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How do we know what people see when they look at diagrams?

Introduction

Widespread recent use of e-learning has raised issues about the effectiveness of learning (for earlier articles on e-learning effectiveness, e.g.: Kiboss and Tanui, 2013, and Luaran *et al, 2014*). NSTA (National Science Teaching Association) has claimed an authoritative position of the value of e-learning prior to the Covid-19 pandemic in 2008 but updated in 2016. (https://www.nsta.org/nstas-official-positions/role-e-learning-science-education accessed 19 Oct., 2021).

'NSTA makes the following declarations regarding e-learning for blended instructional approaches for K–16 students (as cited in https://www.nsta.org/nstas-official-positions/role-e-learning-science-education accessed 19 Oct., 2021):

1. Students should have ample opportunities to engage in science and engineering practices experiences, and these opportunities may be increased and enhanced through e-learning (NSTA 2004).
2. E-learning experiences should provide opportunities for students to develop and use science and engineering practices, disciplinary core ideas, and crosscutting concepts in order to explain phenomena or design solutions to problems. (NRC 2012).
3. School districts should support e-learning experiences for all students and provide necessary resources.
4. E-learning experiences and resources, when appropriate, should accurately portray the nature of science.
5. K–16 schools should support the use of well-designed virtual labs that have the ability to enhance understanding.
6. Students should use e-learning tools in the classroom in the same ways that they will be expected to effectively use these tools in the workplace.'

This paper is focused, in the main, on the research methods used to collect data relating to investigations of what participants notice when they read diagrams. The term 'read' is broader than simply looking or even gazing. With textual material, 'read' includes looking at and comprehending the meaning of (written or printed matter) by interpreting the characters or symbols of which it is composed. So, there are two distinct phases of reading. The first is noticing, which we saw as an activity that was purposeful in searching for information from the material presented, that is a cognitive act. Noticing involves scanning the material to find out what is valuable to the reader, and to filter out what is not valuable. This includes decoding what enters the eyes, using what has been previously learned. With diagrams, this can include knowledge about diagram components, their location in space, and their relation to other components through integration of these into the whole diagram. The second part is to use what has been noticed to comprehend, which is related to the purpose of using the material in the first place. To comprehend also includes options to use what has been understood on future occasions. It sets in place the significance and influence of previous learning. The work of the PALAVA research group (see below for a description of the PALAVA group) began with traditional textbook diagrams and developed to include animations, storyboards, and more recently, designing e-learning.

Designing e-learning is a highly skilled activity (e.g. Kearney, 2006), and can be supported by web design software, or by hiring a bespoke web designer. Inevitably, the web design will be rather generic and not targeted specifically at science learning. Nevertheless, many web pages are designed and used. The focus of much research is directed to the young learners (e.g. Deshmukh, 2012) and not to the learning of the teachers. We believe that the learning of the teachers is also important.

Rich use of improving noticing with diagrams can provide an alternative route to understanding, leading to learners being able to triangulate from text and diagrams and so improving their understanding of explanations.

If we improve understanding diagrams, we may also improve designing diagrams as e-learning environment. The aim of this research is to discuss science diagrams and their understanding and effects on design of e-learning.

Eye tracking and noticing

The PALAVA teacher researcher group, based in Reading, UK, has focused on both design of diagrams, perception and comprehension, especially ‘noticing’ of diagrams. The group was aware of ‘eye tracking’ as a tool for noting eye gaze and movement, special glasses, or instruments attached to a computer.

Eye tracking can:

1. Reveal subconscious behaviour.
2. Provide unbiased, objective, and quantifiable data.
3. Allow for natural behaviour.
4. Provide a high level of detail.
5. Offer a visual representation of eye focus.

What eye tracking, on its own, cannot do, is to provide evidence on what happens after light enters the eye, i.e. cognition. We can infer cognition, that is all. However, many researchers have gained valuable data from eye trackers. The PALAVA group chose to develop the Noticing Aloud Protocol, to gain insights into the cognitive processes that take place.

Noticing Aloud Protocol (NAP)

The PALAVA group has worked with learners from 11 years of age upwards, from students in secondary schools, through to pre-service teachers, and then to teachers in service. PALAVA's major focus has been on STEM representations, and particularly diagrams, as a valuable feature of scientific explanations. Such representations and explanations are constructed to provide, not the truth, but the best way to explain evidence collected from the natural world. The representations are created by individuals, groups, and communities. They are then published to the wider community for scrutiny, perhaps subsequent modification, and ultimately for acceptance by the wider STEM community. Members of PALAVA chose to focus on those aspects of diagrams that attracted attention, or were noticed. They asked participants in the research to say out loud what they noticed in a diagram. This method was provoked by the think aloud protocol: a data-gathering method used in a variety of research areas in which a person or a group of people are asked to verbalise their thought processes as they do a specific task which are then recorded on paper, audio or video for further analysis (as cited in https://www.definitions.net/definition/think+aloud+protocol, accessed 19 Oct. 2021). Thinking aloud is a method that requires subjects to talk aloud while solving a problem or performing a task (as cited in M.W.M., Jaspers et. al., 2014) Of special note is that most participants chose to verbalise interpretations, rather than the components themselves, a sign of the intervention of cognition not simply a regurgitation of diagram contents. The group called this method of data collection the Noticing Aloud Protocol.

The group observed patterns of noticing similar to the often-mentioned F pattern studied in relation to web pages (e.g. Nielson Norman Group (2006). The analysis was undertaken by groups of PALAVA at face to face meetings. Audio recordings were discussed until no more ideas emerged (saturation). While one aim of the discussions was to resolve differences and then to present a unanimous interpretation, occasionally this was not possible when mutually respected differences remained and were not resolved. This was more likely the case in complex diagrams such as ecological diagrams. Additionally, participants claimed to notice components that were simply not there. The group put this down to familiarity with the context where some features were expected to be present but were not. This was often the case in chemical displayed formulae, where conventionally some symbols of atoms were omitted and had to be inferred.

The distinction between diagrams and pictures

The distinction between diagrams and pictures is not clear-cut. In PALAVA we appreciated the difference that diagrams are intended to explain by schematic representations that are more or less simplified in some way. By and large, we understood that pictures are illustrative rather than explanatory.

Diagrams are made up of components, some of which are bound by conventions, e.g. in electronic diagrams, symbols are regulated by a variety of standards; in chemical equations, symbols and arrows are regulated by the IUPAC. Additionally, diagrams are made up of whitespace (Oversby, 2017), or areas where the creator intentionally left free of content. Also, the location of components is a significant aspect of diagrams. The PALAVA group noted that, in diagrams where a process was taking place, it was common for inputs to be placed on the left while outcomes were placed on the right. This also applies to chemical equations when interpreted as diagrams.

Complexity v simplicity

We have noted that some disciplines generally use simple diagrams, such as in physics, whereas ecological diagrams are often complex. Such generalisations are beset by exceptions, though. We have also noted a correlation between the level of complexity and the degree of noticing. There is a trade-off between including information and how much is then noticed.

Some examples

Topsakal and Oversby have conducted research using NAP in biology (2012a, 2012b & 2013) where they discovered that future teachers, from science and non-science disciplines, noticed relatively few components and different components. It seems that it is possible to teach sensitive noticing so that progressively more can be noticed. Ge, Unsworth & Wang (2017) noted that 'The factor of prior knowledge was essential in considering the influence of image design as the effect of diagrams was very different for low and high prior knowledge students. Implications are drawn for the importance of visual design in textbooks.' Finally, Peterson *et al* (2021) worked with science educators and graphic designers to create a complex taxonomy of diagrams found in textbooks based on the performance and content of such diagrams. They claimed that this taxonomy would make diagrams more accessible to science educators. Of course, time will tell if this is, in fact, the case, but such research shows that reading diagrams is perhaps more complex than we had first imagined.

In one experiment, we presented teachers with an activity involving balancing a long ruler on one finger of each hand. We asked the participants to bring the two hands together until they touched. We expected them to notice that the ruler moved unevenly over the fingers, but always finished up under the middle of the ruler. Then we asked them to construct a diagram to show a person in the next room how to carry out the activity. We noticed that all of the dozen participants had difficulty in selecting the level of detail to be included, especially those who had difficulty in explaining the unevenness of the ruler movement. We attributed this to a failure in filtering. Clearly, there is much more work to do on this aspect.

Conclusion

The paper focuses on methods of data collection from scientific diagrams, particularly on what viewers notice, i.e. what attracts their attention. It compares Eye Tracking with a Noticing Aloud Protocol. The analysis of the recordings took place within a group of experienced researchers. The participants more often provided interpretations of what they noticed, suggesting a cognitive interaction with what they noticed. The Protocol provided evidence that would support high quality e-learning involving diagrams.

It may be helpful to train teachers in the processes of constructing and reading diagrams for designing an e-learning environment.

Future research

There is still much valuable material to be mined from the vein of diagram noticing:

1. What human variables of age, gender, experience including cultural experience, impact on noticing in diagrams?
2. Are there different patterns in noticing in diagrams from different scientific disciplines?
3. Is it possible to omit some components, making diagrams simpler, while retaining their explanatory power?
4. Is it possible to teach learners to better see explanatory diagrams?
5. How do learners notice different things in story board process diagrams?
6. Can we interpret how learners learn from animations from our work on static diagrams?
7. What do learners see in cutaway, three-dimensional, or two and a half dimensional diagrams?
8. Can we enrich pedagogy in science from our research on diagrams?
9. Can we use the research method of observing diagram construction to understand new features of the role of diagrams in scientific learning?

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How do we know what people see when they look at diagrams?

Abstract

The paper focuses on methods of data collection from scientific diagrams, particularly on what viewers notice, i.e. what attracts their attention. It compares Eye Tracking with a Noticing Aloud Protocol. In the latter case, the researchers simply asked participants to say out loud what they noticed in a diagram, with the resulting conversation being audio recorded. The analysis of the recordings took place within a group of experienced researchers, collecting data on components, location, what was observed (even if it was not really present) or left out. The participants more often provided interpretations of what they noticed, suggesting a cognitive interaction with what they noticed. In this methods paper, generalisations from both published and unpublished evidence are included to give an indication of the scope and benefits of the Noticing Aloud Protocol. These are related to the prevalence of e-learning that includes diagrams.

Key words: scientific diagrams; noticing; methods; group analysis.

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