ASSESSING THE ROLE OF IMPLICIT SCAFFOLDING IN FACILITATING VIRTUAL PHYSICAL SCIENCES LEARNING

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ABSTRACT – This paper reports the findings of a qualitative analysis on the role of implicit scaffolding in facilitating virtual learning of abstract physical sciences concepts. The participant 3rd year physical sciences education students investigated electromagnetic induction (EMI) and the balancing of chemical equations, using simulations. In assessing the role of implicit scaffolding, participants were tasked to reflect on the different activities and mouse clicks within the learning environment using simulations. Data was collected through reflection diaries, follow-up semi-structured focus group interviews and screen shots of interfaces showing learning transitions. Thematic content analysis was then employed in analysing reflection diaries, transcribed textual data and screen shot records, to generate four main themes on the role of implicit scaffolding. Themes included the promotion of self-directed learning, efficient support of guided inquiry, the reduction of cognitive load and adequate pacing of learning outcomes for students of different abilities. It was concluded based on these findings that implicit scaffolding is an important aspect of designing virtual and e-learning science instruction and should be embedded when developing machine learning activities using simulations and virtual laboratories. The findings also indicated that, embedded implicit scaffolding played a fundamental role in pacing students' progress to higher cognitive levels in their learning of abstract physical sciences concepts. Some context-specific implications for practice and relevant recommendations for further research are also provided herein.

Keywords: Virtual learning, simulations, implicit scaffolding, self-directed learning, guided inquiry

INTRODUCTION AND BACKGROUND TO THE STUDY

Scaffolding entails the ability to progressively move students from a place of little or no understanding to one of greater understanding and eventually more autonomy in the learning process (Wood, Bruner & Ross, 1976). Just like physical scaffolding, traditional scaffolding in learning describes a teacher's tendency to provide progressive levels of support on which the student attains higher levels of skills, knowledge and attitudes (Chang & Linn, 2013; Quintana, Reiser, Davis *et al.*, 2004) in a particular subject. Usually, as students make step by step progress the support is gradually removed to enable autonomous learning (Ramnarain & Hobden, 2015). During face to face interactive learning, scaffolding is usually provided in the form of written or verbal instruction, prompts and questions. However, in virtual and e-learning the kind of scaffolding provided is rather embedded in the learning design (Moore, Herzog & Perkins, 2013) of particular simulations or virtual laboratories. In virtual science instruction especially, the scaffold prompts are systematically embedded to navigate students from the least to the most difficult simulations in order to minimize cognitive overload (Chen & Law, 2016). In our quest to examine the learning processes that takes place when students use simulations and virtual laboratories to complement other forms of knowledge acquisition, we realised that there was need for an initial assessment of the role of implicit scaffolding in the virtual learning instruction. We also noted that studies in the South African context focus on reporting the learning outcomes (Penn & Ramnarain, 2018), rather than the learning processes within virtual learning environments. Hence in this study we aimed to examine the role of implicit scaffolding in virtual physical sciences learning using 2-dimensional simulations as reflected on by 3rd year students. To attain the aim of this study the following research questions were posed;

How does implicit scaffolding embedded in virtual simulations facilitate the learning of physical sciences concepts?

How do students benefit from implicit scaffolding embedded in virtual simulations during physical sciences learning?

To answer these research questions the following objectives were outlined;

- Firstly to provide a virtual classroom for learning concepts using PhET simulations.

•	Secondly to conduct a qualitative assessment of the role and benefits of embedded instruction as implicit scaffolding post-virtual learning sessions.

THEORETICAL FRAMEWORK

The main theoretical underpinning for this study lies in the emerging theoretical framework for implicit scaffolding (Podolefsky, Moore & Perkins, 2014) which has its foundations in Vygotskian theories. Vygotskian theories portray scaffolding as a supporting tool aimed at transitioning a student through the zone of proximal development (ZPD) from what they cannot learn on their own, to what they can autonomously accomplish in terms of skills, knowledge and attitudes (Chamberlain, Lancaster, Parson, & Perkins, 2014). In science, in particular physics and chemistry, scaffolding is essential in navigating students through abstract scientific concepts which are difficult to visualise and comprehend. Usually the scaffolding will be explicit in that instruction will be verbal through questioning and puzzles or written in the form of a manual of set of instructions to provoke critical thinking, when students engage in scientific inquiry on a given topic. These kinds of explicit scaffolding, even though helpful in achieving learning goals have been criticised by some researchers as being highly teacher-centred, thus decreasing the ability for students to think critically. The nature of implicit scaffolding is crafted in a way that the student is guided without necessarily feeling guided (Bonawitz, Shafto, Gweon, Goodman, Spelke, & Schulz, 2011).

The Nature of Implicit Scaffolding in virtual learning

PhET simulations developed by the University of Colorado Boulder are free virtual learning tools which are implicitly scaffolded such that students can engage in learning science concepts with minimal guidance (Moore et al, 2013; Podolefsky et al, 2014). Implicit scaffolding which is not a form of verbal or written scaffolding is systematically embedded in the design of a virtual laboratory simulation or illustration. This design is meant to facilitate the learning process such that the student moves through the ZPD without much guidance from an instructor or laboratory manual (Bonawitz et al, 2011). It also provides a platform where individualised learning outcomes of students are reached without interfering with different learning paces. The main difference of the implicit from the explicit traditional scaffolding is that when embedded in simulations demonstrations and illustrations, the tools provide the necessary guidance to the student but changes the nature of students' perceptions and reception of the guidance (Latour, 2005). This implies that the student feels totally in control of their learning and does not really feel instructed as in the case of explicit scaffolding.

Difficulties associated with electromagnetic induction (EMI) and stoichiometry

Based on the results of an online poll conducted with participant students it was indicated that learning Faraday's law of electromagnetic induction was difficult because, the relationship between electricity and magnetism was more complex than students could visualise. They also noted that it was difficult to comprehend the effects of change in time (dt) through a magnetic field and several challenges associated to the flux rule as alluded by the participants in a similar study by Jelicic, Planinic and Planinsic (2017). Also associated with this topic are misconceptions, for example where some students see flux as the flow of a magnetic field (Zuza, Almudí, Leniz, & Guisasola, 2014). Following these identified difficulties, a learning intervention was then designed to cater for these different aspects of electromagnetic induction using PhET laboratory simulations and the accompanying embedded activities in the simulated learning environment. For the learning interventions, the researchers firstly designed lesson plans to cover specific lesson objectives; secondly constructed activities to assess the specific learning objectives, covering all levels of the revised Bloom's taxonomy; thirdly provided the provided participant with reflection questions and screen capture instructions, then began with the tutorial sessions. Figure 1 below shows two levels of scaffold used to attain the learning outcomes of the first intervention on EMI.

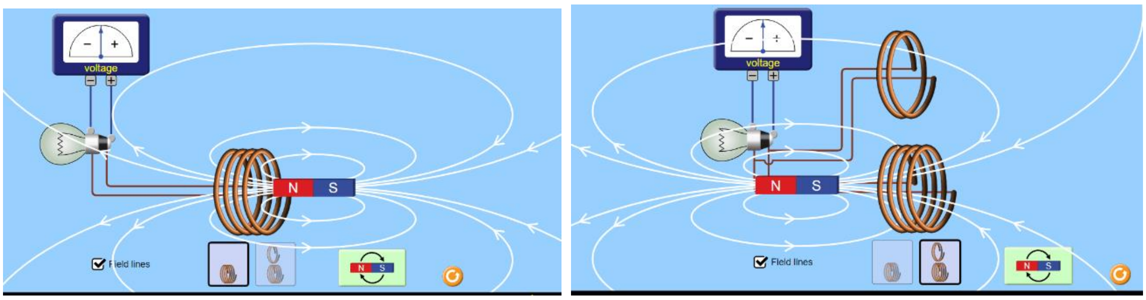

Figure 1: Levels of prgressive scafold in faraday's law lab
https://phet.colorado.edu/sims/html/faradays-law/latest/faradays-law_en.html

As seen in Figure 1 above, students are able to progressively manipulate the relationship between magnetic flux across the different number of turns of a coil, measuring the electromotive force (emf) generated as they change other variable such as time, direction, number of turns in a coil and magnetic poles. After this point they advanced to different aspects of Faraday's law applications in electrical motors, solenoids and transformers.

With regards to balancing chemical equations, 3rd year students expressed difficulties in the general understandings of stoichiometry. As noted in some studies, the balancing of chemical equations is one of the concepts where the direct inter-relation between Mathematics and chemistry comes into play (Marais & Combrinck, 2009). This usually requires that students understand the relationship between relative quantities of substances in a chemical reactions and compound formation in ratios of whole integers (Marais & Combrinck, 2009). Students found the topic abstract due to the complex relationship in applying mathematical principles while ensuring that chemical phenomena are not compromised (Taskin & Bernholt, 2014). Figure 2 below shows the levels of embedded scaffolding for the tasks which students had to engage in.

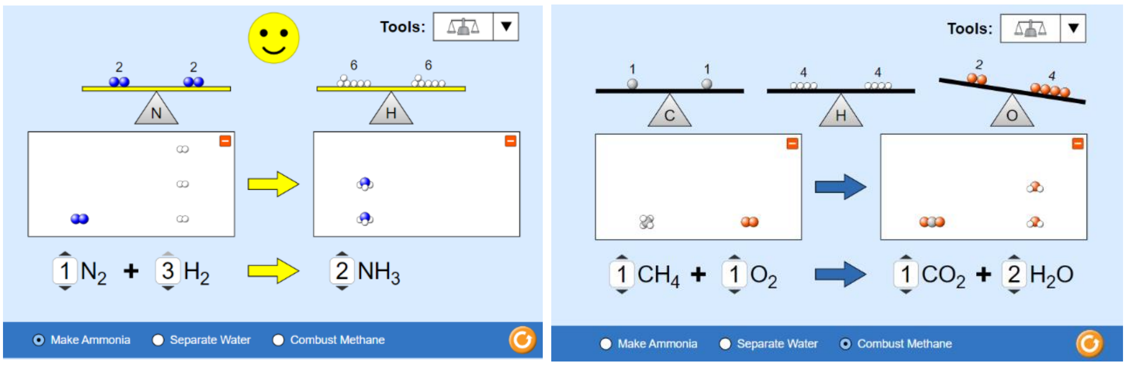

Figure 2: Levels of embedded Scaffolding in balancing chemical equations
https://phet.colorado.edu/sims/html/balancing-chemical-equations/latest/balancing-chemical-equations_en.html

As seen in Figure 2 above students were able to first balance the equation for making Ammonia, then proceed to separate water and finally combust methane. When an equation was adequately balanced it would be reflected on the embedded scale balance and a smiley face will be flashed on the screen as a reward. In the case where the student got for instance, the combustion of methane equation wrong, an imbalanced scale would be shown and the screen will remain blue. With this kind of embedded instant feedback system, students are able to self-assess, self-correct and eventually progress into the balancing of more complex chemical equations.

METHODOLOGY

The study followed a generic qualitative methodology in which data was collected from 10 groups of 3rd year physical sciences education students (n=50) at a South African tertiary institution of learning. These participants were purposefully selected because they all took courses in physics and chemistry. It is important to indicate here that the groups were carefully constructed by the tutor (one of the researchers), based on the achievement levels of students such that all levels of ability were duly represented in each group consisting 5 members. After identifying the concepts which they considered abstract, via an online poll, students were exposed to alternative virtual learning simulations during 2 tutorials over two weeks for learning the identified concepts. The tutor did not provide any face to face instructional guidance besides elaborating on the learning outcomes targeted at the end of virtual learning sessions.

Data collection and analysis

Data was collected from each group's reflection diaries (with guided reflection prompts) and screen shots of tabs within the simulation interphase at the end of each learning outcome for 2 tutorial sessions. The aim of using reflections and screen shots was to assess the role of the implicit instructions that were embedded in the simulations and to examine the visual representations of the embedded controls seen on the screen with each mouse click. Each group had a single reflection diary in which participants' collective thoughts were captured and a separate document in which their screen shots were captured and pasted with captions. Ten (10) follow-up focus group interviews were thereafter conducted with all the participants to examine students' perceptions of this kind of implicit guidance and how they benefited from the embedded implicit instructions. Audio recorded data from interviews were transcribed verbatim and all textual data and screen shots were analysed using thematic content analysis with the aid of a Computer-Assisted Qualitative Data Analysis Software (CAQDAS), Atlas ti version 8. Two coders, coded the data separately and consolidated the codes for an inter-coder reliability of 95% in order to diminish subjectivity of the findings. Table 1 below shows a single response to 1 of the six reflection prompts and how the represented data was analysed to generate the themes that emanated.

Table 1: Sample of data analysis steps

Reflection prompt	**Group written reflection**	**Summarised categories**	**Theme generated**
How did you perceive the simulation interface and embedded guidance for balancing chemical equations? Please elaborate on your reflection.	*We found that the interphase had embedded guidance in the 3 different tabs as seen on the screen shots we provided* *When we made an error with the equations, the scale balanced was uneven and we tried again until the product-reactant balance was attained and we got that smiley face. Overall, it felt great to be in charge of our own learning.*	• Different levels of guidance • Instant feedback • Easy to see errors, correct, then proceed • Autonomous learning promoted.	Self-directed and autonomous learning

RESULTS

Based on the analysis of data from reflection diaries, PrtScr shots and focus-group interviews, students reported on their direct engagement with the virtual learning process using the PhET simulations without tutor guidance. The following themes emerged from the analysis.

(1) Self-directed learning

Of the 10 groups of participants, 9 groups indicated that each simulation had three different interphases that guided them in manipulation each aspect of the concepts they investigated. Groups further mentioned that feedback was instant and real time data could be collected when changing variables, especially with the EMI investigations. For the balancing of chemical equations, a balancing scale was embedded within the simulations to guide the way equations where balanced. With all of these built-in scaffolds, students indicated that they found these features quite fascinating and could navigate their way through the simulations to attain the learning outcomes after the first ten minutes of the one hour tutorial slot. In the respective groups participants acknowledged that this embedded guidance empowered them to self-teach and assess without any direct assistance from the tutor or lecturer. It was specifically indicated by all the groups of students that, the simulations on the balancing of chemical equations were quite enjoyable because of the game-embedded features like emoticons.

(2) Guided inquiry

Group members of all the 10 groups indicated they followed the implicit instruction to systematically engage in inquiry-based learning. They noted that they were able to set their own investigation questions and answer them, by following the embedded prompts to eventually manipulate variables and collect data from the simulation laboratories. The main observation here again was that they attained the set learning outcomes without feeling as if they were guided.

(3) Reduction of cognitive overload

In the last reflection prompt which asked the students to state what they perceived to be the ultimate benefit of the simulations, they indicated that simulations were designed such that they did not feel overwhelmed with learning too many concepts at a time, hence adequate cognitive load was maintained, through the use of all virtual learning task. They indicated that as with literal scaffolding, the concepts were systematically built on what they already knew in the form of prior knowledge.

(1) Pacing

All groups also reported that they enjoyed the manner in which learning trajectories could be attained at different times for the different groups such that there was no rush in terms of what could be attained when. In essence, within the virtual learning space the pace was well negotiated based on one's learning ability so that no one was under any pressure to proceed if they did not understand a particular concept, while those who were fast to grasp, were not held back in waiting.

DISCUSSION OF RESULTS

Findings from this study are closely associated with the findings of studies like Moore et al, (2013) who indicated that the nature of implicit scaffolding which is incorporated in simulations laboratories are able to guide students in attaining their learning outcomes with very minimal explicit instructions. One of the principal findings was that students felt that they could benefit in the pacing of tasks such that in some of the simulation laboratories, they were not able to progress without attaining certain milestones. Those who attained the learning milestones made progress while those who did not attain, had the chance to repeat the simulation over and over. This finding concurs with the findings from other studies (Chamberlain et al, 2014; Chen & Law, 2016) where the researchers found that scaffolded guidance promoted time on task engagement with the phenomena that students were investigating. Students also indicated that, guided inquiry was positively promoted (Quintana & Fishman, 2006) and self-directed learning was enhanced, with immediate feedback on tasks as postulated by Reeves and Reeves (2012). Participants enjoyed the fact that learning trajectories can be individualised when implicit scaffolding is embedded in a virtual learning tool. Contrary to these findings some researchers suggest that cognitive load will always be experienced with all forms of virtual learning whether by 2 or 3-dimensional simulations, based on the strain machine learning poses on human senses (Makransky, Terkildsena, & Mayer 2017). However, these cognitive overloads are better managed when using 2-D simulations as is the case with PhET simulations (Makransky & Petersen, 2019). The main contribution of this study refers to the need for examining the processes that students engage in when learning in virtual spaces, rather than only the products that emanate from virtual learning interventions as reported in Penn and Ramnarain (2018).

CONCLUSION AND RECOMMENDATIONS

Based on these findings we concluded that it is essential to incorporate implicit scaffolding when designing virtual learning simulations and illustrations. Theoretically this ideology is supported by the assertion that scaffolded instructions will usually move students step-by step across the zone of proximal development (ZPD), to autonomy in the learning process as they strive to understanding abstract scientific concepts. Implicit scaffolding, also facilitates guided inquiry and autonomous learning of abstract scientific concepts by affording students guidance as they construct essential knowledge to answer scientific questions. Some implications of this kind of scaffolding for science instruction, in the South African context include the fact that though implicitly guided, learning is still very much student-centred rather than teacher-centred. That is, students will still feel very much in control of their own learning as oppose to direct lecturing techniques, which limits peer learning and interactions. Based on these conclusions we suggest that further research be exploited on the different levels of embedded instructions that could assist context-specific learning processes, in virtual-science learning. It is also worth investigating students' perceptions of implicit scaffolding as a mediation tool in virtual science learning and finally employ quantitative techniques to assess, the relationship between the embedded implicit scaffolding and achievement in content tests.

REFERENCES

Bonawitz E., Shafto P., Gweon H., Goodman N. D., Spelke E. and Schulz L., (2011), The double-edged sword of pedagogy: Instruction limits spontaneous exploration and discovery, Cognition, 120, 322–330. doi: 10.1016/j.cognition.2010.10.001.

Chamberlain J. M., Lancaster K., Parson R. & Perkins K. K., (2014). How guidance affects student engagement with an interactive simulation. *Chemistry Education Research and Practice, 15*(4), 628–638. DOI: 10.1039/c4rp00009a.

Chang H.-Y., & Linn M. C., (2013). Scaffolding learning from molecular visualizations. *Journal of Research in Science Teaching, 50*(7), 858–886.

Chen, C-H., & Law, V. (2016). Scaffolding individual and collaborative game-based learning in learning performance and intrinsic motivation. *Computers in human behaviour, 55*, 1201-1212. https://doi.org/10.1016/j.chb.2015.03.010.

Jelicic, K., Planinic, M., & Planinsic, G. (2017). Analyzing high school students' reasoning about electromagnetic induction. *Physical Review Physics Education Research, 13*(1), 010112.

Latour, B. (2005). *Reassembling the Social: An Introduction to Actor-Network Theory*. Oxford: Oxford UP.

Makransky, G., Terkildsena, T. S., & Mayer, R. E., (2017). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. https://doi.org/10.1016/j.learninstruc.2017.12.007

Makransky, G. & Petersen, G. B. (2019). Investigating the process of learning with desktop virtual reality: A structural equation modeling approach. *Computers and Education, 134*, 15-30. doi.org/10.1016/j.compedu.2019.02.002.

Marais, F., & Combrinck, S. (2009). An Approach to Dealing with the Difficulties Undergraduate Chemistry Students Experience with Stoichiometry. *South African Journal of Chemistry, 62*, 88-96. Retrieved from http://www.scielo.org.za/pdf/sajc/v62/17.pdf

Moore E. B., Herzog T. A. and Perkins K. K., (2013), Interactive simulations as implicit support for guided-inquiry. *Chemistry Education Research and Practice, 14*, 257–268.

Penn, M., & Ramnarain, U. (2018). Pre-Service Teachers' Understandings of Chemistry Concepts Using Virtual and Hands-On Laboratories. In proceedings of the 9th Annual UNISA ISTE Conference On Mathematics, Science And Technology Education: 21-26 October 2018 Skukuza Camp in Kruger National Park, Mpumalanga, South Africa. (pp. 240-246).

Podolefsky N. S., Moore, E. B., & Perkins, K. K. (2014). Implicit scaffolding in interactive simulations: Design strategies to support multiple educational goals. Retrieved from http://arxiv.org/abs/1306.6544.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., et al. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences, 13*(3), 337-386.

Quintana, C., & Fishman, B. J. (2006). Supporting science learning and teaching with software-based scaffolding. In Annual conference of AERA, San Francisco, CA. Retrived from Thhttps://pdfs.semanticscholar.org/6ce3/8816c8cbc7f76ef8934d4cb63abaacf24aa2.pdf

Ramnarain, U. & Hobden, P. (2015). Shifting South African learners towards greater autonomy in scientific investigations. Journal of Curriculum Studies, 47(1), 94-121. https://doi.org/10.1080/00220272.2014.966153

Reeves, T. C. & Reeves, P. M. (2012). *Designing online and blended learning, in Hunt L. and Chalmers D. (ed.), University teaching in Focus: A Learning centred Approach,* Oxford: Routledge.

Taskin, V. & Bernholt, S. (2014). Students' Understanding of Chemical Formulae: A review of empirical research. *International Journal of Science Education, 36*(1), 157-185, DOI:10.1080/09500693.2012.744492

Wood,P., Bruner,J., & Ross,G.(1976).The role of tutoring in problem solving. *Journal of Child Development and Psychiatry, 17*, 89–100.

Zuza, K., Almudí, J.-M., Leniz, A., & Guisasola, J. (2014). Addressing students' difficulties with Faraday's law: A guided problem solving approach. *Physical Review Special Topics-Physics Education Research, 10*(1), 010122.

https://phet.colorado.edu/sims/html/balancing-chemical-equations/latest/balancing-chemical-equations_en.html.

https://phet.colorado.edu/sims/html/faradays-law/latest/faradays-law_en.html