Prior knowledge, confidence and understanding in interactive tutorials and simulations

Jason M. Lodge
ARC Science of Learning Research Centre
Melbourne Centre for the Study of Higher Education, University of Melbourne

Gregor Kennedy
ARC Science of Learning Research Centre
Melbourne Centre for the Study of Higher Education, University of Melbourne

The balance between confidence and understanding can be difficult for students to manage, particularly in digital learning environments where they start with different levels of prior knowledge. The level of prior knowledge and perception of how well understood this prior knowledge is will drive the level of engagement and integration of new knowledge as students are exposed to it. Exploring the relationship between these factors is therefore important for the design of digital learning environments. In this paper we describe two studies examining the levels of confidence and understanding reported by students completing interactive and non-interactive exercises in a digital learning environment. The reported levels of confidence and understanding are then contrasted against pre- and post-test performance and self-reports of the experience completed at the conclusion of the session. The results suggest that students' prior knowledge influences their confidence and perceived difficulty of the material but does not necessarily influence performance.

Keywords: prior knowledge, confidence, simulations

The importance of not being too confident

Confidence is generally seen as an important trait for individuals in many facets of life. Being confident in work and in social settings has been shown to have significant benefits (Bénabou & Tirole, 2002). Despite this, the evidence for the benefits of high levels of confidence in the learning process is uncertain (e.g. Lester, Garofalo & Kroll, 1989). Research related to judgements of learning, for example, indicates that it is common for novices in many knowledge domains to overestimate their level of understanding (Dunlosky & Rawson, 2012). This is most evident in the Dunning-Kruger Effect (Kruger & Dunning, 1999); the observation that the unskilled are often unaware of being unskilled. What these observations suggest is that it might be more productive to be less confident during learning. These observations allude to a broader need for greater understanding of the role of subjective experiences during the learning process so that more effective digital learning environments can be developed.

The aspect of subjective experience that has perhaps been most difficult to research is the role of emotions. Emotion in learning has received renewed attention in recent times (Pekrun & Linnenbrink-Garcia, 2014). Among the many emotional states being investigated, confusion, in particular, seems to play an important role in the process of acquiring new conceptual knowledge (D'Mello, Lehman, Pekrun & Graesser, 2014). Confusion has been a particularly difficult state to examine historically as there has been conjecture about whether it is a purely emotional state, a side effect of cognitive processing or a mixture of both (Rozin, & Cohen, 2003). Researchers have recently settled on the notion of an 'epistemic emotion' as an operational description of confusion (D'Mello & Graesser, 2014). In other words, confusion is an affective state directly related to knowledge and knowledge acquisition that provides important cues to the learner in relation to their learning (D'Mello, Lehman et al., 2014). This definition recognises the important role that confusion can play in the process of conceptual change.

The normalisation of confusion as part of the learning process could help overcome the problem of overconfidence. Confusion can be seen as a standard part of the conceptual change process in several ways. For example, confusion is particularly beneficial when students need to overcome misconceptions (e.g. Lehman, D'Mello & Graesser, 2012). Misconceptions about various content areas can occur for several different reasons. New content can be counterintuitive, complex, systemic or novel (D'Mello, & Graesser, 2012). In each of these cases, students need to be able to monitor the strategies they draw on to learn the material and adapt the strategy accordingly. Confusion thus serves as a cue that the strategy they are employing is not effective at acquiring the new knowledge and assimilate it with what they already know (D'Mello & Graesser, 2014). Without recognising this confusion, an overconfident learner will attempt to assimilate new information into existing mental representations that remain misconceived (Cordova, Sinatra, Jones, Taasoobshirazi & Lombardi, 2014). As such, it is evident that overcoming both overconfidence and achieving conceptual change could be contingent on the recognition that there is a mismatch between the new information and the existing mental model, a process most often accompanied by the subjective experience of confusion (D'Mello & Graesser, 2014).

Much of the research on confusion in digital learning environments to date has focused on creating adaptive intelligent tutoring systems (e.g. D'Mello, Lehman et al., 2014) that build on recent work in affective computing (e.g. Calvo, D'Mello, Gratch, & Kappas, 2014). This line of enquiry has been useful in helping to better understand how systems can be developed that can provide a more nuanced response to learner progress in digital learning environments than would be possible through modeling based on behavior alone. This research, however, has only begun to uncover the complex relationship between confusion, conceptual change and the mental models learners already have in place, i.e. students' prior knowledge. The research reported in this paper attempts to address this gap in the research literature with emphasis on learning in digital environments.

Confidence, confusion and prior knowledge

Confusion is important in the context of the studies described here as it is directly related to the process of conceptual change, particularly in situations where the to be learned knowledge is conceptually complex, counterintuitive or commonly misconceived (see also Lodge, 2015). Previous research has found that misconceptions in certain knowledge domains can be particularly difficult for students to overcome. For example Hughes, Lyddy and Lambe (2013), conducted a thorough overview of the misconceptions in psychology. They argue that some notions, such as schizophrenia being characterised by multiple personalities and the myth that we only use 10% of our brains, are particularly persistent. The existence of persistent misconceptions is evident in many disciplines (Hughes et al., 2013).

Of equal importance for overcoming misconceptions is the relationship between confusion and prior knowledge. If confusion is not adequately resolved (i.e. students reach an impasse), it often results in either boredom or frustration (D'Mello & Graesser, 2014). These are the negative side effects of confusion. The implications of these side effects are that students either need to be guided beyond the impasse using effective and timely feedback or scaffolding or need to self-regulate their own learning. If any of these processes break down, it is likely that students will rely on their prior knowledge to make sense of the new information. This, in turn can lead to misconceptions being reinforced rather than updated. Therefore understanding this prior knowledge and how it impacts on the conceptual change process is vital if digital learning environments are to be developed to provide the required interventions needed to help students overcome impasses and confusion.

There are numerous ways of creating digital learning environments that can adapt to students' responses. Digital learning environments provide affordances such as the possibility of providing real-time feedback based on student interaction with the environment (e.g. Kennedy, Ioannou, Zhou, Bailey & O'Leary, 2013; Roll, Aleven, McLaren & Koedinger, 2011). However, the sequencing and timing of the task and the feedback has been traditionally linear and built on the assumption that all students start from the same point. In most disciplines in higher education, there is great diversity in the knowledge students have when they first begin a degree program or subject. Better understanding how this prior knowledge influences the strategies students use, their ability to incorporate new knowledge and the interaction between these factors and their level of perceived confidence and understanding will help to better determine how to do so.

To progress previous literature on the emotions and judgements of learning in digital learning environments, this paper focuses on the relationship between these factors. Our aim was to determine whether self-reported confidence and understanding collected while students complete tutorial and simulation sessions in digital learning environments relates to their post-hoc self-reported experience and performance. Understanding the relationships between these variables is important if we are to provide more nuanced and timely scaffolding and feedback during the learning process in digital learning environments.

Study 1

The purpose of study one was to build on the limited research to date examining the roles of confusion and confidence in relation to judgements of learning in a digital learning environment. As the first attempt to do so within a broader program of research, this initial study went about examining these factors in an interactive tutorial that would be perceived as highly difficult for learners unfamiliar with the content (see also Lodge & Kennedy, 2015). This was a deliberate decision in order to ensure that there was a maximum likelihood that participants would find the material confusing.

The interactive session used in this first study was based on a session that is used in an undergraduate degree program in biomedical science. In this case however, the study was conducted in a computer laboratory rather than 'in the wild'. Our reasoning for doing so is that we intend to build on this work to later incorporate multiple measures and indicators for confusion including facial electromyography, electroencephalogram and eye-tracking. Combining the laboratory-style methodology commonly utilised in psychological science with authentic educational material can be a difficult proposition given the different paradigms of research in educational technology and psychological science. As the studies reported here are somewhat novel in this regard, there was an exploratory element to the process described here.

Methods

Participants
Volunteers for this study were drawn from the population of students at The University of Melbourne. An advertisement was placed on the careers website. Students from any disciplinary background were invited to participate. Thirty participants were recruited for this study. Twenty of the participants were female. The mean age of the participants was 23.3 (SD = 4.6) years. Students were studying a range of degree programs. Most commonly, students were admitted into Bachelor of Arts, Bachelor of Commerce or Bachelor of Science degrees. No students reported having significant experience with biomedical science. Participants were compensated with a $20 retail voucher for participating in this study.

Materials
The experimental sessions were conducted in computer laboratories in the Melbourne Graduate School of Education. The computer-based material was presented on a 21.5 inch iMac computer. All other instruments were printed out for ease of use during the experimental sessions.

The tutorial material used for this first study is a module on pharmacodynamics developed for use by students in second year biomedical science. The content is complex in nature and is difficult for novice learners to comprehend given the extensive use of technical terms and assumption that users have one or more full time years experience with concepts and processes in biomedical science. This module was used as we wanted to ensure the maximum likelihood that participants would find the material difficult and potentially confusing. Given the nature of the material and the participants, there should also be low levels of prior knowledge, hence providing a basis from which to understand how prior knowledge (or in this case, a lack thereof) interacts with the other factors of interest. Doing so gives us a solid foundation upon which to explore the relationships between variables in this study.

Pre and post-tests were developed with the assistance of a content matter expert in The Department of Medical Education at The University of Melbourne. The pre-test consisted of a series of multiple choice questions covering the full range of material included in the pharmacodynamics module.

While participants completed the module, they were asked to fill out a series of questions about their experience during the session. An instrument was developed asking students to respond to each new screen in the module. Three questions were asked in relation to each screen. The first question asked the participants to report their level of confidence that they understood the material. The second question was set out in the same way but asked participants to report their perceived level of understanding of the material on the screen. They were provided with a visual analogue scale from 0 to 9 with the anchor points at 0 'Not confident at all' / 'Not challenging at all', at 5 'neutral' (for both) and at 10 'Very confident' / 'Very challenging'. A final question asking participants to report their overall experience in a few words was also included for each screen.

A questionnaire was developed to both collect demographic details and post-hoc self-reported experiences of the module. Standard age and gender questions were incorporated into the instrument as were a series of questions specifically asking for the emotional reaction participants had to the session. This set of questions was adapted from the retrospective affect judgement protocol developed by Graesser et al. (2006) for their studies on emotion in intelligent tutoring systems. All instruments were given to participants in pencil and paper form.

Procedure

Participants were told of the nature of the study and completed informed consent paperwork before completing a pre-test of their knowledge about pharmacodynamics. After completing the pre-test, participants were then given access to the pharmacodynamics module. They were instructed to complete the paper and pencil instrument at the conclusion of each screen in the module. Participants were given unlimited time to complete the module. Once complete, they were then asked to fill out the questionnaire and lastly to complete the post-test. At the conclusion of the session, participants were debriefed and informally asked about their experiences using the tutorial and participating this the study. After the data for this study were collected, each set of responses was scored and entered into spreadsheet software for further analysis.

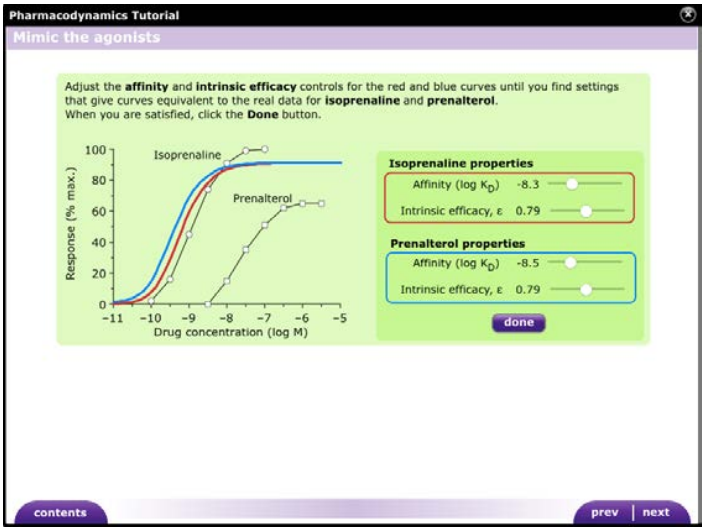

Figure 1: Sample screen from pharmacodynamics tutorial

Results

Participants performed marginally worse than chance on the pre-test (M = 7.63, SD = 2.68). After exposure to the module, the mean score across all participants improved to above chance (M = 10.9, SD = 2.83). The difference between pre- and post-tests was significant, t (30) = 6.97, $p < 0.001$.

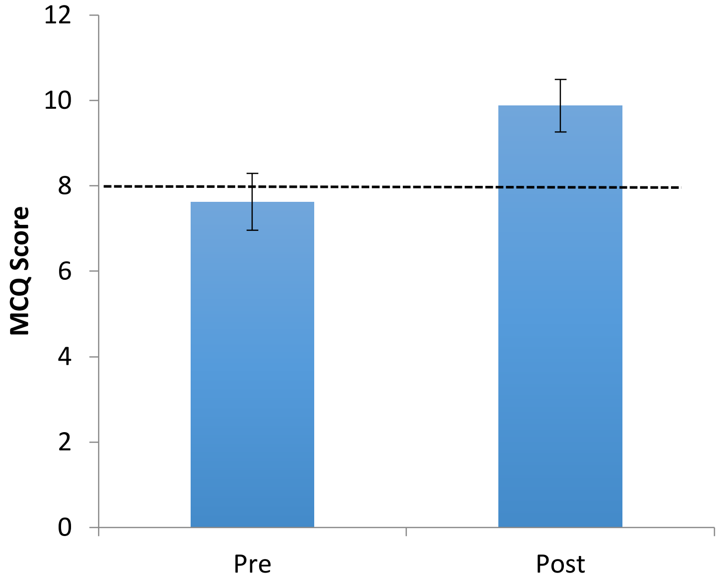

Figure 2: Mean pre and post-test scores (SE) with chance performance level emphasised

Examining the responses to the questions asked throughout the session, it is apparent that there was some variation in reported levels of confidence and understanding. While there is no direct benchmark to compare these mean responses to, it is apparent that different screen designs led to different response patterns. For example, screen 24 included several interactive elements that relied on consolidation of material presented earlier in the module. This can be compared to screen five, for example, where participants reported being more confident in their understanding and found the screen less challenging. This screen was far less interactive and was predominantly informational in nature. The pattern of responses to these questions can be seen in figure 3.

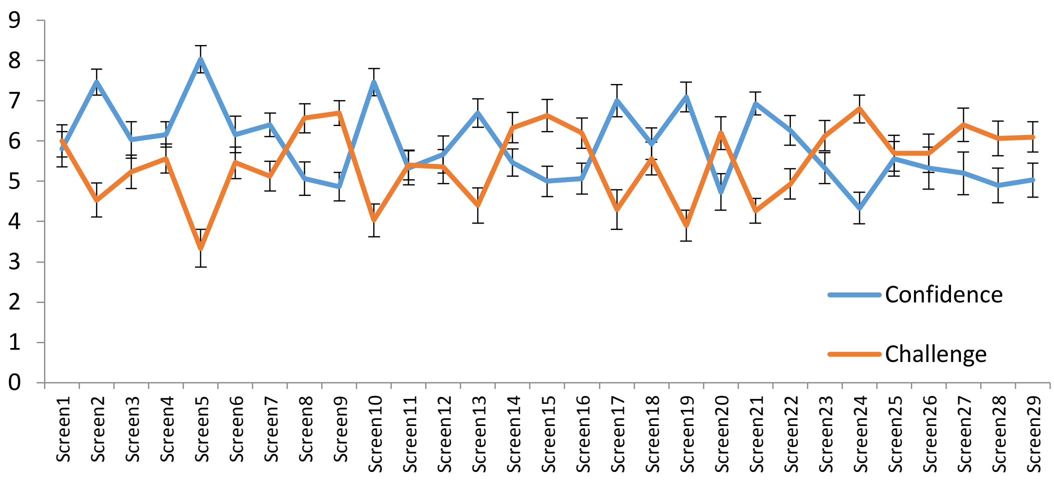

Figure 3: Mean confidence and challenge ratings/10 during session (SE)

The responses to the post-session questionnaire revealed that participants found the session exciting confusing and enjoyable but relatively less interesting, boring or frustrating. This pattern of responses is presented in figure 4.

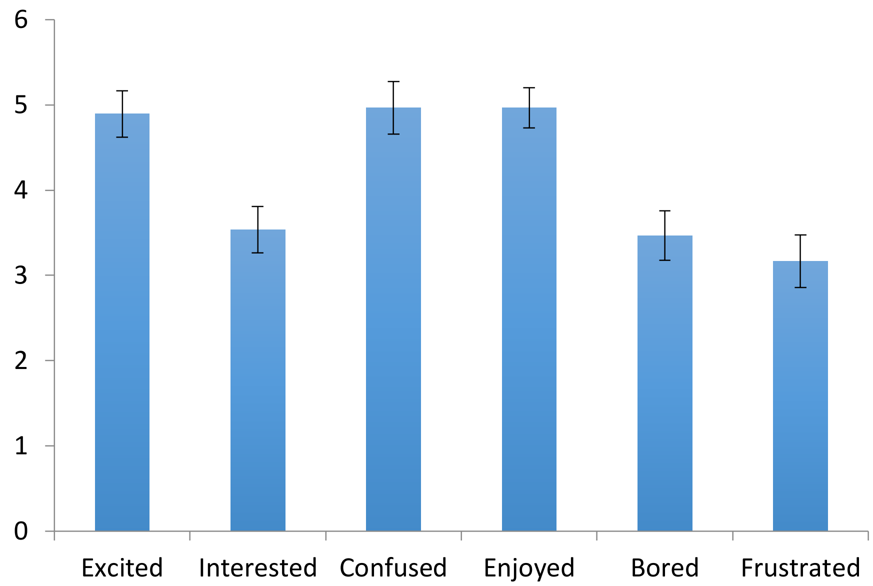

Figure 4: Mean (SE) emotion ratings/10 post-session

Discussion

The results of this first study suggest several interactions between the variables of interest in this program of research. Despite not being particularly confident and finding the material difficult in the pharmacodynamics tutorial, participants significantly improved their overall performance between pre- and post-test. This improvement was also independent of the fact that students reported little to no previous experience with the content of the module.

The results of this first study support previous studies suggesting that student levels of confidence are not necessarily a clear indicator of improved performance. While participants did not feel particularly confident in their learning during the session and reported that the material was relatively difficult, their performance between the pre-test and post-test still improved significantly.

It is of course recognised that both the ratings made by participants and their performance are relative. The sample size was also comparatively small for this first study. Our aim with this first study was to induce confusion in a laboratory environment whilst attempting to control for previous knowledge. On that count, the results of this study have been successful. Participants indeed appeared to be confused but their confusion did not appear to impair their capacity for learning, independent of prior knowledge. From here we need to develop a better understanding of how these results apply in diverse environments where prior knowledge is a factor.

Study 2

The purpose of study two was to expand on the findings of study one by using content that students are much more likely to have prior knowledge of and to expand the range of environments the research program is interested in. The overall design was similar to that used in study one. There were two main modifications. Firstly, the stimulus material was changed to allow for prior knowledge to have some impact. The tutorial module on pharmacodynamics was replaced with a session on blood alcohol concentration (as per Dalgarno, Kennedy & Bennett, 2014). This module has been effectively used in laboratory-based studies as a proxy for realistic educational material. The module also has two distinct versions; a tutorial version and a simulation version. Participants in the tutorial condition were led through the material in a similar manner to the linear progression available in the pharmacodynamics tutorial used in study one. The simulation condition allowed participants to manipulate variables within the simulation to see how various factors impact on blood alcohol concentration. For a full description of how the module operates, please refer to Dalgarno et al. (2014). Beyond the benefit provided by using established material, the blood alcohol concentration module afforded the added benefit of tracking the methods used by participants in the simulation condition hence giving insight into how the factors of interest in this research impact on student behavior. Audit trails were collected for this purpose and add further richness to the results of these early forays into the role of confusion, confidence and prior knowledge on student learning.

Methods

Participants

Participants were recruited via the same methods as study one. Fifty participants volunteered for the study. Twenty of the participants were male. The mean age of the participants was 23.1 (SD = 4.6) years. As per study one, participants were most commonly students admitted into Bachelor of Arts, Bachelor of Commerce or Bachelor of Science degrees. Participants were again compensated with a $20 retail voucher.

Materials

The materials used in the second experiment were broadly the same as those used in the first. The main differences in this second study are that a content area that should be more familiar was used. In this instance, the module to be completed was on blood alcohol concentration. An example screen is displayed in figure 5.

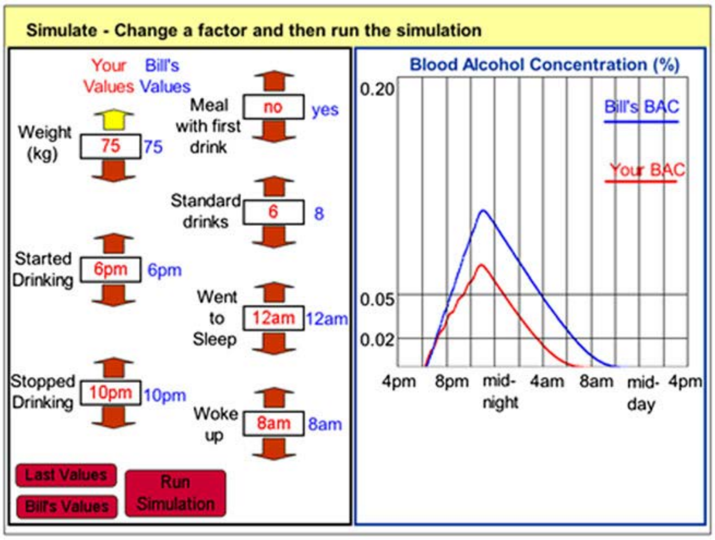

Figure 5: Sample screen from blood alcohol concentration simulation

A further additional manipulation was added. For the second study, two versions of the module were tested; one, a tutorial version, the second a simulation version. The manipulation was simply that participants in the simulation condition were able to alter the factors associated with blood alcohol concentration (as seen on the left of figure 5.) but participants in the tutorial version were not. In this condition variables were altered between screens and participants watched rather than interacted with the module.

Procedure

The procedure was broadly the same as that for study one. Participants were given content relevant pre and post-tests on the material, asked to rate confidence and understanding during the session and completed a post-session questionnaire on their experience. Participants in the tutorial condition were instructed to work through the entire tutorial whereas the simulation group was asked to complete a corresponding number of runs through the simulation. This approach corresponded with the procedure used by Dalgarno et al. (2014) in that the strategies used by participants formed part of the analysis. They found that participants using a systematic, as compared to a non-systematic approach, to work through the simulation outperformed others in the simulation and tutorial conditions. To ensure the approach taken by students did not influence performance in the current study, results were analysed in a manner consistent with that of Dalgano et al.

Results

The participants in the simulation condition were split on the basis of the strategy they used to work through the simulation. As reported, Dalgarno et al. (2014) found a significant difference between participants who used a systematic approach (varying one factor at a time and seeing the effect) and those who did not use a systematic approach (all other approaches, mostly manipulating the variables haphazardly). Of the 25 participants in the simulation condition, only five could be considered to have used a systematic approach. We have conducted an analysis on these groups with some caution given the sample size and differences between the numbers of participants in each condition.

When separating the participants out into the three groups (tutorial condition, simulation condition with systematic approach and simulation condition with non-systematic approach), it is apparent that the participants in each group tended to improve their scores between pre and post-test. The scores for each are presented in figure 6. While it is evident that the mean score in each of the three groups improved significantly from pre-test to post-test, F (1, 47) = 19.99, $p < 0.001$, there was no main effect for the overall differences between the groups, F (2, 47) = 3.136, p = .053 and no interaction effect, F (2, 47) = .331, p = .720. This means that there was no difference between the groups in terms of their increase in performance between pre-test and post-test.

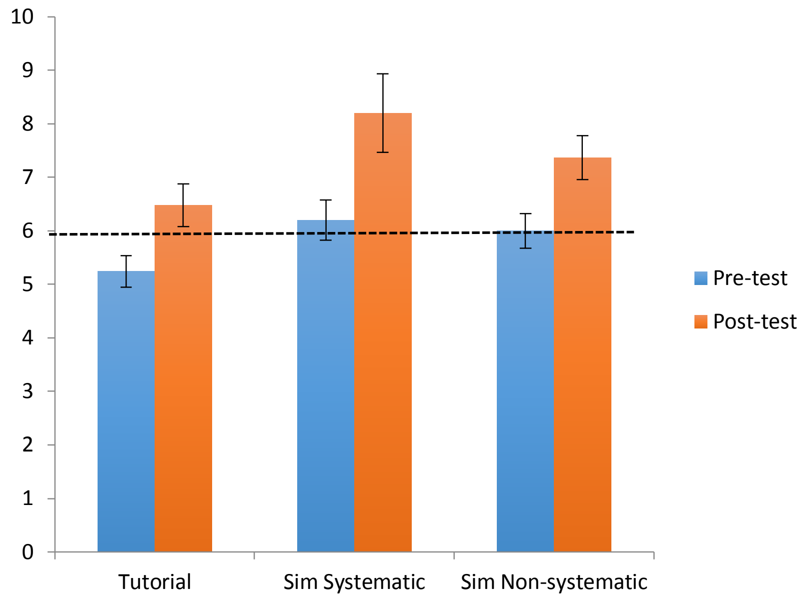

Figure 6: Mean (SE) pre and post-test scores by condition with chance performance level emphasised

While there is no statistically significant difference between the conditions, there is a trend towards the enhanced performance in the simulation group using a systematic approach over the other two conditions. Given the difficulty in predicting in advance whether participants will adopt a systematic or non-systematic approach, the failure to obtain a significant difference in scores in this case could be due to insufficient statistical power. As we did not find a significant difference between the participants using a systematic and non-systematic approach in the simulation condition, all further analyses were conducted on the basis of a comparison between tutorial and simulation conditions.

Ratings of perceived challenge and confidence in understanding the material followed a different pattern than was evident in study one. Participants were highly confident that they understood the material and reported that is was not particularly challenging. The mean responses to these questions are presented in figure 7. Further analysis of this data interestingly showed no difference in this pattern between the tutorial and simulation conditions.

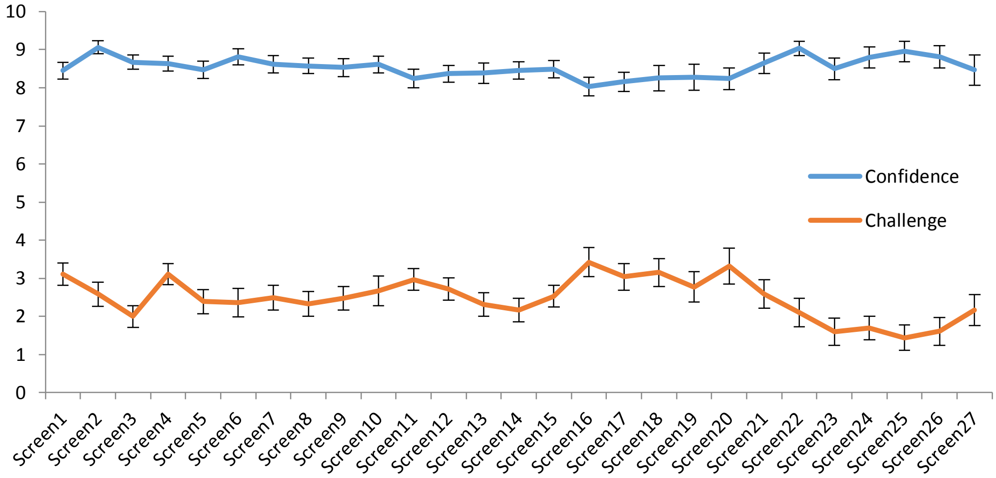

Figure 7: Mean confidence and challenge ratings/10 during session (SE)

When examining the post-session responses, tutorial and simulation groups were again considered separately and compared. The mean response scores for each are presented in figure 8. As can be seen in the figure, participants in the simulation condition reported being slightly more interested and slightly less confused, bored or frustrated. Again, these differences were not statistically significant, which may again be an artifact of the size of the sample and a lack of statistical power.

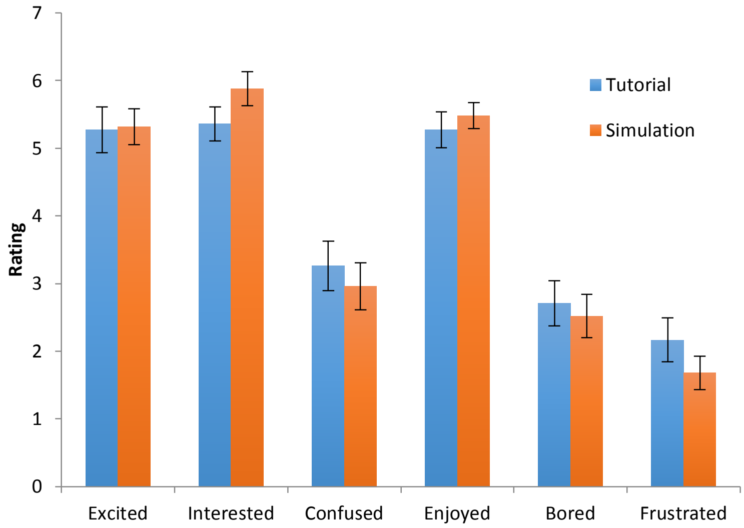

Figure 8: Mean (SE) emotion ratings/10 post-session by condition

Discussion

The results from this second study differ to an extent those of Dalgarno (2014). In this case, we did not find a significant difference in performance between the tutorial and simulation conditions, which also did not extend to a deeper analysis on the differences between participants who used a systematic as opposed to a non-systematic approach. These were not the main areas of focus for the current study so a failure to replicate this previous work is not of concern in this instance. Overall, there were some differences in post-hoc reports of experienced emotions during the session but these also proved not to be statistically significant. What is of interest in this study is that, despite there being negligible differences between the conditions in performance, there was a marked difference in the pattern of responses during the session compared to study one. This is a finding we will delve into further in the general discussion.

General Discussion

The two studies presented here were attempts to investigate the interplay between emotion, confidence, perceived understanding and prior knowledge in digital learning environments. The first study used a module that included content that was broadly unfamiliar to the participants who volunteered. Participants reported being simultaneously confused, excited and interested in the study but reported relatively low levels of confidence and a high degree of challenge. While performance improvements in study two followed a similar pattern to those in study one (i.e. the mean scores improved from pre-test to post-test but did not approach ceiling), the responses to perceived challenge and confidence were vastly different between the two studies. As the performance improvements did not appear to differ markedly between the studies, it suggests that prior knowledge influences confidence and perceived difficulty of the learning but may have little impact on student capacity to learn new material. This has implications for the role of confusion and confidence in learning. Prior knowledge could seemingly mediate whether students find the material challenging and feel confident in dealing with it but this judgement could be false. Given that participants in study one felt less confident and reported that they found the module challenging in comparison to the participants in study two but still significantly improved their performance between pre-test and post-test, perhaps they underestimate their capacity for absorbing the new material. Perhaps this feeling is related to them finding the material confusing and attaching a negative value on that experience. Further work is required to determine how these factors contribute to the judgements students make while engaged in the learning process.

Across the two studies reported, it is also evident that the combination of emotional reactions to the modules participants worked through are varied and complex. This is perhaps not surprising given that emotional aspects of the learning process are difficult to investigate (Immordino-Yang & Damasio, 2007). Further studies in this program of research will focus on a wider range of digital learning environments and different methods that will give a fuller picture of the interaction between subjective experience and prior knowledge and the effect of this interaction on learning. For example, in addition to the audit trail data relied upon in the current study to examine behaviour, psychophysiological measures such as facial electromyography (EMG; e.g. Hussain, AlZoubi, Calvo & D'Mello, 2011) and electroencephalography (EEG) can be used as more objective measures of emotional arousal than are available through self report.

Conclusions

The results we obtained across the two studies presented here could be so for many reasons. As we discussed in the introduction, there is a renewed emphasis on the role of emotion and subjective experience in education. One of the reasons why these factors had previously not received as much attention as they are now is because emotion is complex and varies greatly between individuals. Studying emotions like confusion in relation to confidence, understanding and prior knowledge in digital learning environments is thus a difficult exercise. Our aim with these studies was to make an initial foray into the area by attempting to employ mixed methodologies gleaned from the disparate paradigms of psychological science and educational technology. While this research perhaps raises as many questions as answers, the studies described here provide a solid foundation for further work on the role of prior knowledge, confidence and understanding in learning. What is most evident from these studies is that the interplay between these factors is complex and will require a multidimensional approach to reach conclusive findings that will provide categorical principles for guiding the design of digital learning environments. If digital learning environments are to become truly adaptive and able to provide targeted and personalised scaffolding and feedback, a more complete understanding of these factors will be vital.

References

Bénabou, R. & Tirole, J. (2002). Self-confidence and personal motivation. *Quarterly Journal of Economics*, 117 (3), 871-915. doi: 10.1162/003355302760193913

Calvo, R. A., D'Mello, S., Gratch, J., & Kappas, A. (Eds.). (2014). *The Oxford handbook of affective computing*. Oxford, UK: Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199942237.013.040

Cordova, J. R., Sinatra, G. M., Jones, S. H., Taasoobshirazi, G., & Lombardi, D. (2014). Confidence in prior knowledge, self-efficacy, interest and prior knowledge: Influences on conceptual change. *Contemporary Educational Psychology*, *39*(2), 164-174. https://doi.org/10.1016/j.cedpsych.2014.03.006

Dalgarno, B., Kennedy, G., & Bennett, S. (2014). The impact of students' exploration strategies on discovery learning using computer-based simulations. *Educational Media International*, *51* (4) 310-329. doi: 10.1080/09523987.2014.977009
D'Mello, S., & Graesser, A. (2012). Dynamics of affective states during complex learning. *Learning and Instruction*, *22*(2), 145-157. https://doi.org/10.1016/j.learninstruc.2011.10.001
D'Mello, S. K. & Graesser, A. C. (2014). Confusion. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education*. New York: Routledge.
D'Mello, S. K., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction*, *29*, 153-170. https://doi.org/10.1016/j.learninstruc.2012.05.003
Dunlosky, J., & Rawson, K. A. (2012). Overconfidence produces underachievement: Inaccurate self evaluations undermine students' learning and retention. *Learning and Instruction*, *22*(4), 271-280.
Goswami, U. (2006). Neuroscience and education: from research to practice? *Nature Reviews Neuroscience*, *7*(5), 406-413. https://doi.org/10.1038/nrn1907
Graesser, A. C., Witherspoon, A., McDaniel, B., D'Mello, S. K., Chipman P., & Gholson, B. (2006). Detection of emotions during learning with AutoTutor. In R. Son (Ed.), *Proceedings of the 28th Annual Meeting of the Cognitive Science Society*. Mahwah, NJ: Erlbaum.
Hughes, S., Lyddy, F., & Lambe, S. (2013). Misconceptions about psychological science: A review. *Psychology Learning & Teaching*, *12*(1), 20-31.
Hussain, M. S., AlZoubi, O., Calvo, R. A., & D'Mello, S. K. (2011). Affect detection from multichannel physiology during learning sessions with AutoTutor. In*Proceedings of the The 15th International Conference on Artificial Intelligence in Education (AIED),* Berlin: Springer.
Immordino-Yang, M. H., & Damasio, A. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. *Mind, Brain, and Education*, *1*(1), 3-10.
Kennedy, G., Ioannou, I., Zhou, Y., Bailey, J., & O'Leary, S. (2013). Mining interactions in immersive learning environments for real-time student feedback. *Australasian Journal of Educational Technology*, *29*(2). doi:10.1234/ajet.v29i2.700
Kruger, J., & Dunning, D. (1999). Unskilled and unaware of it: how difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of Personality and Social Psychology*, *77*(6), 1121.
Lehman, B., D'Mello, S., & Graesser, A. (2012). Confusion and complex learning during interactions with computer learning environments. *The Internet and Higher Education*, *15*(3), 184-194.
Lester, F. K., Garofalo, J., & Kroll, D. L. (1989). Self-confidence, interest, beliefs, and metacognition: Key influences on problem-solving behavior. In D. B. McLeod & V. M. Adams (Eds.) *Affect and mathematical problem solving*. New York: Springer. https://doi.org/10.1007/978-1-4612-3614-6_6
Lodge, J. M. (2015). Conceptual change in psychology: Why being confused is beneficial for learning. *50th Australian Psychological Society Conference, Gold Coast, Australia.*
Lodge, J. M. & Kennedy, G. (2015). Performance and emotional responses in simulation versus tutorial style learning. *Australasian Experimental Psychology Conference, 2015, University of Sydney, Sydney, Australia.*
Pekrun, R., & Linnenbrink-Garcia, L. (2014). *International handbook of emotions in education*. London: Routledge. https://doi.org/10.4324/9780203148211
Roll, I., Aleven, V., McLaren, B. M., & Koedinger, K. R. (2011). Improving students' help-seeking skills using metacognitive feedback in an intelligent tutoring system. *Learning and Instruction*, *21*(2), 267-280. https://doi.org/10.1016/j.learninstruc.2010.07.004
Rozin, P., & Cohen, A. B. (2003). High frequency of facial expressions corresponding to confusion, concentration, and worry in an analysis of naturally occurring facial expressions of Americans. *Emotion, 3,* 68–75. https://doi.org/10.1037/1528-3542.3.1.68

Notes: The authors wish the thank Michael Lew and Terry Judd from The Department of Medical Education at The University of Melbourne for their invaluable assistance in setting up the experimental protocols used in these studies. The Australian Research Council provided funding for this work as part of a Special Research Initiative for the ARC-SRI Science of Learning Research Centre (project number SRI20300015).

Lodge, J. M. & Kennedy, G. (2015). Prior knowledge, confidence and understanding in interactive tutorials and simulations. In T. Reiners, B.R. von Konsky, D. Gibson, V. Chang, L. Irving, & K. Clarke (Eds.), *Globally connected, digitally enabled*. Proceedings ascilite 2015 in Perth (pp. 190-201)

https://doi.org/10.14742/apubs.2015.973

Note: All published papers are refereed, having undergone a double-blind peer-review process.