistry. Course documents at this level include statements such as "*describe the formation of ions in terms of atoms losing or gaining electrons*" or include activities such as audio visual material to illustrate lattice formation or "*prepare standard solutions of common acids and alkalis, titrate to check accuracy*". Two types of simulation, typical of many commercial products in terms of their appearance, their quality and their purpose, were used. Some of the simulations portray experiments; they provide opportunities to conduct experiments without

incurring costs for equipment or resources, and they allow for multiple repeat experiments. From a teaching perspective the microscopic representations provide an opportunity to animate what has until recently only been shown as static models in textbooks, or as ball and stick models in classroom demonstrations. On the website, some of the simulations were accompanied with tutorial worksheets. However, for the purpose of this project, the simulations were used without accompanying worksheets as the intention was to determine what guides and influences pupil engagement when they have access to simulations and to see what pupils attend to, focus on, or continue to pursue. These aspects are important for two key reasons. First, the call for autonomous learning, suggests that pupils should take ownership for their learning. It is therefore important that we explore what it is that will engage pupils and encourage them to take ownership. Second, in Scotland the assessment portfolio is moving toward the inclusion of electronic forms of assessment. It is quite possible that simulations may be included in formal assessment practices for science education, and it is therefore important to design simulations that assess science appropriately.

The project used a simulation that depicts the microscopic level. These types of simulations usually involve the movement of coloured circles or spheres to represent the various ions, atoms, molecules or particles. Examples selected for the project included an illustration of a neutralisation reaction between sodium hydroxide and hydrochloric acid, an illustration of sodium chloride dissolving, and an illustration of the reaction between ozone and nitrogen oxide. In all three cases, various coloured circles moved around the screen. The neutralisation simulation contained text on screen prior to and during the simulation. The dissolving simulation provided text at the end of the action sequences and allowed the user to replay, zoom in, or select a particular viewing position. The ozone simulation involved the circles making contact, an equation remained on screen throughout, and there were tab navigation instructions on the top edge of the screenshot. It could be argued from a modelling perspective, that the spacing of the coloured circles in the simulations that were used probably reflect more accurately the spacing associated with particles in a gas and that this could influence the development of pupils' alternative conceptions. However, as the project aimed to investigate pupils' engagement with simulations commonly found in schools, none of the simulations were modified to address this spatiality issue.

The second type of simulation used was a representation of an experiment that included static equipment but required the user to complete text boxes, change quantities or move dials or scales. Examples of this type included experiments on titration, on the combustion of an organic gas and on the electrical conductivity of solutions. In all three, the user had to follow a particular sequence to make the simulation operational. In all three, error messages appeared if the user was incorrect. In one of the three, the user was provided with feedback showing how to correct the error made. In all three, there were tabs (with menus) to pullout, there were button type selection options, there were text boxes for users to key in information, there were sliders to change quantities, and there were submit buttons.

Methodology

There were two phases to the project. In both the pupils and their parents/guardians signed informed consent forms prior to participation. The pilot phase involved three male volunteers (private secondary school pupils aged 15-16 years). They used the two simulations individually and were interviewed individually. The interview questions, methodology and survey were refined during the pilot phase. However, the pilot study data provides some useful insight into the nature of pupil behaviour, and has therefore been included in this paper.

The main phase involved a well-regarded public secondary school and twenty-one volunteer, male and female, pupils (aged 14-15 years). Working in pairs, the pupils used two

simulations for up to five minutes. In the main phase, pupils were asked to work in pairs (but due to the number of volunteers, there was also one group of three). The paired approach was an attempt to access pupils' thinking. While working together some pupils 'thought aloud' as they sought clarification from their peer or as they reacted to a screen shot. Working in pairs also reduced their perception of the exercise as a test. Their engagement was digitally recorded, to show the computer screen and to record their dialogue.

Directly after using the simulation, the pupils, in their pairs, were interviewed. The digital record was replayed. The pupils were asked to explain particular actions and behaviours (how they knew how to complete particular tasks, deployed particular protocols, and knew how or when to use particular actions). The retrospective interview account was initiated when the researcher replayed the digital record and asked the pupils to comment on their actions and engagement. When pupils' responses were particularly animated or they drew attention to aspects of their engagement, the researcher probed for clarification. In addition, during the pilot phase, the three pupils made comments about certain aspects; these were used as prompts in the main phase. For example, pupils in the pilot phase all mentioned design elements and were then asked for advice to a software designer. Consequently in the main phase, toward the end of the retrospective account-interview, all pupils were asked for advice to a software designer. In addition pupils' science concepts were explored briefly and informally.

This methodology is based on the work reported by Clarke (1998) in which retrospective accounts were used to access pupils' thinking and it uses a 'thinking aloud' strategy usually credited to Ericsson and Simon (1984), which is an approach that has often been used in cognitive psychology research, usually to explore pupils' problem solving strategies. In recent times research investigating human-computer interactions or involving usability testing have deployed thinking aloud protocols to evaluate new software (Crowther et al., 2004). The Ericsson and Simon (1984) method requires the researcher to provide initial general instructions and then withdraw, leaving the pupils to verbalise their thoughts whilst undertaking the task. The semi-structured retrospective interview technique included presenting pupils with a digital record of their pathway data documenting pupil behaviour and actions and asking pupils for retrospective comment. The digital record provided pupils with an artefact to support recall after the event and provided the researchers with opportunities to explore pupils' science understandings, and their engagement protocols, in a little more detail. A key project aim was to collect data on pupils' interactive decision making, taking into account the evaluation areas outlined by Milton and Lyons (2003): interface usability (how easy did the pupils find it to use?), content validity (what sense does it make to the pupils?) and educational utility (what do the pupils learn?)

Various perspectives can be used to analyse transcript episodes. In this project the pilot phase helped the researcher identify a set of circumstances. For example pre-determined questions, based on feedback collected during the pilot phase, were included during the retrospective interview accounts in the main phase. The researcher also identified what were considered to be intriguing pupil phenomenon (for example pupil repeated actions, returning to particular segments, or pressing particular buttons) and these were used as markers or cues when viewing the digital records of others). This fits in with conversation/discourse analysis methodology, as conversation/discourse analysis encourages research to be "data-driven" rather than pre-specified, and allows the study of pupil focus as it manifests in their interactions, resulting in a best fit heuristic (Hutchby and Wooffitt, 1998). Using common sense the researcher then interpreted episodes, elucidated the interpretation and provided some reasoning.

During explication, the researcher used personal knowledge (years of experience as a teacher, awareness of general pupil classroom behaviour, knowledge of curriculum content,

research experience involving pupils use of various ICT, conversation analysis techniques, etc.) as a resource to study the pupil-computer-pupil interaction episodes. Clearly, the transcriber-researcher's interpretation of what pupil utterances imply is informed by the transcriber-researcher's perspective. However, validity can be promoted by ensuring that transcripts and interpretations are post-checked by others including, in this project, the pupils. Pupils were given their digital records and transcripts. Validity is also possible, because the pupil may, in later transcript episodes, refer to a previous interaction episode, and provide additional evidence to support or challenge the researcher's analysis. Also, episodes and their analysis can be compared, allowing an observation made in one interaction episode to be used as the trigger or starting point for further analysis of other episodes and engagements with the same or other pupils (Heath, 2004). The transcript excerpts provided are brief, but representative of the mechanisms and procedures in evidence in the wider data set. The selection of particular excerpts was primarily based on conversation thread length. The examples provided in this paper, are simply that, illustrative examples of the interaction episodes.

The digital recording of their behaviour was given to the pupils and the digital record was transcribed. The transcript excerpts provided in this paper are coded. DHS refers to the pilot school and the volunteers from the pilot are numbered. SMA refers to the main phase school, and the volunteers are represented with initials. Additional data was collected by asking the pupils to complete brief (one side) pre and post surveys. The pre survey had four questions on one side of A4, and collected information about pupils' perceptions of their experience and comfort in using a variety of ICT. One question asked about general computing ability, using a 5 point Likert type scale. Another question asked for their experience rating, the options were 'a lot of experience', 'some experience', 'a little experience', 'no experience'. A third question asked for their comfort level rating, the options were 'very comfortable', 'moderately comfortable', 'need some help', 'need lots of help'. The final question asked about computer use to perform particular tasks at home or school (send an email, played a computer game, posted messages on bulletin boards). These types of survey items are common in surveys on ICT use. The post survey had six questions on one side of A4. It included questions that sought pupils' views, and therefore included three open ended survey items asking pupils what background information and skills they needed in order to use the simulations they used, and what advice they would give a friend who was going to use the simulation. The post survey also asked the pupils to rate the technical demand, the science demand and the potential for confusion when using the simulation. A final statement allowed for any other comments. All surveys were piloted before being used in the main phase.

Findings

In the pre-survey, the twenty-one pupils in the main phase and the three in the pilot phase were asked to rate their experience level and comfort level for several applications. Table 1 documents their experience rating value. The pilot phase pupils' responses appear in brackets. Therefore, sixteen of the twenty-four pupils felt they had lots of experience of word processors, seventeen said they had lots of experience of computer games and seventeen said they had lots of experience of the internet, but only four said they had lots of experience with simulations. The Table 2 documents the pupils' perceived comfort level rating.

Table 1. Pupils' perceived experience for some ICT.

Activities using technology	a lot of experience	Some experience	A little experience	No experience
Word processing	13 (3)	6	2	0
Databases	3	7 (1)	11 (2)	0
Presentation software PowerPoint	3	10 (1)	6 (2)	2
Computer games	14 (3)	5	2	0
Internet search engines	15 (2)	6 (1)	0	0
Simulations	2 (2)	6	7 (1)	6
Desktop publishing	2	4	9 (2)	6(1)

Table 2. Pupils' comfort ratings for some ICT.

Activities using technology	Very comfortable	Moderately comfortable	Need some help	Need lots of help
Word processing	10 (3)	10	0	1
Databases	3	5 (1)	12 (1)	2 (1)
Presentation software/PowerPoint	5 (2)	5	9 (1)	2
Computer games	15 (3)	5	1	0
Internet search engines	16 (2)	4 (1)	1	0
Simulations	2 (2)	5	10 (1)	4
Desktop publishing	1	5 (2)	9	6 (1)

Twenty-three of the twenty-four felt that they were very or moderately comfortable with word processing and playing computer games, while only nine said they were very or moderately comfortable using simulations. These experience and comfort ratings are of interest for two reasons. First, it would appear that many pupils do not equate computer games with simulations, and second, their Internet use does not predominantly involve simulations.

Analysis of the pupils' digital recordings suggests that there were three key aspects that influenced the process of engagement. These were:

- distraction (led astray by interesting, but at the time redundant, segments) and vividness (items that stand out),
- logic (factors influencing ability to organise information) and instructions
- prior knowledge.

These factors played a significant role in determining the nature of engagement and the outcome of engagement as shown by brief excerpts from the transcripts.

Distraction and vividness

Some of the pupils highlighted particular elements within the simulation as aspects that determined their course of action. For example, the following is taken from the retrospective interview when two male pupils were watching their digital recording. The replay showed that when the titration simulation appeared, the two boys started with instruction 5, "push the slider...."

Transcript 1

Pupil S *It said to push the slider up to add volume. But when we tried to push the slider up it didn't seem to want to work.*

Researcher *Why did you start with that instruction? Push slider to....*

Pupil S *I don't know actually, because that is number 5. Eh?! (chuckles)*

Researcher *But you were automatically drawn to that one?*

- Pupil M *Yeah*
 Pupil S *Yeah*
 Researcher *And then you were clicking away at something.*
 Pupil M *Yeah, the drop wise.*
 Researcher *Oh the dropper. So why were you clicking on the dropper?*
 Pupil M *It was the biggest thing that you can see. (SMA MS)*

Transcript 2

- Researcher *Oh, ok. So what made you think you had to move that slider up?*
 Pupil C *Because it was like, red and*
 Pupil L *Like, it just looked like you are supposed to do it. (SMA CL)*

These two transcripts are representative of the feedback received from all the pupils with respect to the influence of these particular elements on the simulation. Notably, all those who tried the titration simulation were intuitively drawn toward using the slider and a red 'dropper' button. However, neither action resulted in any productivity as these actions were required during the experiment, and not at the start.

Logic and instructions

Analysis of the digital recordings of the pupils using the titration simulation also identified a similarity in their information processing skills. All the pupils had problems with the titration simulation, regardless of their familiarity with the science, or of their ability, age, and gender. Furthermore, unless the pupils followed the sequence of instructions, the simulation would not work. None of the pupils, who used the simulations representing 'practical experiments', followed the numbered instructions. In some cases the number went undetected and in other cases the number sequence was noticed, but their relevance was not identified. Some pupils accounted for their failure to follow the sequence by drawing attention to the placement of the instructions.

Transcript 3

- Researcher *...And see that? It has got a sequence of numbers there, one, two...*
 Pupil J *Yeah, I think the sequence could have been in order.*
 Researcher *What do you mean by that?*
 Pupil Lu *Well see its got like one, two (points to screen) and three is down there (points), it is like at the side, which is a bit...*
 Pupil J *Then there is four (points to lower screen) and there's five (points to upper screen)*
 Pupil Lu *And five is at the top and six is right in the middle which is a bit...*
 Researcher *So the positions aren't in sequence?*
 Pupil J *Yes.*
 Pupil Lu *It should have like one, two, three. (points across screen) (SMA LuJ)*

Transcript 4

- Pupil C *Step one button, but there was no step three so.*
 Researcher *Ok so you were following the steps.*
 Pupil L *Yes. I was trying to move it up, but I didn't see step three...*
 Researcher *Oh yes, that instruction. Right. So you were then following the written instructions to try and get it to work and you were going across the screen.*
 Pupil L *Yes.*
 Pupil C *Instead of going down. It makes more sense to go across. (SMA CL)*

Transcript 5

- Pupil 1 *I didn't really notice the number sequence, no.*
 Researcher *So the order that you were doing it in was...*
 Pupil 1 *Was largely by the spacing, by where they were positioned. (DHS 1)*

The sequence and position of instructions was noted by all who used the 'practical experiment' simulation. All the pupils signalled what they perceived to be the logical position of the instructions. The fact that the instructions were numbered did not register with the pupils, instead all focussed on the location of the instructions.

The following excerpt is indicative of a viewpoint shared by all the pupils. When they were asked what advice they would give a designer involved in constructing these simulations, two pupils provided the following:

Transcript 6

Pupil M *To make the instructions more clear.*

Researcher *And how could they do that? Because the instructions are all numbered.*

Pupil M *Aye, but you put the instructions on the side no one reads.*

Pupil S *See if you had them all in like in a row, because you have number five over here, and on the other side of some test tubes, so you might not even think about looking at the numbers and that, and your eyes are drawn to something. But if you have them all in like order going down or something. (SMA MS)*

It should also be noted that some of the pupils commented on the nature of the instructions.

Transcript 7

Pupil 1 *I would maybe make the tab for choosing the acids and alkalis a little more obvious and I would make it clear that you couldn't type in the boxes that you couldn't type in. (DHS 1)*

Though familiar with various forms of technology, they experienced some difficulty with the instructions.

Prior knowledge

All the pupils explained their progress by referring to their prior knowledge and what they considered to be the relevant field of science. Some even went as far as differentiating their experience in terms of being familiar with biology, chemistry or physics. Consequently some explained their difficulty in working the simulations, or understanding the simulations, in terms of labelling themselves as physicists or biologists and associating the simulations they were asked to do as chemistry. Those who did identify themselves as pupils with chemistry experience relied heavily on this prior knowledge to determine their process of engagement. Numbered sequences of instructions to guide progress were ignored as pupils relied on their prior real time experience for particular experiments, to determine the nature of engagement. In the following excerpt a pupil who has practical experience of titration experiments, draws on this to make sense of the titration simulation:

Transcript 8

Researcher *So you went for weak acid and strong base.*

Pupil 3 *Yeah. And I think I went for base or was it acid to...*

Researcher *Stick it in the burette? Any reason for that?*

Pupil 3 *In chemistry in class we always put the acid in the burette.*

Researcher *In the burette. Ok, then what happens?*

Pupil 3 *I went for the indicator. I remember using bromothymol blue in chemistry so that is what I chose. (DHS3)*

Relying on their prior experience to help with the simulations depicting practical experiments was not as problematic as relying on prior experience to make sense of simulations showcasing microscopic interactions. Many made inaccurate associations that were not necessarily misconceptions, but simply mistaken microscopic identity when the pupils viewed the simulations of the microscopic interactions. For example, the next transcript is about a simulation representing acid-base neutralisation.

The centre of the simulation entry screen contains the following text “*The following is an acid-base neutralisation when aqueous NaOH is added to aqueous HCl*”. At the top of the screen are tabs with ‘replay’ ‘continue’ ‘pause’ and ‘one back’. In the simulation, water is represented by combined red and two white circles, the hydrogen chloride has dissociated leaving a chloride ion represented by a green circle with a negative charge beside it, and a hydroxonium ion, represented by a red circle attached to three white circles with a positive charge sign next to it. A few seconds into the simulation, a purple circle close to a red circle and white circle (meant to represent sodium hydroxide) enter the simulation at the top of the screen, just below the row of navigation tabs. During the retrospective interview, while watching their digital recording, the following conversation took place.

Transcript 9

Researcher *What sense did you make of it then?*
 Pupil S *Basically that those lost their...*
 Researcher *Which are those?*
 Pupil J *Positons.*
 Pupil S *Those (points to the H_3O^+ ions)*
 Researcher *The red and white ones with the plus?*
 Pupil J *Yes*
 Pupil S *Those lost their protons, their plus when the purple ones came in.*
 Pupil J *Yeah there's the minus ones there and they like smash up. (points to the chloride ion)*
 Researcher *Ok. Oh ok. So what do you think was happening?*
 Pupil S *They were joining together. Or something.*
 Pupil J *Becoming neutral.*
 Pupil S *Neutrons.*
 Researcher *What was becoming neutral?*
 Pupil J *The protons.*
 Pupil S *and the minus ones.*
 Pupil J *Electrons.*
 Researcher *Ok. So what are the green things then?*
 Pupil S *Neutrons. I mean electrons. (SMA SJ)*

These pupils did not hold misconceptions; they had simply confused the identity of the circles, and were guided by the signal of the charge written along side the circles. For the two pupils in the previous transcript, the clues provided in the simulation were missed. Thus, although the designers had inserted Cl^- beside the green circle, and H_2O beside the red circle attached to the two white circles, the pupils had not made those associations. These two pupils were not alone. Several of the pairs of pupils using this simulation initially made the same links. They related the reaction to subatomic particles. Most of the pupils modified their explanations when the icons and symbols were clarified. In some cases the pupils had debated whether the simulation was a representation of a subatomic particle reaction or a representation of ionic interaction.

Some of the pupils also explained their progress and their ability to engage with the simulations by referring to their prior knowledge of similar types of computer-based activity. For example two girls in the main phase of the project, had experience of the ‘BBC Bitesize’ revision online programme, they said:

Transcript 10

Pupil Ca *We knew instinctively that the button would change.*
 Researcher *Did you, how did you know that?*
 Pupil T *Because I use the ‘Bitesize revision’ so it is quite handy and they have got a lot of diagrams like this. (SMA CaT)*

Some of the pupils were familiar with technology button functions and that either helped or hindered their progress.

Transcript 11

Researcher *Ok. You went to acid. So what was your thinking when you were doing that?*

Pupil 2 *I wasn't very sure what I was meant to be doing. And at first I didn't actually know that there were tabs on the side. I usually associate those radio buttons with just selecting options. (DHS 2)*

Those with prior knowledge of various types of computer based presentations also experienced productive and unproductive moments. Some were able to draw on their prior experience to help make progress, while others found some of the technology to be at odds with what they had previously experienced.

In general, prior science knowledge was a key factor in deciding how to progress through a simulation. In all cases, prior science knowledge was recalled in order to engage with the simulation, and prior science knowledge was used to determine the course of action. In the simulations representing practical work, the pupils drew on their prior practical science knowledge to determine their course of action. In most cases this overrode the directions available in the form of numbered instructions. In the practical experiment simulations this was problematic, as the format of the simulation did not always allow for divergence to take into account the pupils' prior science knowledge. In the microscopic representation simulations this was problematic, as the prior science knowledge that pupils tapped into did not match the science knowledge presented by the designer. In addition, in some cases the role of prior science knowledge was problematic, because pupils discounted their capacity to undertake the simulation because they perceived themselves as not having experience in the relevant field of science.

Conclusion

The simulations used were of good quality and reflected the standard available to most schools. The simulations also addressed the levels identified in the various curricula documents. Analysis of the digital records for the pupils suggests that three key aspects influenced their ability to engage fruitfully with the simulations. These three aspects were:

- Distraction and vividness
- Logic and information
- Prior knowledge.

All the pupils commented on the logical placement and the nature of instructions, and this was seen to be instrumental in guiding progress. So, though the instructions in the titration simulation were assigned numbers to help identify the sequence for engagement, their location on the screen was not in a sequence identified by the pupils as logical. Earlier it was stated that Baddeley's (1992) two modality systems are often used to explain findings and that some studies demonstrating modality effects claim a reduction in cognitive load, as a consequence of more efficient use of available memory resource. However, these findings support the views of Tabbers et al. (2004), who suggested that a reduction in visual search may be the key factor. In this project, peripheral content appeared to have an effect on comprehension. As was seen, the third instruction in the titration simulation, which contained vital information and without which the burette could not be 'filled', was missed by all the pupils, because it was on the periphery and inserted as a vertical tab. The pupils appeared to attend to items that required minimum visual search. The pupils appeared to be drawn to items on screen that were vivid, for example the 'red dropper', or the slider instruction in the centre of the screen.

All the pupils referred, at some point, to their prior science knowledge, which they used

to determine the course of action. In some cases this was problematic because pupils focussed on particular aspects of symbolic representations and mistakenly construed explanations based on these assumptions. For experts, or those very familiar with the use of symbolic representations of the microscopic level, these mistakes may appear to demonstrate a lack of understanding. However, I would suggest that this is not the case. When the symbols found in these symbolic representations were clarified, the majority of pupils were able to explain the designer intended science. Therefore their retrospective narrative, in which they identified particular microscopic particles erroneously, does not reflect their understanding of the science, but it does reflect their information processing capacity. Therefore, it is important that we ensure that symbolic representations used in multimedia software do not assume that the pupils will assign meanings to symbols as intended by the designers. As the pupils suggested, keys may help them clarify the identity of the icons used in the animations, and may then provide a more realistic opportunity to inspect their science understanding. Likewise, though most of the pupils were unable to carry out the titration because they relied on their prior knowledge and discounted the instructions available, those who had undertaken titrations in the past, were able to explain clearly the process, their intentions and their science understanding for the reaction.

In light of the fact that recent developments in assessment practices in education in Scotland have come to include the use of electronic formats, it is quite possible that e-assessment protocols will also be used in science education in the near future. The findings from this project suggest that e-assessment involving the use of multimedia or symbolic representation in science education will have to take great care if it is to ensure that what it is assessing is the pupils' science capability and not information processing skills that rely on shared symbol identification or on their ability to discern the designers' logic of instructions.

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