Understanding Soil Acidification Process Using Animation and Text: An Empirical User Evaluation With Eye Tracking

P. Russo, C. Pettit, A. Coltekin, M. Imhof, M. Cox and C. Bayliss

Abstract This chapter presents a user study in which the participant performance is comparatively measured using two ways of presenting information: animation and text. The stimuli contain equivalent information, but use fundamentally different ways of communicating this information. We designed a workplace to simulate the process as it may occur in the real world. First, a representative task from an actual website was selected (i.e., understanding the soil acidification process). 50 participants first took part in a short 'study session', where they were told to remember as much as possible. Then they took a multiple choice test using either the animation or the text in an "open book" setting. The tested media have been assessed through the classical measures of *effectiveness* (error rate), and *efficiency* (time to complete the multiple choice test). Text users achieved a slightly higher score in the multiple choice test and required less time compared to animation users. In contrast, more of the animation users considered the questions "easy". Thus, against all intuition (yet in agreement with some of the previous findings in literature) animation does not appear to perform better for the tasks in this experiment. To further strengthen the experiment, an eye tracking study was also conducted with the animated displays for a more in-depth effort to explore user strategies when asked to 'remember as much as possible'.

P. Russo · C. Pettit
Faculty of Architecture, Building and Planning, The University of Melbourne, Parkville, VIC 3010, Australia

A. Coltekin (✉)
Department of Geography, University of Zurich, Zurich, Switzerland
e-mail: arzu@geo.uzh.ch

M. Imhof · M. Cox
Department of Primary Industries, Future Farming Systems Research Division, Parkville, VIC 3053, Australia

C. Bayliss
Melbourne eResearch Group, Faculty of Engineering, The University of Melbourne, Parkville, VIC 3010, Australia

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1 Introduction

Animations are often used for visualising scientific concepts with spatial and temporal aspects in a dynamic form. Several studies have been conducted to compare animation versus other forms of representations including text (e.g., Tversky and Morrison 2002; Rebetez et al. 2010 and Lewalter 2003). For a variety of tasks, such as comprehension, learning, memory, communication and inference, previous research consistently shows that animations are not necessarily "better" than other forms of graphics or text (e.g., DiBiase et al. 1992; Tversky and Morrison 2002; Hegarty et al. 2003; Griffin et al. 2006; Harrower and Fabrikant 2008). Indeed, effective learning with animations depends on a number of factors, including the design and speed of animation and the prior knowledge of the users (Hegarty and Kriz 2008).

The design of the animation, for example, influences the internal cognitive processes and therefore how much users learn. Gog and Scheiter (2010) report that users learn better if spoken text (and not written) is integrated into animations. When written text accompanies an animation, users tend to read the text and largely ignore the pictorial information. Conversely, the presence of spoken text allows users to pay attention to the visual display. Seemingly, users' attention can also be better captured if the speed of the animation varies over time. For example, Mayer (2010) proposed that learners benefit more from an animation if its speed decreases with increasing playtime (and not vice versa). Furthermore, highlighting relevant features may also improve learning ability according to Mayer (2010).

The spatial ability and the prior knowledge of the learner may also influence learning outcomes when using animations as study material (Hegarty and Kriz 2008). Among others, Yang et al. (2003) demonstrate that people with high spatial abilities may have fewer problems in processing visualizations compared to people with lower abilities; thus potentially gaining a stronger benefit from using animations when learning. Similarly, recent eye tracking studies demonstrated that users with prior knowledge of the subject matter seem to distinguish more between relevant and irrelevant information by gazing faster and more often at the relevant display elements (Gog and Scheiter 2010; Çöltekin et al. 2010). Also, Mayer (2010) maintains that experts benefit more, in terms of learnability, from animations, compared to novices. Lowe (2003) suggests that the potential of animation as a learning tool may not be fully realised unless the design of such presentations supports learners' extraction of domain-relevant information and its incorporation into existing knowledge structures.

Based on our (non-exhaustive) review of the literature, it appears likely that the contribution of animation in supporting learning outcomes depends also on the topic. In some studies, animations are reported to have slight advantages in comparison to static displays in communicating spatial aspects of dynamic processes since they support learners in constructing mental representations (Lewalter 2003). Various other studies also indicate that animation may be a useful tool for refreshing and retaining knowledge. Best results for comprehension have been found when using animation collaboratively (i.e., several viewers) and in combination with text (Rebetez et al. 2010). An overall superiority of animations over text on learning outcome is, however, clearly not evidenced.

We do not intend to discuss all such influencing factors in detail in this chapter. Rather, in this chapter, we demonstrate the challenges for an effective real world application of animation. In the process, we contribute to the body of knowledge in user studies with animation, by testing the efficiency of *information extraction* from an animation in comparison to text in a case study featuring a real world application. More specifically we pursue two research questions in this study: Firstly, "is it more efficient (and effective) to extract information from an animation or from a body of text describing the same animation in a complex real world learning task?" (RQ1) and secondly, "do the eye movement measurements recorded during the inspection of the animation underpin in any way the performance measurements of RQ1?"(RQ2).

The real world application utilised in this study has been designed to enhance understanding of the soil acidification process. Soil acidification can negatively impact a number of natural resources and the process itself is a complex environmental process which requires understanding many chemical concepts as well as interactions within and between them. The featured animation is created by soil science experts from the Department of Primary Industries and made available through the Victorian Resources Online (VRO) website for public use: http://www.dpi.vic.gov.au/vro. Visualisations such as these provide a means for capturing expert knowledge in an explicit way to be used for knowledge transfer (Imhof et al. 2010) and science communication. The text stimulus is provided on the same website; and this is because, according to the Whole of Victorian Government Website Standard; "to assist people that may have impeded access to the web, graphical elements, such as animations need to be accompanied with an accessible alternative (e.g. Word, text, RTF or HTML) that appropriately describes the content shown".[1]

[1] http://www.egov.vic.gov.au/victorian-government-resources/website-management-framework-wmf-/government-website-standards-victoria/whole-of-victorian-government-website-standards-overview.html

2 Experiment

2.1 Design

To balance experimental control with ecological validity, we simulated a workplace in which people use the provided stimuli (i.e., animation and text) to eventually answer questions on the soil acidification process. The experiment consisted of three sections (Fig. 1). The Sect. 1 was a 4-min training session. Half of the participants studied the animation[2] and the other half the text (Appendix 1). The content of the stimuli was explained to the participants before the beginning of the training session and the participants were asked to memorise as much information as possible, including the location of information within the stimuli. In Sect. 2 participants completed a multiple choice (MC) test answering questions relevant to the content of the stimuli with a time limit of 10-min. For this task, participants were allowed to use the stimulus as in an 'open book exam', i.e., the users were allowed to look at the stimulus as often as they needed. This behaviour is similar to how the online user population is expected to utilise such stimuli. In Sect. 3, participants' background and satisfaction with the stimulus were assessed by a brief questionnaire.

2.2 Participants

The group of participants comprised 50 students (27 male, 23 female, average age of 22) from the University of Melbourne (under- and postgraduates, PhD students). None reported any colour vision problems, which would have excluded them from the test as this may have caused a bias. 40 % of the participants reported beginner's knowledge of soil chemical processes and 10 % indicated that they had studied or worked in related fields (Table 1).

2.3 Stimuli

The stimuli contain the exact same information though their representation differs fundamentally. Comparing *informationally equivalent* media with differences in representation is a fairly common practice (Simon and Larkin 1987; Coltekin et al. 2009).

The animation depicts soil processes in the context of a dairying agro-ecosystem. It has been developed to convey complex processes to a broad target

[2] http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_acidification

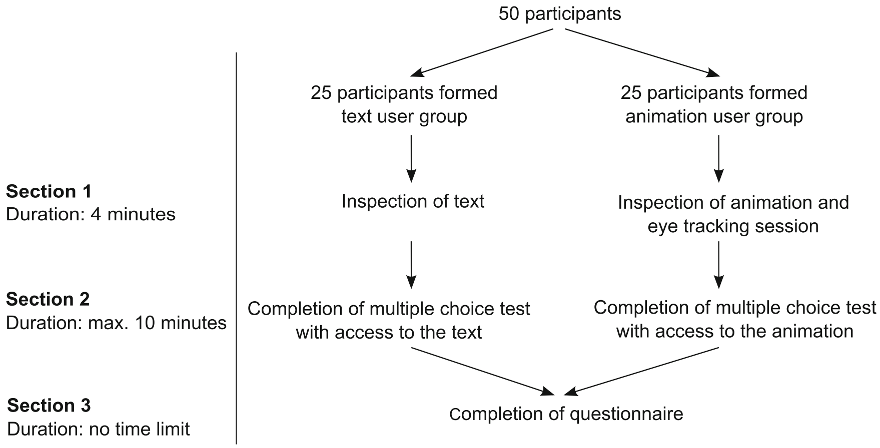

Fig. 1 Design of the experiment

Table 1 Summary of the data collected during the experiment

	Animation	Text
Number of participants	25	25
Mean participants' age	24.1	20.4
Multiple choice test		
Mean number of correct answers	8.52	8.60
Required time (min)	06:17	05:38
Questionnaire		
Prior knowledge about chemical processes in soils (1 = no knowledge, 6 = high knowledge)	2.6	2.8
Participants rating information extraction 'very easy'	4	2
Participants rating information extraction 'easy'	17	15
Participants rating information extraction 'difficult'	3	5
Participants rating information extraction 'very difficult'	0	1

audience e.g., researchers, administrators, educators, students and the general public. The animation was created from 'storyboards'—a series of hand-drawn sketches outlining all the successive events in the animation—derived from workshop sessions with subject matter specialists. An entire scene was initially created that included all the graphical elements from each of the single storyboards. This was then Web-enabled using Adobe Flash to create a sequence of animated scenes that users can move through scene-by-scene or play in a continuous animation (with pre-set timing intervals). The animation contains various graphical elements (10 scenes), text and voice-over. The information provided by the written and spoken text was identical. The ability to switch the audio off was disabled during the experiment, thus the animation was always coupled with sound.

The other stimulus (text) contained the same information as the animation and based on the animation transcript.[3] In the experiment it has been provided as an MS Word document and included only written text of almost one page length without any figures (Appendix 1).

2.4 Tasks

The MC test was based on 10 questions on factual and procedural knowledge presented (Appendix 2) in the animation and text (Lewalter 2003). For each question, three answers (two incorrect and one correct) were provided. Participants were asked to select the correct answer. For the completion of the MC test, participants had a maximum of 10 min time and were allowed to use the stimulus inspected in Sect. 1. Thus, the upper half of the screen used by the participants was covered by the multiple choice test, whilst either the animation (Fig. 2a) or the text (Fig. 2b) was displayed on the lower part of the screen.

After the MC test, a questionnaire was provided to the participants. Participants were asked whether they needed to look at the stimulus to complete the MC test in Sect. 2 or whether they remembered the information. Participants were also requested to rate the degree of ease or difficulty in undertaking the tasks using a 4-point Likert scale (i.e. 'very easy', 'easy', 'difficult', 'very difficult') (Komorita 1963). The same questionnaire was used to collect information on the participants, including their age, gender, field of study and whether they have any visual impairment. They also assessed their prior knowledge of soil chemical processes using a 6-point Likert scale ranging from 1 (=no knowledge) to 6 (=high knowledge) (Appendix 3).

2.5 Procedure

After welcoming the participants, the experimenter provided a brief introduction to the experiment and the eye tracking system. All participants signed a consent form for video and eye movement recording (text users were also recorded but not analysed in the scope of this chapter). Before recording began, participants were instructed to assume a comfortable position and not move too much during the experiment, to maximize the eye movement recording accuracy. A calibration with the eye tracker followed. Participants were then provided with a mouse to scroll up and down the text and a keyboard to mark the answers in Sect. 2. During the entire test, participants wore headphones to reduce background noise and to assist listening to the spoken text in the animation (Fig. 3).

[3] http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_acidification_transcript

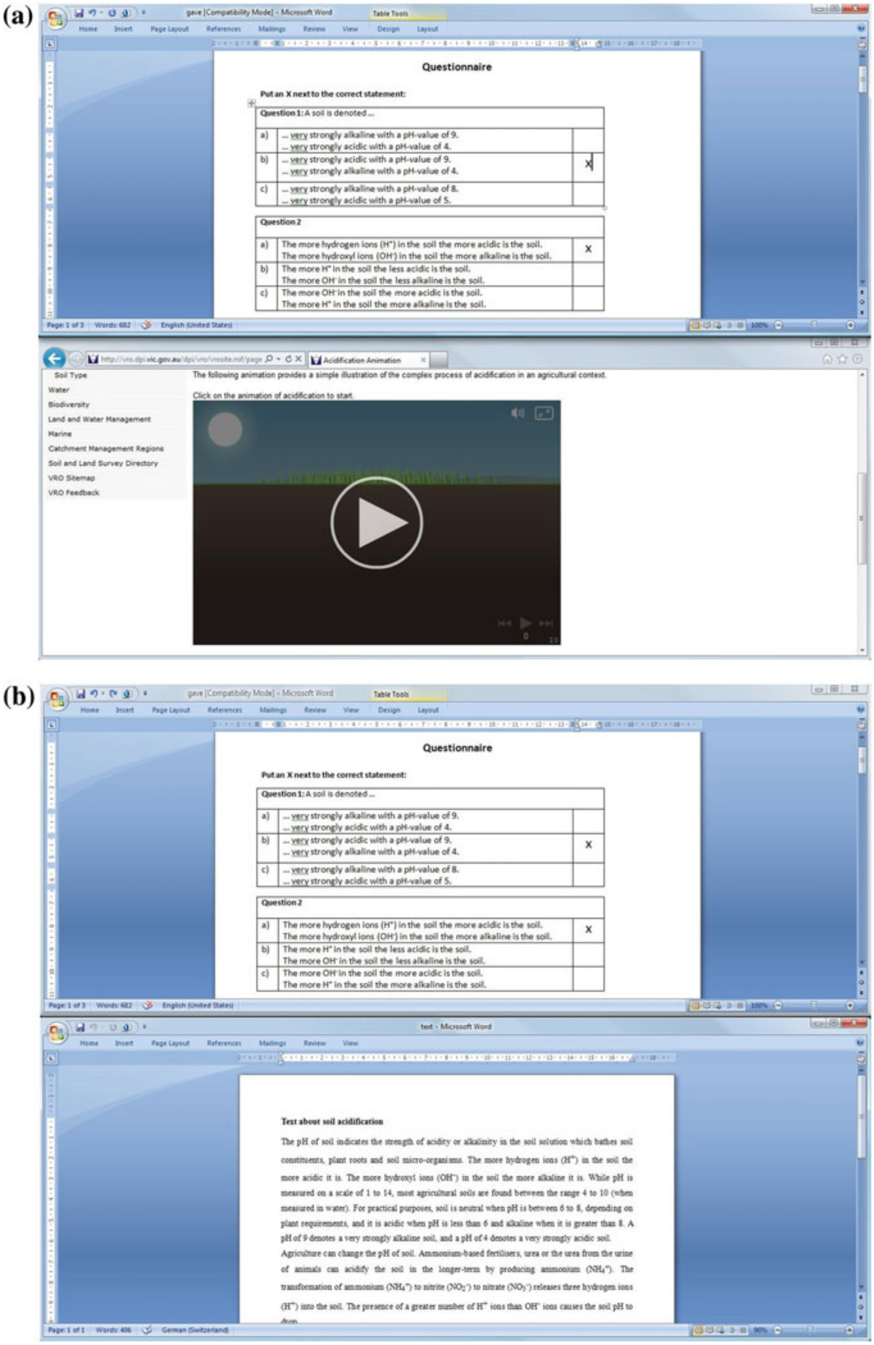

Fig. 2 **a** Display of multiple choice test with animation **b** Display of multiple choice test with text

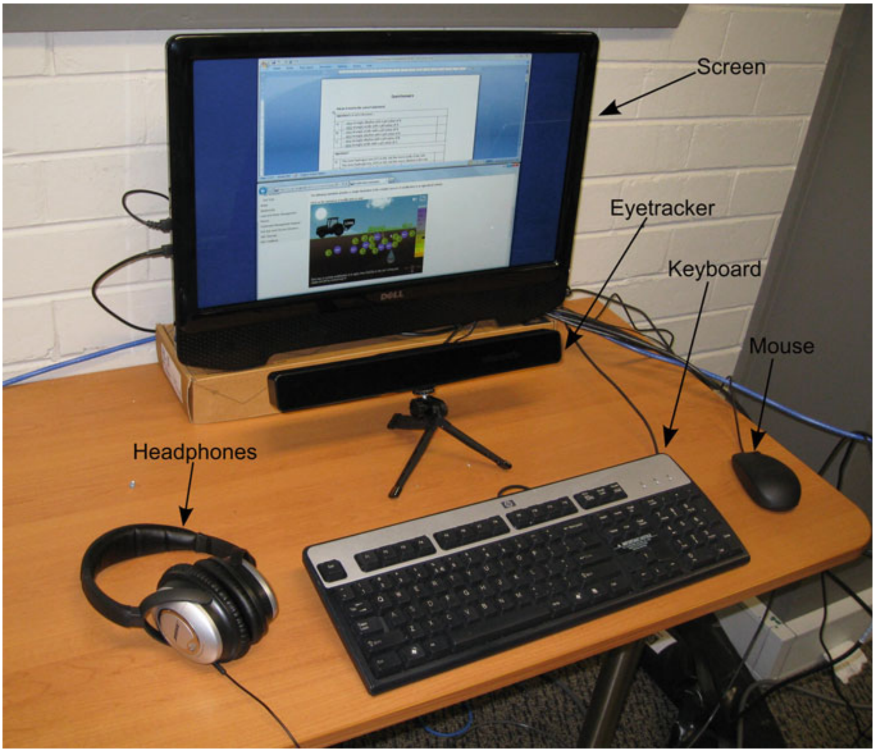

Fig. 3 Experimental hardware set-up

The experimenter ensured that participants inspected the stimulus for 4 min in the first section and that the second section did not exceed 10 min. As an incentive to undertake the experiment a 20 AUD voucher was given to each participant.

3 Methodology

Usability metrics. The methodology is strongly linked to our two research questions, i.e., "is it more efficient (and effective) to extract information from an animation or from a body of text describing the same animation in a complex real world learning task?" (RQ1) and "do the eye movement measurements recorded during the inspection of the animation underpin in any way the performance measurements of RQ1?" (RQ2). For the first question, we can resort to most classical usability evaluation metrics of satisfaction, effectiveness (accuracy) and efficiency (speed) (Nielsen 1993). In fact, efficiency as we intend in RQ1 is closely linked to effectiveness and can be defined as the relation between the accuracy with which a task is completed and the time required to complete that task

(Frokjaer et al. 2000). Accordingly, the performance measurements to assess RQ1 are (i) the number of correct relative to incorrect answers chosen in the multiple choice test, and (ii) the required time to complete the multiple choice test. Questionnaire responses on the difficulty of extracting information from the stimulus should reveal the level of difficulty experienced during the tasks.

Eye tracking. The eye movement measurements report the location and duration of the gaze. In this study we consider a common eye movement metric, the *Mean Fixation Duration* (MFD), on specifically defined Areas Of Interest (AOI) within each scene of the animation (Schmidt-Weigand et al. 2010) (Fig. 4). According to Jacob and Karn (2003) a fixation (where the gaze is relatively still) is typically defined by a dispersion threshold of $\sim 2°$ and minimum duration of ~ 100–200 ms, however, it is necessary to note that fixation threshold is currently arbitrarily defined in literature and varies from 50 to 500 ms (Coltekin et al. 2009). In this study, we adopt a minimum duration of 144 ms for defining a fixation. This value is within the window of fixation thresholds that are commonly reported in usability studies with eye tracking. Figure 5 shows a sequence of fixations. The examination and interpretation of the measurements is based on Jacob and Karn (2003) and assumes that the longer the MFD, the more effort participants have exerted to extract information from the AOI. In relation to RQ2; we analysed if there is any correlation between the time the participants took to complete the multiple choice test and the MFD on the AOIs that contain the information to answer the questions correctly ("relevant AOIs"). That is, if animation users

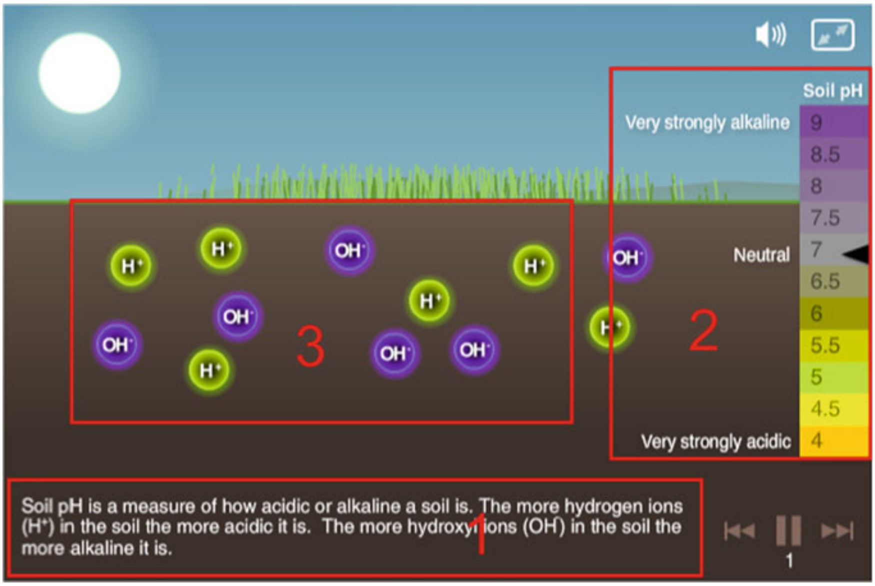

Fig. 4 Scene 1 of the animation and the chosen AOIs (outlined as *rectangles* and numbered as *1*, *2* and *3*)

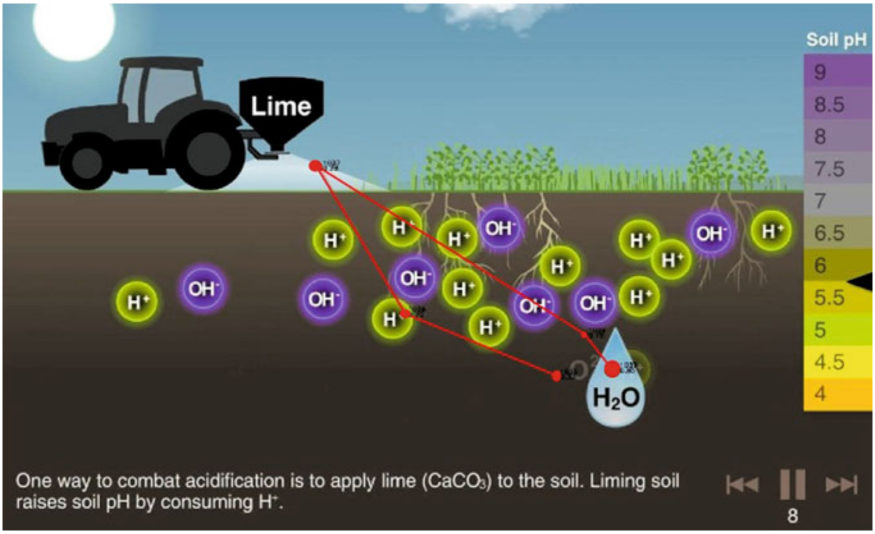

Fig. 5 An example (the trajectory starts at the water drop)

required more time to complete the MC test, we studied the eye movements in the training session that took place before the MC test. If the MFD on the relevant AOIs were relatively high, then we interpret that animation users may have been delayed by difficulties encountered in decoding the information.

4 Results

4.1 Multiple Choice Test and the Questionnaire

Table 1 shows the results of the MC test and questionnaire. On average, the text users have achieved a slightly higher score of correct answers compared to the animation users. The mean time to complete the MC test was about 40 s less for text users. In contrast, more of the animation users stated the extraction of information 'very easy' and 'easy'.

While the text users appear to have a slightly higher prior knowledge on the topic, nearly all participants (47 out of 50) have returned to the stimulus as they were responding to the questions. Thus, at this point, we do not further analyze the differences among participants in relation to their prior knowledge.

To better understand the differences between the two stimuli, a sum of rank test (Mann–Whitney U test) was carried out to statistically test the distribution of correct answers. The required time has been analysed with a t test for equality of means. For both methods, a decision criterion of $p = 0.05$ has been applied. The

Mann–Whitney U test revealed ($p = 0.895$) that the difference in performance between animation and text users is not statistically significant. Because time data are typically non-normally distributed, the required times were first logarithmically transformed before statistically analysed (Pettersson et al. 2009). According to the t-test there was no significant difference between the two stimuli for the completion time of the MC ($p = 0.228$).

4.2 Eye Tracking

According to the initial tests, we observe a consistent difference in favour of text in our findings in terms of efficiency (Table 1). However, since the results are not statistically significant, the findings are inconclusive. To strengthen the experiment, we recorded eye movements with animation users in Sect. 1. In our limited eye movement analysis, we investigate if the animation users have spent more time (fixated longer) or as much time (fixated equally) in 'irrelevant' parts of the visualizations as they did in the 'relevant' parts during the training session. Note that the participants did not know what was relevant or irrelevant for the tasks at the time of recording, but were asked to 'remember as much as possible' (similar to studying for an exam). We defined *relevant AOIs* as those that contain necessary information for answering the MC questions. *Irrelevant AOIs* are selected areas that contain information which is not necessary for answering the MC questions. Once AOIs were defined and classified, we compared the MFDs between 'relevant' and 'non-relevant' AOIs. Table 2 shows the MFDs for each scene in relation to the relevant/non-relevant AOI in seconds. The numbers in the column *Question* show which of the 10 questions of the MC test is answered with this scene and AOI. For example, AOI 2 of Scene 1 (Fig. 4) answers question 1 of the MC test (Appendix 2).

The results (Table 2) demonstrate the MFDs for relevant AOIs are not higher than the MFDs for the non-relevant AOIs in any case. The mean MFD of the relevant AOIs (0.36 s) is lower than the mean MFD of the non-relevant AOIs (0.40 s) (Table 3). In other words, the relevant AOIs have been fixated for a shorter time than the non-relevant AOIs in average. The mean MFDs have been statistically analysed with a t-test for equality of means with a decision criterion of $p = 0.05$. The test revealed ($p = 0.160$) that there is no significant difference between the mean MFDs of the two AOIs. Based on these findings, one possible interpretation is that the animation users have not been delayed due to difficulties in extracting the required information, but rather may have been distracted by (or attracted to) the other elements that are displayed on the studied scenes.

Table 2 Eye tracking measurements (MFD) for each scene and relevant/non-relevant AOI

Scene of animation	AOI		MFD (s)	Question
	Non-relevant	Relevant		
Scene 1			0.37	
		1	0.36	2
		2	0.35	1
	3		0.39	
Scene 2			0.36	
		1	0.33	3,6
	2		0.50	
	3		0.36	
Scene 3			0.37	
		1	0.30	7
	2		0.44	
		3	0.38	7
Scene 4			0.38	
	1		0.33	
	2		0.37	
		3	0.39	8
Scene 5			0.41	
		1	0.35	4
	2		0.73	
		3	0.40	4
Scene 6			0.36	
		1	0.33	5
	2		0.30	
		3	0.37	5
Scene 7			0.39	
	1		0.32	
	2		0.37	
	3		0.45	
Scene 8			0.39	
	1		0.35	
	2		0.40	
		3	0.41	10
Scene 9			0.40	
		1	0.30	9
	2		0.43	
	3		0.45	
Scene 10			0.46	
	1		0.33	
	2		0.24	
	3		0.47	

Table 3 Mean MFD of relevant/non-relevant AOIs

Mean MFD (s) of relevant AOIs	Mean MFD (s) of non-relevant AOIs
0.36	0.4

5 Conclusions and Outlook

The differences between the animation and text users' performance in this study is not statistically significant, thus essentially the experiment remains inconclusive in terms of a 'clear winner'. Nonetheless, we observe a trend in the results which slightly favours text over animation, both in the number of accurate responses and in the time required to complete the tasks. Despite the 'feeling' that animations seem to induce in the viewers that information is easier to grasp (as a trend, animation users have rated the tasks 'easier' compared to those who used text), animation users did not seem to perform better within the limits of this study. The perceived difficulty with text, or rather the perceived ease with animation, remains unexplained. This may be because of the tedious appearance of the text and the visual appeal of the animation. Qualitative feedback by the participants supports this; the text has been described as 'dry' and 'boring' by some. Upon closer examination, the animation is visually highly demanding due to frequently changing details and multiple AOIs which may cause distraction and lead to inefficiency while trying to extract information. Also, the animation contains more interruptions (i.e. scene changing) while the text is more fluent which may facilitate comprehension. Furthermore, the information in the animation is more fragmented among the three sources (spoken and written text and image). In this regard, a participant stated that the three sources were 'competing'. We surmise that this may be due to the availability of three integrated sources of information making it difficult to focus on any one of them. The text may be more monotonous for many users but the information is extracted from it seemingly 'just as well', perhaps due to the simple structure of the text and with fewer opportunities for users to explore the information in a non-linear way (which is possible with the animation). These are possible explanations for the greater time required of animation users which suggests that further in-depth investigations will be useful.

This study, however, has shown controversy results within the Satisfaction, Effectiveness, Efficiency (SEE) analysis with satisfaction not correlating with effectiveness and efficiency. Users seem to be more stimulated to use the animation because of its visual appeal, but the extraction of information from text seems to be no less efficient if we look at the trends (also see e.g., Tversky et al. 2002). Participants' misguided confidence based on the qualities of the stimulus has been also reported in earlier studies (e.g., Zanola et al. 2009). A more in-depth inspection to study this conflict is worthwhile as other findings in literature suggest animation to be a complex form of visualisation that does not have facilitating effects as expected. Explanations for animation users' delay in completing the tasks can also not be intuited from the eye tracking results. The descriptive results indicate that animation users spend more time in 'irrelevant' parts of the display. These results encourage further research on the potential contribution of eye movement measurements for explaining efficiency differences between media.

At this stage, we have early indications from the observations in this experiment that allow us to build hypotheses. In follow-up research, modifications may be undertaken on the animation to further strengthen the current study and understand better if/when animations are good 'learning material' in real world applications for science communication and learning. As earlier literature indicates, the efficiency of animated displays is very likely task dependent, thus further tests with a variety of (ideally taxonomized) learning tasks should be designed. Display complexity also plays a clear role and there are numerous possibilities to vary in the visualisation design. For example, incorporation of buttons for switching written text and audio on/off, changing animation speed, highlighting thematically relevant features (Mayer 2010; Harrower and Fabrikant 2008), and simplifying animations to contain only one specific AOI would be all valuable to test the various aspects that are relevant to further understanding the potential of animated displays as 'learning material'. Thus, it would be useful to analyse if such changes increase the performance of the animation users in respect to the time required for completing the multiple choice test. Additional testing could also be undertaken on the value of each type of media for facilitating longer term knowledge retention by users and improving their understanding of complex soil processes.

Appendices

A.1 Appendix 1: Text Used in the Experiment

Soil Acidification

The pH of soil indicates the strength of acidity or alkalinity in the soil solution which bathes soil constituents, plant roots and soil micro-organisms. The more hydrogen ions (H^+) in the soil the more acidic it is. The more hydroxyl ions (OH^-) in the soil the more alkaline it is. While pH is measured on a scale of 1–14, most agricultural soils are found between the range 4 and 10 (when measured in water). For practical purposes, soil is neutral when pH is between 6 and 8, depending on plant requirements, and it is acidic when pH is less than 6 and alkaline when it is greater than 8. A pH of 9 denotes a very strongly alkaline soil, and a pH of 4 denotes a very strongly acidic soil. Agriculture can change the pH of soil. Ammonium-based fertilisers, urea or the urea from the urine of animals can acidify the soil in the longer-term by producing ammonium (NH_4^+). The transformation of ammonium (NH_4^+) to nitrite (NO_2^-) to nitrate (NO_3^-) releases three hydrogen ions (H^+) into the soil. The presence of a greater number of H^+ ions than OH^- ions causes the soil pH to drop.

Nitrate leaching, where NO_3^- moves below the root zone and cannot be used by plants is a significant source of agricultural acidification. Furthermore if the ammonium (NH_4^+) living in nodules on legume roots is not all used up by the crop or pasture the soil can become more acidic. Agriculture can also accelerate acidification by removing alkaline products such as wool, milk, cereal grain, legumes and hay. The reverse is also true, where the introduction of manure, decaying animals, silage and stockfeeds can add alkalinity back into the soil and therefore increase soil pH.

Plant production can be constraint on strongly acid soils by aluminium toxicity and manganese toxicity. Both are more soluble at low pH, for example, aluminium dissolves into the soil solution as Al^{3+} that is taken up by the plant causing root deformation and stunted plant growth.

If a soil continues to acidify until it becomes very strongly acidic, biological activity, soil structure and nutrient toxicity and deficiency can become significant challenges to productive agriculture. One way to combat acidification is to apply lime ($CaCO_3$) to the soil. The breakdown of lime ($CaCO_3$) in the soil produces oxygen (O_2^{-})·and water (H_2O). This reaction consumes H^+ ions and increases soil pH.

A.2 Appendix 2: Multiple Choice Test

Put an X next to the correct statement:

Question 1: A soil is denoted…	
(a)	... Very strongly alkaline with a pH-value of 9.
	... Very strongly acidic with a pH-value of 4.
(b)	... Very strongly acidic with a pH-value of 9.
	... Very strongly alkaline with a pH-value of 4.
(c)	... Very strongly alkaline with a pH-value of 8.
	... Very strongly acidic with a pH-value of 5.

Question 2	
(a)	The more hydrogen ions (H^+) in the soil the more acidic is the soil.
	The more hydroxyl ions (OH^-) in the soil the more alkaline is the soil.
(b)	The more H^+ in the soil the less acidic is the soil.
	The more OH^- in the soil the less alkaline is the soil.
(c)	The more OH^-in the soil the more acidic is the soil.
	The more H^+ in the soil the more alkaline is the soil.

Question 3
(a) The use of fertilisers and urea increase soil pH.
(b) The use of fertilisers and urea decrease soil pH.
(c) The use of fertilisers and urea decrease soil pH if air temperature is higher than 20 °C.

Question 4
(a) By harvesting hay, grain and legumes alkaline products are removed which decreases the pH-value.

(continued)

(continued)

(b) By harvesting hay, grain and legumes alkaline products are removed which increases the pH-value.

(c) By harvesting hay, grain and legumes acidic products are removed which increases the pH-value.

Question 5

(a) With the introduction of manure, decaying animals, silage and stockfeeds acidic products are added to soils which increases the pH- value.

(b) With the introduction of manure, decaying animals, silage and stockfeeds alkaline products are added to soils which increases the pH-value.

(c) With the introduction of manure, decaying animals, silage and stockfeeds alkaline products are added to soils which decreases the pH- value.

Question 6

(a) Agriculture has only acidifying effects on the pH of soil.

(b) Agriculture is an important factor of influence on pH of soil since it can accelerate acidification but also add alkalinity.

(c) The acidifying and alkaline effects of agriculture on soil compensate in order to not change the pH of soil.

Question 7: The transformation of ammonium (NH_4^+) to nitrite (NO_2^-) to nitrate (NO_3^-)…

(a) ... releases OH^- ions raising soil pH.

(b) ... releases H^+ ions raising soil pH.

(c) ... releases H^+ ions reducing soil pH.

Question 8: NH_4^+ on Iegurne roots and NO_3^- leached below root zone because it is not used by animals and plants

(a) ... can lead to increased soil alkalinity.

(b) ... causes soil acidification.

(c) ... does not change soil pH.

Question 9: Aluminium toxicity dissolves…

(a) ... easier.a.t low pH, The product Al3+ is taken up by the plant constraining it production.

(b) ... easier at high pH, The product Al3+ is taken up by the plant constraining it production.

(c) ... easier at low pH, The product Al3+ defenses plant against lice attacks.

Question 10: The dissolution of lime ($CaCO_3$)

(a) ... comsumes H^+ ions resulting in the soil become more alkaline.

(b) ... comsumes H^+ ions resulting in the soil become more acidic.

(c) ... comsumes OH^- ions resulting in the soil become more alkaline.

A.3 Appendix 3: Questionnaire

1. Did you use the animation/text to respond to the questions? (Yes/No) If yes:
2. How easy was it to find the answers in the animation or in the text (very easy/easy/difficult/very difficult)?

Participant's background questions:

1. Age:
2. Gender (m/f):
3. Do you have any visual impairment? (If yes, please describe the constraints)
4. How much do you know on a scale from 1 (no knowledge) to 6 (high knowledge) about chemical processes in soils?
5. Do you study or work in the field(s) of:

- Agriculture
- Soil science
- Chemistry
- Biology
- others

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