INVESTIGATING THE EFFECT OF PROCESS-ORIENTED WORKED EXAMPLES IN A GAME-BASED PROBLEM-SOLVING ENVIRONMENT ON KNOWLEDGE-ACQUISITION AND TRANSFER

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This paper is dedicated to all of you. I am because you are.

Sharanya

Abstract

A long-standing question in the field of game-based learning (GBL) is that of knowledge-transfer, or how to enable players to apply what they have learned in gameplay to other contexts in real life (Girard et al., 2013; Perkins & Salomon, 1992). Given the parallelism of games and problem-based learning, previous studies have attempted to answer this question by adding worked examples (depictions of step-wise problem-solving procedures) to GBL environments with limited success. It was hypothesized that adding process-information would overcome the shortcomings of conventional worked examples and result in knowledge-acquisition and transfer. To investigate this, two versions of a game-based problem-solving environment (one with process-oriented worked examples and one without) were developed and tested on a sample of university students (N=49); the results matched our expectations. The findings of this study not only add to the current knowledge base on instructional support for games but also have implications for the design of effective process-oriented worked examples.

Keywords

Process-oriented worked example, game-based learning, transfer, knowledge-acquisition

Introduction, Problem Statement and Conceptual Framework

Games have probably been around since the beginning of humankind , yet it is the last couple of decades that have seen a steep rise in interest in game-based learning (GBL) (Oliver, 2017; Wouters & van Oostendorp, 2013). GBL is the use of games for learning purposes – this can include the use of off-the-shelf commercial games in an educationally-relevant way or games specifically designed to educate (van Eck, 2006). A game in turn, may be defined as an activity involving one or more players, that takes place in an interactive and competitive (even if the competition is with one's self) environment within a framework of agreed rules and constraints to meet a challenging goal (Dempsey, Haynes, Lucassen, & Casey, 2002; Leemkuil, 2006; Craig, 2003; Prensky, 2001). GBL is based on the premise that games are fun and hence offer captivating experiences for learners (McGonigal, 2011). In fact, research shows that playing educational games can have a positive effect on learner motivation and engagement (Rosas et al., 2003) This makes GBL a powerful learning methodology. Consequently, it has drawn the interest of both practitioners and the scientific community.

However, the outcomes of research investigating the effectiveness of game-based learning environments (GBLEs) on learning outcomes are inconclusive (Bakhuys Roozeboom, Visschedijk, & Oprins, 2017; Clark, Tanner-Smith, & Killingsworth, 2016; Girard, Ecalle, & Magnan, 2013). A point that has often been raised is that of transfer of learning, or the ability to use one's knowledge in a related or different context (Girard et al., 2013; Perkins & Salomon, 1992). Studies show that learners often find it difficult to apply learning gained through game-play to the real world. This is a major drawback and over the years, researchers have attempted to overcome it in various ways. One widely used approach is that of supplementing GBL with explicit instructional support that might aid transfer. Past studies have included the investigation of the impact of support such as metacognition strategies, feedback, provision of hints etc, but have met with limited success (Wouters & van Oostendorp, 2013). And so, the research community remains divided on what might be the most effective ways to support GBL, and the issue of transfer remains unresolved. Consequently, this necessitates further investigation into the matter and serves as the context for the present study.

Now, the point of departure for this investigation is the idea that one can draw parallels between GBL and problem-based learning (i.e. learning by working through a problem). According to Chang, D'Zurilla and Sanna (2004), effective problem-solving can be seen as comprising of the following steps: a) the definition and construction of the problem space, b) generation of possible approaches/solutions, c) comparison of the different approaches/solutions and decision-making, d) implementation of a solution and e) evaluation of the outcome. These very elements double as game-play in most GBL environments, where the player is generally given well-structured rules to solve a possibly ill-structured problem with an unknown outcome, through one of multiple pathways to the solution (Cicchino, 2015; Ebner & Holzinger, 2007). Therefore, several researchers agree that games provide a germane environment for problem-solving (Kim, Park, & Baek, 2009). In fact, Kiili (2005) states that games themselves may be seen as big problems that are "composed of causally linked problems". Consequently, one might deduce that instructional support in GBL that also effectively complements problem-solving would be beneficial to learners**,** thus building the case for the proposed intervention: process-oriented worked examples (PoWEs).

The plan to study the effects of PoWEs builds on past research on the use of worked examples (WEs) as a form of instructional support in GBL environments and elsewhere. Conventionally, WEs are a representation of an expert's problem-solving procedure; they contain the problem, final solution and steps taken to arrive at this solution (Atkinson, Derry, Renkl, & Wortham, 2000; Booth, Mcginn, Young, & Barbieri, 2015; Sweller, 2006; Sweller & Cooper, 1985). Previous studies with worked examples in other domains have shown that they can improve transfer, especially among novice learners (Atkinson, Renkl, & Merrill, 2003; Atkinson & Renkl, 2007; Sweller & Cooper, 1985) and it is believed that support such as WEs can add value to GBLEs for reasons such as the following:

Firstly, games are generally complex environments; this needs to be taken into consideration while planning for instructional support for GBL. For instance, learners often find it difficult to discern learning content in games because it is ordinarily masked by other (distracting) elements (for example, gameplay or narrative) (ter Vrugte et al., 2017). Another challenge is that games often have multiple goals and learners often have difficulty in distinguishing between goals of the game and learning goals (Oyen and Bebko 1996). In their meta-study, Wouters and van Oostendorp (2013) find that instructional support that helps learners select relevant content can improve learning, and one such support is worked examples. Worked examples focus only on information related to the learning task and can thus focus the learner's attention (ter Vrugte et al., 2017). Secondly, the notion of GBL emphasises player-experiences such as experimentation and trial and error (Kirriemuir &

Mcfarlane, 2004). This can mean that learners resort to such practices to arrive at the correct solution without actually learning. WE-steps provide learners with the correct approach, that learners can study and emulate. This allows the learner to apply a tested approach, rather than shooting in the dark.

However, research with WEs in the domain of GBL has yielded mixed results for transfer (Lang, 2007; Shen & O'Neil, 2006; ter Vrugte et al., 2017). To explain why this may have happened, we turn to previous studies in process-oriented worked examples and designing instructional design for GBL, as discussed below.

Firstly, van Gog, Paas and van Merriënboer (2004) note that problem-solving a recurrent task requires one to simply identify the steps within the problem domain and hence have a narrow problem space. Whereas, non-recurrent tasks have multiple paths possible and this requires a strategy to 'narrow the search space' and 'select' steps to arrive at the solution, i.e. one has to know how to choose an optimum solution path. In other words, when there is only one way to solve a problem, the end goal can be achieved simply if one knows the procedure. But, if there are multiple ways to solve a problem (which is normally the case in games), the learner needs to know how to choose the best approach (Ebner & Holzinger, 2007; Cicchino, 2015). In this line of reasoning, one can also surmise that for effective problem-solving , the learner should be able to make use of domain knowledge ('if-then' rules) for recurrent aspects of performance and be able to use judgement to interpret this knowledge in the case of non-recurrent aspect (van Merriënboer, 2013). In other words, 'understanding', or the knowledge involved in the process is essential to the task of problem-solving and transfer to a new problem-space; procedural-knowledge alone does not suffice (Ohlsson & Rees, 1991; van Gog et al., 2008). In games, players are expected to display a certain level of astuteness while solving ill-structured problems. Most such problems cannot be solved with just the knowledge of the 'if-then' rules and there is often a need for know-how (that comes with experience or expertise) to take non-recurrent decisions. This here is the limitation when using conventional WEs that provide only procedural knowledge in GBLEs.

Secondly, GBL makes profit of experiential learning in the sense that learners learn by doing (van der Meij, Leemkuil, & Li, 2013). This experiential learning leads to learning that is generally implicit (ter Vrugte & de Jong, 2017). Research finds that this implicit learning gained during gameplay does not necessarily result in explicit knowledge (on knowledge or transfer tests), which is what instructional support in GBL should aim to foster (Leemkuil, 2006). Now, knowledge can be made explicit by an intervention itself (direct instruction) or by eliciting explanation from the learner (self-explanation) and past studies find that not all learners (especially those with low experience or domain knowledge) are capable of this self-explanation (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Renkl, 1997; ter Vrugte et al., 2017; Vandercruysse et al., 2016). This applies to conventional WEs which require students to self-explain the logic behind choosing a problem-solving approach and the rationale for a step.

This study seeks to address the limitations of WEs in GBL by adding process-information to the intervention (and is in response to a call for future research by ter Vrugte (2016)). 'Process-information' may be described as an expert's problem-solving process or rationale: a combination of a) principled information (the accepted rules and concepts of a problem-space on which predictions and actions are based), b) the purpose of an action (what it means to take a particular step while solving a problem), and c) expert-strategy (why an approach was chosen)(van Gog, Paas, & van Merriënboer, 2006; van Gog et al., 2008). Consequently, it is suggested that by explicitly providing procedural information and reasoning, PoWEs limit the need to self-explain, and foster knowledge-acquisition and transfer, particularly in novice-learners (ter Vrugte, 2016; van Gog et al., 2004).

Now while some studies in other domains partially or fully corroborate the notion of PoWE-effectiveness (Brooks, 2009; van Gog et al., 2006, 2008), there are some that do not (Darabi, Nelson, & Palanki, 2007; Hoogveld, Paas, & Jochems, 2005). We find that shortcomings in research or instructional design (discussed in various sections of this paper) may explain the unsatisfactory results of many of these studies and also seriously limit their generalizability. Moreover, the scarcity in literature on this topic especially in the context of GBL means that we find merit in investigating this line of thought and testing the veracity in the theory that PoWEs can facilitate transfer.

Present Study

The present study was conducted with students of the University of Twente, a research university in the Netherlands. It employed a game-based problem-solving environment called 'Agent Monde: Operation Logic' (described in the 'Methods' section) which was designed to help students learn the fundamental concepts of logic gates and combination circuits in electronics and evaluate the effectiveness of in-game instructional support in the form of process-oriented worked examples. A value-added approach was employed to test the generalizability of the theory i.e. two versions of the game were compared: a standard-design (play-only) and a version augmented with instructional support (worked example before play) (Clark et al., 2016).

The key research question of this study was:

Do process-oriented worked examples in a game-based problem-solving environment effectively support knowledge-transfer?

This encompassed a sub-question:

Do process-oriented worked examples in a game-based problem-solving environment effectively support knowledge-acquisition?

Following the line of reasoning detailed above, two hypotheses guided this study: Hypothesis 1: *Learners who received process-oriented worked examples would display greater acquisition of knowledge than those who did not receive this support.*

Hypothesis 2: *Learners who received process-oriented worked examples would display greater knowledge-transfer than those who did not receive this support.*

Methods

Research Design and Method

A Post-test Only Control Group design was adopted for this study. Such a design would prevent an over-estimation of the effects of the intervention due to practice or pre-test sensitization (Frey, 2018). The independent variable PoWE-support is binary with values 'absent' (for the control condition) and 'present' (for the experimental condition). The dependent variables are the acquisition and transfer of knowledge; both are ratio variables. Knowledge-acquisition refers to understanding the why, what and how of the problem-solving process and being able to apply this knowledge in the same problem-space as that of the game, whereas knowledge-transfer is conceptualised as being able to apply this acquired knowledge to a) a different domain, and to b) a different problem category in the same domain (Amer, 2006; van Gog et al., 2004; Anderson, & Krathwohl, 2001).

The study used a mixed methods approach. While both quantitative and qualitative data were collected simultaneously, the qualitative data played a supportive role to the primary data (quantitative) (Creswell, 2013). The dependent variables were measured using a post-test (quantitative research); additional information that could be used to glean deeper insight was collected through semi-structured interviews (qualitative research).

Participants and Sampling

Forty-nine bachelor's and master's students aged between 18 and 39 years (M= *22.26*; SD= *4.68*)[1] at the department of Behavioural, Management and Social Sciences (BMS) volunteered to participate in this study. Students of this department were approached because most of them do not have a background in electronics. The sample consisted of 37 Psychology, 9 Educational Sciences, 1 Communication Sciences and 2 Business Administration students. Of these, 14 were males and 35 females. Two participants self-reported high prior knowledge in the game's domain (see 'Materials' section); conveniently, they happened to be in different test-conditions. Bachelor of Psychology Students were registered on the SONA system and received 1.25 course credits for participation in the study. All participants had sufficient computer and English skills. Participants were randomly assigned to the conditions; a balanced gender-division was found.

Materials

Domain. Process-oriented worked examples are most effective for learning of complex cognitive tasks (that include recurrent and non-recurrent components); this validates the usefulness of adding strategic information (van Gog. et al, 2004). Therefore, the concept of logic gates and circuits (electronics) was chosen as the domain for the problem-solving task. This is because solving circuits requires complex cognitive skills that consist of multiple related skills (such as knowing how each logic gate works, selecting correct input combinations to obtain a specific output or tracing multiple combinations of logic gates to conclude the output).

The game. The self-developed game 'Agent Monde: Operation Logic' is based on the concept of logic gates and combination circuits and is targeted primarily at high school or university students without a background in electronics. It is designed to be played individually.

Design & development. The game was developed on the graasp.eu[2] authoring platform, uses circuitry created on a freely available online simulator called 'The Logic Lab' (Appendix A) and contains images and videos in compliance with Creative

[1] The ages of two participants were not registered in the system.
[2] This platform was chosen to comply with the data location requirements of the EU General Data Protection Regulation (GDPR) enforced on 25 May 2018.

Commons License. While it can be played on any internet browser, the simulation itself requires the installation of the software, Adobe Flash Player.

It was developed using a rapid prototyping process (Jones & Richey, 2000; Tripp & Bichelmeyer, 1990) in consultation with a high-school electronics teacher. Keeping the target audience into consideration and keeping away from gaming-stereotype, the game does not feature explicit language and is gender-, race- and age-neutral (Mitchell & Savill-Smith, 2004). It draws heavily from several GBL design guidelines (Cicchino, 2015; Malone, 1983; Prensky, 2001; Wilson et al., 2009). For instance, one design guideline is the need for one or more learning objectives. In the present study, the game had multiple learning goals, namely that students would be able to, a) recognize, recollect and understand the rules of the NOT and AND logic gates, and while applying this knowledge, b) use correct input values to get a particular output in a combination circuit, d) determine the output of a combination circuit, given a set of inputs. Another example is the fantasy storyline which is an important component of the game- the learner is given the role of a secret agent charged with a secret mission to retrieve a treasure of great importance. He/she must enter a heavily-guarded safehouse and crack codes to retrieve this treasure without setting off any alarm that may expose his/her presence. Such a narrative generates learner-interest, helps students connect prior knowledge to the new learning and provides an immersive learning environment (Barab et al., 2009). A frequently suggested guideline that was however consciously ignored was that of allowing collaborative learning through social-interaction of players. This was to ensure consistency in participant-experience for the sake of the study.

The circuits themselves were designed in such a way that there would be multiple possible ways of arriving at a solution, thus warranting the use of process-oriented worked examples (van Gog et al., 2004).

Game-structure and game-play. The game consists of three levels or combination circuits (involving NOT or/and AND gates) that get progressively more complex (figure 1). (This is in alignment with a GBL design guideline that we consider fairly more relevant to the problem-solving aspect of the study: scaffolding the difficulty of game-challenges (Prensky, 2001)). Players are expected to solve each circuit (or in terms of gameplay, crack the code of the lock) before advancing to the next one. The game ends when the codes to all the locks have been found. A link to the game can be found in Appendix A.

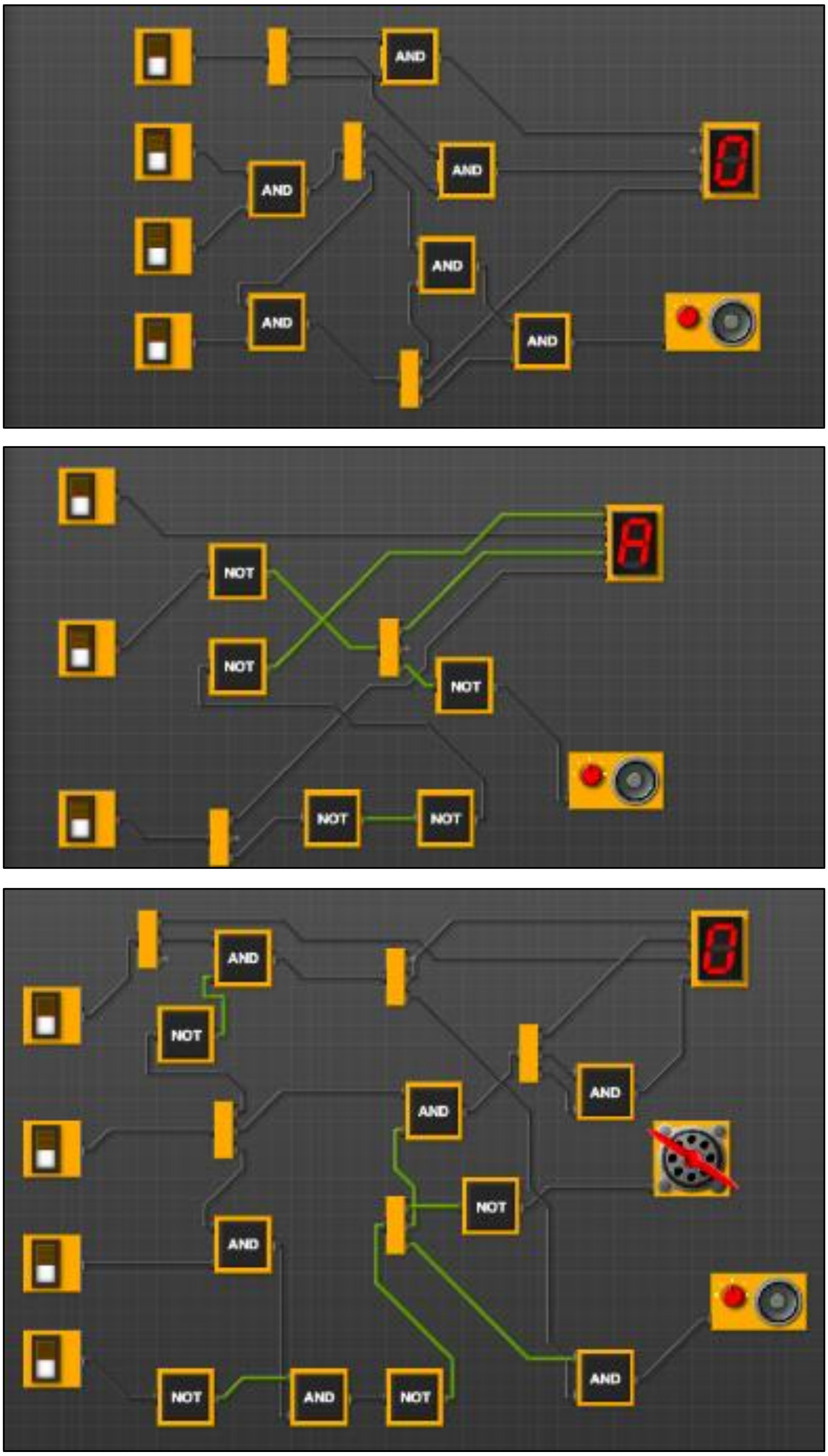


Figure 1. The three combination circuits or levels of the game (in order)

A note on game-progression: An observation from some previous GBL studies is that since game-progression generally requires a learner to complete the learning tasks at each level, players who are unable to do so, do not get exposed to new domain information present in subsequent levels (Ke, 2008). Thus, testing their knowledge on those topics is purposeless. Therefore in the present study, a conscious design-decision was taken to ensure that all study-participants had access to the same amount of domain knowledge: At each level of the game, it is possible to arrive at the solution after a few rounds of trial-and-error; this means that players can progress through the different levels even if they do not meet the learning objectives.

Instructional support in the two versions. Both versions of the game contain an instructional video that introduces them to the concept of 0s and 1s in computers, the elements of the combination circuits present in the game and the logic gates involved. Additionally, features such as demonstration circuits and partially-filled truth tables ensure that learners using the control version have access to all the information necessary to construct learning through interaction with the game environment (see figure 2). Players are encouraged to make use of these tools but doing so is optional. The experimental version of the game provides additional instructional support through three process-oriented worked examples. Therefore, this instructional video acts as a pre-training for learners by familiarising them with the names and some characteristics of the main concepts described in the worked examples (Mayer, 2014, Pre-training principle).

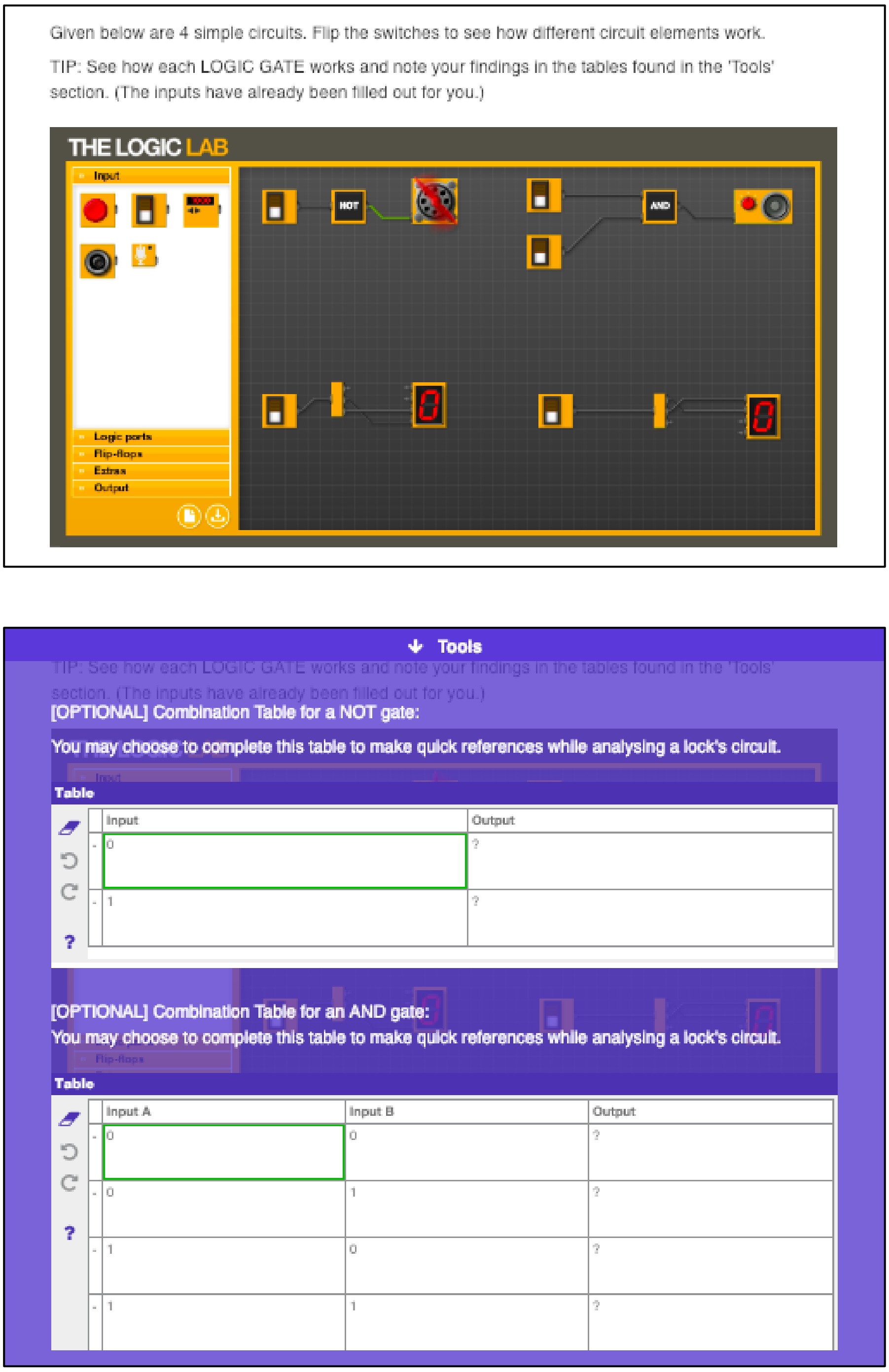


Figure 2. Demonstration circuit and partially-filled truth tables available in both game-versions

Process-oriented Worked Examples. The experimental version of the game contains three process-oriented videos. Here we discuss key characteristics of this intervention and the research that guided its development:

Format. As with the GBLE, the PoWEs too were developed using a rapid prototyping process (Jones & Richey, 2000; Tripp & Bichelmeyer, 1990). Usability testing during the development process showed that when users were provided text-based PoWEs, they found the GBLE extremely text-heavy and hence missed a lot of important information. Consequently, this study employs the use of PoWEs in a video-format. The PoWEs are embedded YouTube videos that allow for user-control (a 'slider bar' that allows viewers to move to any point in the video, a pause/play button and the options to speed up or slow down the video). Such functionalities that enable learner-control has been shown to be more beneficial for learning than system-pacing (Hasler, Kersten, & Sweller, 2007). This is an improvement from a previous study on the effect of PoWEs that utilised a unidirectionally linear video-format (Hoogveld et al., 2005).

Content. Content-creation was steered by guidelines on adding process-information to worked examples, an analysis of previously used PoWEs and research on facilitating problem-solving (Chang et al., 2004; van Gog et al., 2004, 2006). All the PoWEs are structurally similar and comprise of five steps that can be compared to the problem-solving process as described earlier by (Chang et al., 2004):

Step 1: Note down the rules of the logic gate(s)

Step 2: Identify crucial tasks, if any

Step 3: Choose a strategy to complete the task

Step 4: Identify path direction

Step 5: Apply the rules of the logic gate(s) to complete the task

In steps 1 and 2 the expert lists down the working of the logic gates that are present in the combination circuit and breaks down the problem statement to identify the key tasks, thus defining and constructing a problem space. In step 3, she compares different possible approaches and chooses one. Steps 4 and 5 comprise of orienting towards a problem-solving direction (forward or backward) and finally applying the domain principles and strategy. It is worth noting that feedback from the GBLE (for example, in the form of the game's alarm setting off or a code being accepted by the system) provides an evaluation of the outcome (Chang et al., 2004)

These steps are accompanied by a description of the domain principles being used, specification of the rules of thumb, reasoning behind an action taken and the expert's preferred approach (van Gog et al., 2004). Thus, the content of the PoWEs comprises of the 'what', 'why' and 'how' of the problem-solving process.

A noteworthy point here is that of fading. Studies with worked examples containing problem-solving procedures suggest that fading out steps little by little until the learner is problem-solving independently, elicits self-explanation and improves learning (Atkinson et al., 2003; Renkl, 1997). This is also one of the ideas van Gog et al. (2004) espouse. However, as discussed earlier, self-explanation is not a skill that we expect novice learners to display; therefore, it is decided to keep the content in the PoWEs complete and unfaded. It is expected that as a learner's skills and knowledge would increase, the amount of information they need would decrease and thus support would have to be adapted accordingly (Atkinson et al., 2003). But this is beyond the scope of the present study.

Design. Design guidelines (Appendix B) have been derived from related research on instructional support in GBL, an analysis of WE-design (conventional and process-oriented) in previous studies and guidelines on adding process-information to WEs and multimedia instructional support (Vandercruysse et al., 2016, Mayer, 2014; Arguel & Jamet, 2009; van Gog et al., 2006, 2008; Hoogveld et al., 2005; Chi, De Leeuw, Chiu, & Lavancher, 1994; Sweller & Cooper, 1985). For instance, breaking the problem-solving process into bite-sized segments (as illustrated above) makes it easier for learners to process this information (Mayer, 2014, Segmentation principle). Additionally, labelling these steps highlights the organization of the PoWE (Mayer, 2014, Signalling principle). Strategies such as this and encircling key points of interest, using arrows, colour (for instance, paths to be avoided in the problem-solving were marked in red and paths to be followed were coloured green) and animations act as visual cues for the learner to focus on key elements of the process; a cursor-spotlight is used to make movements noticeable (Mayer, 2014, Signalling principle). Related images are connected with lines and synchronising spoken and written text/pictures (Mayer, 2014, Spatial continuity principle). In accordance with design guidelines for WEs, all extraneous information is left out; so the PoWEs do not demonstrate how to actually find the digits of the code (a task that is solely related to gameplay and has no relevance to the learning goals) and focus only on solving the combination circuit(Chi et al., 1994; Sweller & Cooper, 1985). This decision also aligns with the coherence principle of designing multimedia instruction that postulates including only relevant material (Mayer, 2014). Other multimedia design principles taken into consideration are the voice, personalization and image principles: the narration is conversational and done in a human voice; the speaker's image is not added to the screen (Mayer, 2014). Moreover, Arguel and Jamet (2009) find that using static images limits the transient effect of animated videos. Therefore, the portion of the PoWEs explaining step 5 is accompanied by a static image of the rules of the logic gate (principled information), allowing the learner to make connections between the previously explained domain principles and the strategy-implementation being described in the step (Arguel & Jamet, 2009; Mayer, 2014, Temporal contiguity principle). (Another strategy employed to limit the effects of information-transience is listing all the process-steps at the end of the video.) Thus, the videos comprise of animation (to show actions to be taken, signal circuit-elements etc), spoken text and static pictures. This allows for effective integration of principled, process and strategic information (van Gog et al., 2004), multiple modalities of the information provided (Mayer, 2014, Modality principle) , and maintaining the 'depiction of micro-steps from the procedure and its natural development' (Arguel & Jamet, 2009). This is also in agreement with the multimedia principle that states that a combination of words and pictures is more effective for instruction than words alone (Mayer, 2014, Multimedia principle). It is worth noting that to further make the content of the videos explicit, they were prefaced with this text in the GBLE: "This video contains the a) domain principles, b) procedure and c) strategy involved."

Integration. There are two ways instructional support can be integrated with GBL – by incorporating it within the GBLE (internal integration) or offering it in addition to it (Vandercruysse et al., 2016). In a study investigating the impact of integration of conceptual information (a support that is very similar to PoWEs), Vandercruysse et al. (2016) found that learners who received internally integrated support performed poorly as compared to those who received externally integrated support. However, in their study, each conceptual clarification comprised of several steps and in the internal-integration version of the game, these steps were made visible only one at a time. Players were forced to click the 'next' button to continue and could not see the problem-solving process as a whole. Such a design also allows only limited control over how a user can view supportive information. We argue that this is a drawback in the design of the support and could have affected the study's outcome. Therefore, given the format of the PoWEs, we found merit in integrating them within the GBLE.

Placement. Each example corresponds to a circuit in the game that players are expected to solve and is consequently placed before the actual task. This is also in line with Tsai, Kinzer, Hung, Chen and Hsu (2013) who found it beneficial to provide learners with content-knowledge before and/or within a game so as to allow them to reflect on it during game-play. Secondly, previous research suggests that learners tend to ignore instructional support provided in games (Nelson, 2007). Hence, these PoWEs were positioned as an integral step within the gameplay, thus making it harder for players to ignore them.

Post-test. The test consisted of two sections (and can be found in Appendix C). The first corresponded to the dependent variable, 'knowledge-acquisition' and comprised of four questions (multiple-choice and open-ended). Of these, two tested understanding of the learning-content, for example, "What logic gate would I use to reverse my input?". The remaining two questions tested the learner's ability to apply their understanding in the same problem-space. Figure 3 shows an example of such a question.

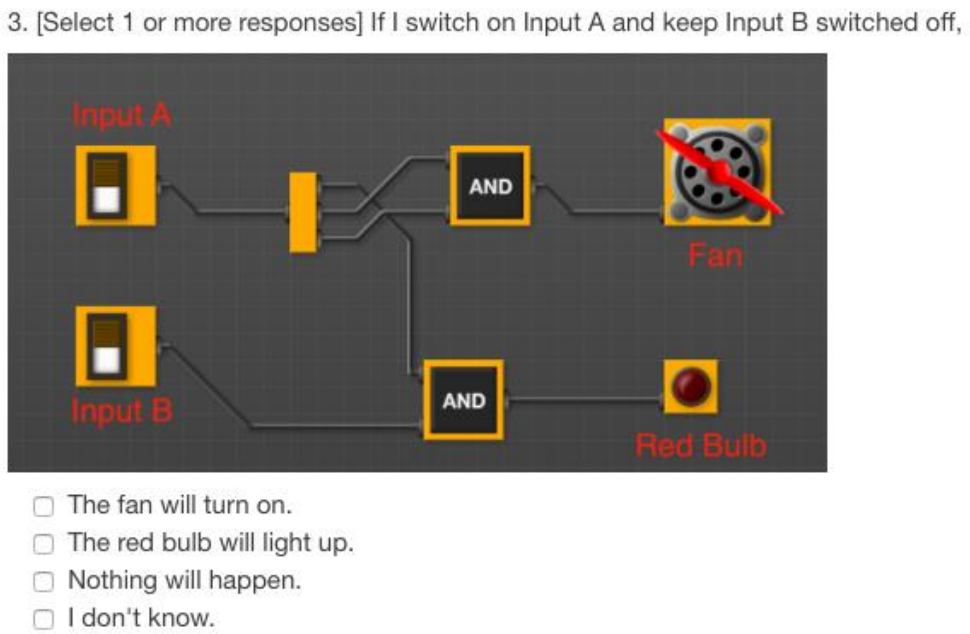
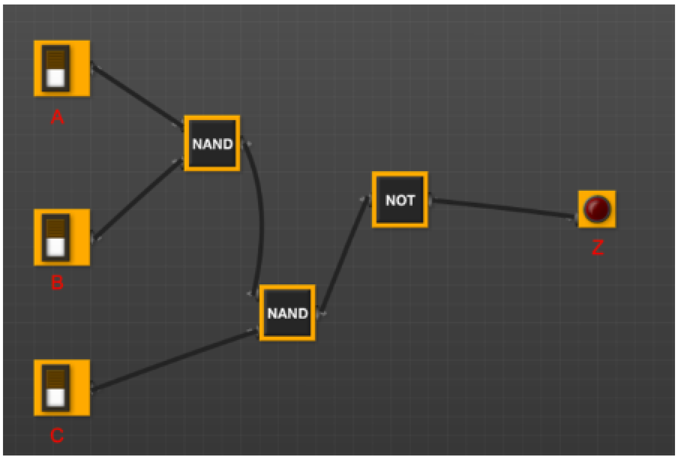


Figure 3. Post-test question that tests knowledge-acquisition.

The second section of the test consisted of seven questions that measured the second dependent variable, 'knowledge-transfer'. Of these, four questions tested the ability to apply acquired knowledge to a different problem-space in the same domain (question 9 in figure 4 shows an example). The remaining three questions tested transfer to a different domain (for example, question 11 in figure 4).

9. A NAND gate gives the opposite of an AND gate and can be seen as an AND gate followed by a NOT gate. For the figure below, mark whether this statement is true or false:Z=0 for A=0, B=0, C=1



- ☐ True
- ☐ False
- ☐ I don't know.

11. Halloween is here and as usual, clown-costumes are very popular. Unfortunately, my dog fears clowns. What is funnier is that it only barks when it sees **two** clowns in the room.

a) It did not bark when Fifi and Maurice entered the room.

b) It did not bark when it saw Maurice and Dani together.

c) It barked when it saw both Dani and Jo together.

d) It did not bark when it saw Fifi and Lola walk in together.

Select all the correct statements

- ☐ Fifi is in a clown-costume.
- ☐ Fifi is not in a clown-costume.
- ☐ Given data is insufficient to reach a conclusion about Fifi's costume.
- ☐ Lola is in a clown-costume
- ☐ Lola is not in a clown-costume
- ☐ Given data is insufficient to draw a conclusion about Lola's costume.

Figure 4. Post-test questions that test transfer.

In total, participants had ten minutes to complete all 11 questions. To limit guesswork, a note at the start of the test indicated that participants were expected to only respond to questions to which they knew the answers.

Interview questions. The interview was structured around a set of three guiding questions, namely: a) On a scale of 1 to 5 (1 being 'not confident at all' and 5 being 'extremely confident'), how confident does the participant feel about what they may have learned in the game, and why? b) What was the participant's game-experience? c) What was the participant's experience with the PoWEs? (For experimental condition only.)

The interview also included a probe into the participant's prior knowledge on the subject- whether they were familiar with the concepts of binary coding (i.e. 0 is 'off' and 1 is 'on') and logic gates, and if so, how much they had already known. This was in place of a pre-test.

Procedure

Ethics Committee Approval. Approval from the BMS (Behavioural, Management and Social Sciences) faculty's Ethics Committee was obtained at least a week prior to data collection.

Call for participation and communication with participants. Calls for participation were put out on various official and unofficial social networking platforms and the SONA system. Interested students signed up for a time-slot that was made available to them through the SONA credit system (Bachelor of Psychology Students) or an online form (other students). Depending on their preference, they then received an email or text message confirming their participation, followed by at least one reminder a few hours before the actual study.

The study. Each experimental study session consisted of the following elements:

Orientation. Participants received an overview of the process, an introduction to the gamified environment and general instructions (for example, to inform the researcher before they start the test and to keep their mobile phones on 'Silent') (see researcher's guidelines in Appendix D). They were encouraged to watch all the videos present in the game and follow the given game-progression. While participants were aware that the study investigated instructional support in game-based learning, they were not made aware of the kind of support or the condition they were assigned to. They then logged into the system with a unique user ID that they had been assigned and completed the consent form. This took no more than 5 minutes.

Game-play. Participants played the game on individual computers and were free to take notes during the game on a sheet of paper they had been given. The time allocated for this was a maximum of 50 minutes- players were expected to finish the game within this timeframe, failing which the researcher would ask them to stop.

Post-test. When a participant finished the game, (s)he informed the researcher. The researcher then set the timer and the participant proceeded to complete the post-test (10 minutes).

Interview. Participants engaged in a one-on-one conversation with the researcher (that was also recorded). Since the interview was semi-structured, the guiding questions (mentioned in 'Materials' section) were used to frame the conversation, while probing-questions were used to clarify details. For example, if a participant used the term "challenging" when asked to describe their game-experience or said that they found the PoWEs useful, the researcher would ask them what exactly they found challenging in the game or what elements of the PoWEs they found most value in. Similarly, while discussing gameplay, participants were encouraged to talk about the strategy they used. (approximately 5 minutes).

Close-out. Participants were asked not to discuss the details of the study with other students to ensure unbiased outcomes.

The role of the researcher during the gameplay and test was limited to supervision, procedural assistance (when required) and technical assistance when technology-related issues were encountered; this was done to ensure it was not a confounding variable (All, Nuñez Castellar, & van Looy, 2016).

Operationalisation of Variables and Scoring

Knowledge acquisition and transfer are operationalised as the scores received for the first four and last seven questions of the post-test respectively, hence each section of the post-test was scored separately. While the minimum score possible on either section was 0, the maximum was 4 points and 6.99 points for the first ('knowledge-acquisition') and second ('knowledge-transfer') sections respectively. The evaluation was done by two test-scorers to ensure that there were no flaws. The scoring key can be found in Appendix C.

Data Analysis

A total of 49 students participated in the current study. However, in 1 case, the game broke down and hence, the student could not complete it. In another case, the participant being colour-blind was unable to play the game or comprehend the videos. Therefore, these two cases were excluded, and only data of 47 participants was analysed.

The distributions of ‘knowledge-acquisition’ and ‘knowledge-transfer’ were found to be multimodal implying that they comprised of more than one distribution each. This was an indication of more than one distinct group for each variable. So, both investigated variables were measured condition-wise. Normality tests on ‘knowledge-acquisition’ for the control condition revealed moderate skewness of 0.737 (*SE*= 0.481) and near-normal kurtosis of -0.125 (*SE*=0.935). ‘Knowledge-acquisition’ for the experimental group displayed high skewness of -1.109 (*SE*=0.472) with a large kurtosis of 1.128 (*SE*=0.918). ‘Knowledge-transfer’ for the control group was found to have moderate skewness of 0.949 (*SE*=0.481) with near-normal kurtosis of -0.315 (*SE*=0.935). ‘Knowledge-transfer’ for the experimental group showed moderate skewness of 0.688 (*SE*=0.472) with kurtosis of -0.892 (*SE*=0.918). Regardless, given that sample size n>40 and each group has over 15 participants, the sample was considered ‘large enough’ to conduct parametric tests (The Minitab blog, 2015; Veaux, Velleman, & Bock, 2014).

Levene’s test for ‘knowledge-acquisition’ indicated equal variances (F = 0.043, p = 0.836), therefore a pooled sample t-test was performed. Whereas, Levene’s test on ‘knowledge-transfer’ indicated unequal variances in the two groups (F = 5.107, p = .029), so degrees of freedom were adjusted from 45 to 42 and an independent samples t-test was performed. Given the range of scores possible on the post-test, existing participant-scores and the sample size, the outliers were deemed plausible and were hence not removed.

Results

Table 1 summarizes the descriptive statistics, per condition, for the participants' test scores on the variables ‘knowledge-acquisition’ and ‘knowledge-transfer’.

Table 1. Condition-wise descriptive statistics for ‘knowledge-acquisition’ and ‘knowledge-transfer’ scores on post-test

Test-Section/Variable	Control condition (n=23)		Experimental condition (n=24)	
	M	SD	M	SD
Knowledge-acquisition	1.66	1.11	2.84	1.16
Knowledge-transfer	2.37	1.27	3.58	1.74

Effect of PoWEs on knowledge-acquisition

The pooled-samples t-test indicated that scores were significantly lower for the control condition (M = 1.66, SD = 1.11) than for the experimental (M = 2.84, SD = 1.16), t(45) = -3.547, p = 0.001, d = 1.035.

Effect of PoWEs on transfer

The independent-samples t-test indicated that scores were significantly lower for the control condition (M = 2.37, SD = 1.27) than for the experimental (M = 3.58, SD = 1.74), t(42) = -2.78, p= 0.009, d = 0.79.

Interviews

In this section, we present different samples of participant-interviews[3] to shed light on the quantitative results. Firstly, it was noted that when asked how confident, on a scale of 1 to 5, they felt about what they might have learned through the game, 21 experimental group participants and 10 control group participants reported a 3 or higher. Below, is an illustration of participants' experiences with the game (and PoWEs, in the case of the experimental group):

Control-condition. Participants in this condition were expected to unriddle learning objectives through exploration and observation, as is illustrated in the following interview-samples:

> Participant ID 428: "I didn't have the knowledge. I think when I first saw the circuits, I still didn't know how they worked - what would the switch represent. Would I tell myself 1 is on and off is 0? And when I was progressing in the game, I realised Yes, that's what I had to do…At the beginning it [the approach] was hitting all the switches, but then seeing *[sic]* which gates were connected to the alarm. From there I would go back and see what switches were connected to it."
>
> Participant ID 447: "Sometimes I didn't get the logic right away. But with a little bit of time, I understood it very well…It took time to understand the logic behind it- what I can do and how it works. In the first round, I just clicked around; I didn't know what I was doing. But in the second and third round, it got pretty well *[sic]*, and then I understood that I just have to follow the lines to control what's happening."

[3] Forty-six participants were interviewed- 23 control and 23 experimental.

While these two participants did report being able to uncover learning-content (both answered 3 of the 4 ‘knowledge-acquisition’ questions correctly), there were others who were less successful. For example, participant ID 422 stated, “After the third simulation, I understood it [the game] better, but it finished. I think I got it but not in a really good way… [I got that] in the NOT, there is one input and one output and [in] the AND there is [*sic*] two inputs and one output.” While what this learner has understood is correct, it is hardly the key concept.

Next, it was also gathered that not all participants in this condition were successful in extricating learning objectives from gameplay. For instance, participant ID 414 reported, “During the game I wasn’t really paying attention to the logic gates. Just during the test *[sic]*, I noticed that that was the important bit.” Similarly, participant ID 438 noted, “I was writing which switches are on or off…I did not looked *[sic]* at AND or OR…As I said, I did not look at AND or NOT and the [test] questions were mainly about that.”

Finally, 13 of the 23 control condition participants reported employing hit-or-miss methods to arrive at the solution. For instance, participant ID 455 stated: “I just pressed stuff and was trying to make sense of it but couldn’t”.

Experimental-condition. Firstly, it was observed that the general perception of the learners in this condition was that the PoWE-support was useful. While all experimental-condition participants found value in at least one element of the support, twenty-one of the twenty-three experimental-condition participants interviewed, reported finding both, procedural and process information in the worked example as useful. As participant ID 433 put it, “[It was useful] seeing it [the problem-solving] before having to do [it] myself…seeing where I could press without setting off the alarm, by seeing you [the expert in the video] do it.” Moreover, all but three of these participants reported employing the problem-solving strategy described in the PoWEs. As participant ID 449 who observed, “I just followed the strategy of the video...because it was the most logic [*sic*] one, and the easiest one”. The exceptions included a participant who thought that she was expected to use a novel strategy in the game, another who wanted to explore and try for himself and the third who felt that she had already thought of the strategies before they were introduced.

Discussion

The aim of the current study was to investigate the effectiveness of instructional support in the form of process-oriented worked examples in a GBLE based on the topic of logic gates and combination circuits for university students. It was found that on average, learners who received PoWEs displayed greater acquisition of topic knowledge than those who did not receive this support. The intervention generated a Cohen's *d* of 1.035 which may be deemed as a large effect. Secondly, it was found that learners with PoWEs were more successful in transferring learning from the game-based learning environment to another problem-space than learners who did not receive support. The difference in the mean scores on knowledge-transfer was found to be significant and generated a medium effect size of Cohen's d=0.79. These findings are in line with our expectations and indicate that PoWEs can indeed help improve game-based learning.

Reflections, Limitations and Recommendations

At this point, we find it relevant to revisit some literature that guided this investigation in an attempt to explain our findings. it had been suggested that PoWEs would help learners because they not only contain procedural steps but also the expert's problem-solving rationale, thus providing them with the conceptual understanding required for transfer (van Gog et al., 2004). As reported above, learner-perception seems to align with this theory. The interviews also seem to support the thought (as discussed earlier) that without support, it can be difficult for learners to extricate learning objectives from gameplay in a GBLE (ter Vrugte et al., 2017). These reasons may well explain why the control group on average had relatively low post-test scores than the experimental group.

Another line of explanation may be found by referring to Kiili (2005) who associates games and discovery learning: most GBLEs offer learners the opportunity to discover rules and ideas and manipulate objects in the game-world to test their hypotheses, thus discovering learning content through interaction with the game environment. In the present study, this holds true for the control version of the game where learners were expected to use the available tools and pieces of information to unriddle the domain principles through experimentation and derive meaning through their observations. This may be likened to unguided discovery learning and past studies suggest that such an instructional method is generally ineffective (de Jong & Lazonder, 2014; Mayer, 2004). (On the other hand, the experimental condition directly guided learners to the learning material and therefore cannot be equated to unguided discovery.)

This paper had also discussed that not all learners, especially those with low prior knowledge, are capable of producing correct self-explanations (Renkl, 1997; ter Vrugte et al., 2017; Vandercruysse et al., 2016). This can result in incorrect or incomplete understanding (Booth et al., 2015). On the other hand, the PoWEs explicitly discuss the functioning of the logic gates and path-directions while solving a circuit (input to output or output to input), leaving little need for self-explanation. It is inferred that this has played a role in the better learning outcomes of the experimental condition as compared to the control.

The results of this study corroborate our design-decisions for the instructional material. As discussed earlier, efforts were taken to mitigate the shortcomings of the worked examples used in previous studies. For instance, a drawback in the PoWE videos used by Hoogveld et al. (2005) was that the information was not explicitly verbalised and had to be extricated from expert-interviews. These interviews also contained information that was not directly relevant to the learning objective and the videos themselves offered no user-control. A design-flaw in the examples used by van Gog et al. (2006) was that they did not display an integrated view of text and pictures. These were some important points of consideration during the design of the PoWEs for this study. This might explain why PoWEs generated a positive effect on knowledge-acquisition and transfer in the present study, but not in the previous two. On the other hand, the examples in this study are structurally similar to those used by van Gog et al (2008), which could explain why the results of the two studies are in agreement. Clearly, this has implications for the design of effective PoWEs and future researchers are encouraged to bear in mind the importance of instructional design even if that may not be their studies' focus.

Though the overall effects of the intervention were positive and aligned with our expectations, it is essential to consider them in combination with other related research, while taking cognizance of the following limitations of this study:

Length of study. The game focuses on a very narrow topic in the field of electronics; therefore, a maximum playtime of 50 minutes was considered sufficient. This however, is relatively short as compared to the time players spend on games in the real world (days, if not months) and therefore might limit the generalizability of this study's findings (Loh, Sheng, & Ifenthaler, 2015). Secondly, the post-test was conducted immediately after gameplay. The scope of this study did not cover a delayed post-test; such a step could have provided valuable information on the long-term effectiveness of the intervention (such as knowledge-retention) and generalizability (Brooks, 2009).

Technical difficulties. While developing the GBLE, different applications to capture in-game performance and player-system interactions were embedded. The motive was to use the game log files produced by these applications to glean information such as time taken on each game-task, a player's movements along the game (for instance, whether he/she returned to a step), number of attempts to arrive at the correct solution, time taken per PoWE and the kind of interaction learners had with the PoWE videos (which parts were replayed and how many times). Unfortunately, due to technical glitches in the system, the log files were found to be inconsistent and unreliable and hence could not be used in the analysis. We believe that this data would have greatly enriched this study and recommend future researchers to pay special attention to collecting in-game data (All et al., 2016).

Post-test design*.* It is quite possible that participants who struggled in the first section of the post-test spent more time here and were hence unable to explore all the transfer questions. In retrospect, we feel that it would have been prudent to allocate time for each test-section separately to ensure that all participants spent the same time on each variable-measure. Secondly, it could be useful to know which questions a participant does not know the answer to and which he/she leaves unanswered due to time-constraints. In the present test, only five of the eleven questions explicitly offered the option to select "I don't know" from a list of answers. While some questions were not multiple-choice, test-takers could have been encouraged to mark the questions that they had read but did not know the answer to.

Researchers are encouraged to improve upon these elements for future studies.

Having said that, there are two significant aspects of this study that need to be noted in relation to previous research on PoWEs:

Firstly, it is crucial to note that the amount of information presented in the current study's PoWEs differs from that in previous studies, namely that in the expert-strategy component. While these studies agree that providing a reason for choosing a problem-solving approach is important, the older PoWEs do not actually explore or compare other paths for the learner to see why the chosen approach is the best fit (Hoogveld et al., 2005; van Gog et al., 2006, 2008). On the other hand, PoWEs in the present study listed out the approaches one could take and narrowed down to the most effective one, while providing learners with the explanation for the choice. This is in fact, a distinguishing feature of the present study. As one participant noted, “They explained very elaborately…what are the options I could do [*sic*]..and I think it was very handy as well that they put four different options and as this person [the expert] was explaining, they would scratch off what we shouldn’t do”. We believe that not providing learners with this crucial piece of information entails some self-explanation on the part of the learner (just as when only procedural information is provided) which may explain why some previous studies have not found PoWEs more effective than conventional WEs. However, further, and applied research is needed to investigate the strength of this claim.

Secondly, it is that in addition to concurring results on transfer, van Gog et al. (2008) also found that when learners’ understanding increased, the process information became redundant, and started to hamper learning. While there is no way of knowing whether this ‘redundancy’ actually impeded learning in the present study, the interviews do indicate (as was naturally expected when the decision to not fade the WEs was taken) that participants found the PoWEs repetitive and many resorted to skipping portions of the videos that they felt they had already understood.

It follows from above and Renkl (1997), that the ideal progression of support might be: unfaded process-oriented worked examples (such as the ones used in this study), followed by gradual fading of process-information to eventually arrive at conventional worked examples (with only procedural steps) that would in turn be gradually faded. Future research might explore such a sequence. Another interesting question worth exploring would be how to balance this instructional support with players’ inherent tendency to explore GBLEs (as illustrated in the ‘Results’ section by the responses of the three exceptional experimental-condition participants).

The last thought we would like to present is that of two factors that are deemed pivotal in knowledge-transfer, and their role in GBL: motivation and perceived utility of support (Grossman & Salas, 2011). Within GBL, motivation may be described as the “the initiation and sustainment of engagement in a particular task or behavior” and is positively related to knowledge-transfer (Tu, Sujo-Montes, & Yen, 2015; Grossman & Salas, 2011). It would be interesting to study whether learners who receive PoWEs feel more motivated to learn than those who do not receive this support. Next, it is suggested that it may be the perception of the instructional support and not the support itself that affects learning

(Grossman & Salas, 2011). In fact, Lowyck, Elen and Clarebout (2004) find that the effectiveness of games largely depended on the perception of utility by the learners themselves. This is a very interesting line of thought and future studies could look into whether learners' notions of the usefulness of PoWE-support in GBLEs does indeed affect their learning outcomes. We therefore proffer the value in investigating the role of learner-characteristics in determining the effectiveness of instructional support in GBL.

Conclusion

The rise in the global market for GBL products and services (it is predicted to cross 17 billion US dollars in 2023), gives good reason to both game-designers and researchers to find ways to improve learning through games (Adkins, 2018). One such improvement is the stimulation of transfer. The search for instructional support to effectively aid transfer in game-based learning is ongoing. Therefore, this study was an attempt to bring research one step closer to the answer. The aim of the present study was to investigate the effects of supplementing a GBLE with process-oriented worked examples on the acquisition and transfer of knowledge. Results indicate that such a support is indeed effective. These findings not only add to the current knowledge-base on GBL, but also provide interesting insights into design considerations for process-oriented worked examples.

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APPENDICES

Appendix A. URLs

1. The Logic Lab- http://www.neuroproductions.be/logic-lab/
2. Agent Monde: Operation Logic- https://www.golabz.eu/ils/agent-monde-operation-logic-a-game-to-learn-about-logic-gates-and-circuits

Appendix B. Narrowing down on design guidelines for PoWEs

Step 1: Common design guidelines for worked examples derived from van Gog et al. (2004), Chi et al. (2004) and Sweller and Cooper (1985):

1. The example should focus only at the task at hand and be directed towards the goal.
2. Distinguishing steps and sub-steps is important.

Step 2: Design guidelines for PoWEs compiled by van Gog et al. (2004) :

1. Use words and pictures.
2. Avoid split-attention i.e. integrate words and words, words and picture effectively. The 'How' and 'Why' information of the PoWE should be integrated.
3. Avoid redundancy of information.
4. Use multiple modalities (oral and visual) to present information.

Step 3: Comparison of guidelines with multimedia design principles (Mayer, 2014) as seen in Table 2.

Table 2. Design guidelines and related principles

Guideline	Related Principle (Mayer, 2014)
Use words and pictures	Multimedia principle
The example should focus only at the task at hand and be directed towards the goal.	Coherence Principle
Distinguishing steps and sub-steps is important.	Segmenting Principle
Avoid split-attention i.e. integrate text and text, text and picture effectively. The 'How' and 'Why' information of the PoWE should be integrated.	Spatial contiguity Principle Temporal contiguity Principle
Avoid redundancy of information	Redundancy Principle
Use multiple modalities (oral and visual) to present information	Modality principle

Stage 4: Analysis of previous PoWE designs

Previous designs were analysed on the basis of multimedia instructional design principles (Mayer, 2014). Some examples exemplified additional design principles and so these have been added to the list as well (see table 3).

Table 3. Analysis of previous worked examples

Design Principle	van Gog et al. (2004)	van Gog et al. (2006)	Hoogveld et al. (2005)	van Gog et al. (2008)
Coherence Principle	Y	Y	N (Authors mention 'noise' or information unrelated to task)	Y
Signaling Principle	Y	Y (Principled, procedural and strategic information is distinguished using different font-types)*	Y (Relevant material is zoomed into during the video presentation)	Y (Principled, procedural and strategic information is distinguished using different font-types)*
Redundancy Principle	Y	Y	?	Y
Spatial Contiguity Principle	Y	P (The procedural and strategic information is integrated but the text and pictures are not)	?	P (The procedural and strategic information is integrated but the text and pictures are not)

Table 3 (continued).

Temporal Contiguity Principle	Y	-	Y (While experts talk, their computer screen is displayed on the split-screen)	-
Segmenting Principle	Y	Y (There are sub-steps)		Y (Sub-steps are named)
Modality Principle	Y	-	Y (The video consists of expert-interview and powerpoint slides)	-
Multimedia Principle	Y	Y	Y	Y
Personalization Principle	-	Y	?	Y
Voice Principle	-	-	Y	-
Image Principle	-	-	N (Experts are seen talking)	-

Note: Y= Yes (i.e. example aligns with principle), N= No (i.e. example does not align with principle, P= partial alignment, '?' means that the paper does not provide sufficient information to make a decision, '-' means that the principle is not applicable for the corresponding example.

Guidelines derived:

1. Distinguish between principled, procedural and strategic information.
2. Signal key concepts
3. Highlight the organization of steps and use a common skeletal structure.
4. Present information in a conversational manner.

Step 5: Guidelines derived from the previously analysed literature (Hoogveld et al., 2005; van Gog et al.,2004,2006,2008) and literature on integrating similar instructional support in GBL (ter Vrugte et el., 2017; Vandercruysse et al., 2016):

1. The instructional support should allow user-control i.e. the learner should be able to access different points of the problem-solving process whenever he/she wants.

Step 6: User feedback with textual PoWEs indicated that they were very long (an observation made by van Gog (2006) as well) and this also lead to unsatisfactory integration of pictures and text. Therefore, a video format was chosen for the PoWE.
In addition to the design principles already listed above, Arguel and Jamet (2009) propose the combination of static and moving pictures to mitigate the transient effect of videos. Therefore, this was added to the list of guidelines.

Therefore, the final list of design guidelines is:

1. The example should focus only at the task at hand and be directed towards the goal.
2. Distinguishing steps and sub-steps is important; name the sub-steps.
3. Use words and pictures.
4. Avoid split-attention i.e. integrate words and words, words and picture effectively. The 'How' and 'Why' information of the PoWE should be integrated.
5. Distinguish between principled, procedural and strategic information.
6. Signal key concepts
7. Highlight the organization of steps and use a common skeletal structure.
8. Avoid redundancy of information.
9. Use multiple modalities (oral and visual) to present information.
10. Present information in a conversational manner.
11. The instructional support should allow user-control i.e. the learner should be able to access different points of the problem-solving process whenever he/she wants.
12. Use static images for key pieces of information.

A note on redundancy: van Gog et al. (2004) ask a pertinent question "Is the 'Why' information redundant if students are able to self-explain the procedure? " While we do feel this is the case, the present study is directed at novices and is testing the efficiency of non-faded PoWEs and therefore retains the ‘Why’ information.

Appendix C. Post-Test and Scoring Key

Post-Test

Thank you for playing Agent Monde: Operation Logic. I hope you enjoyed it.

The following is a set of 11 questions to test what you have learned. Please respond only to the questions for which you know the answers - do not employ guess-work.

NOTE: Once you start the test, please do NOT go back to previous tabs or the 'Tools' bar.

Quiz Tool

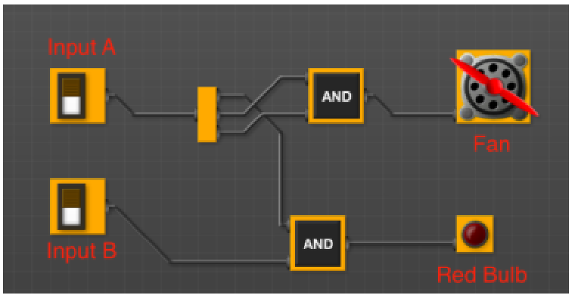
1. If two inputs A and B are connected to an AND gate that gives output C, what are all the possible combinations for inputs and outputs? [Additional rows will appear if you click outside a cell or hit ENTER]

Input A	Input B	Output C

2. What logic gate would I use to reverse my input?

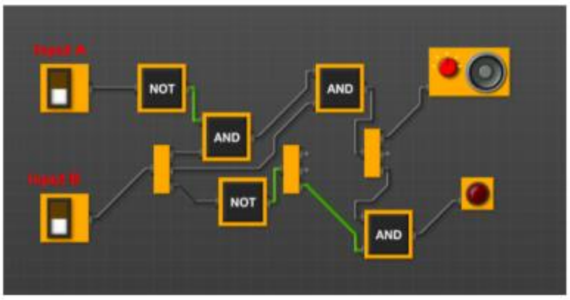
Enter your answer

3. [Select 1 or more responses] If I switch on Input A and keep Input B switched off,



- The fan will turn on.
- The red bulb will light up.
- Nothing will happen.
- I don't know.

4.To switch on the red bulb without setting off the alarm



- Input A should be ON, Input B should be OFF.
- Input A should be OFF, Input B should be ON.
- Both Input A and Input B should be ON.
- Both Input A and Input B should be OFF.
- This is not possible.
- I don't know

5. My room's fan switches on only when the switch is turned off. What logic gate might be responsible for this?

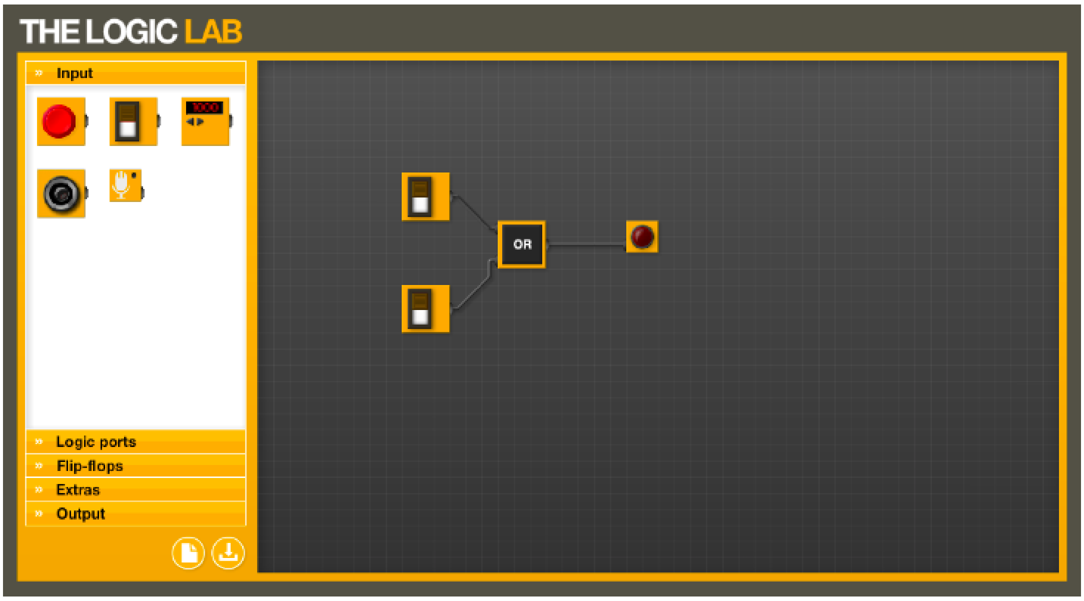
Enter your answer

6. The table below shows the list of combinations for a circuit: When two inputs A & B are given to a combination of logic gates P followed by Q, the output is Z. What can we say from this information? [Select 1 or more responses]

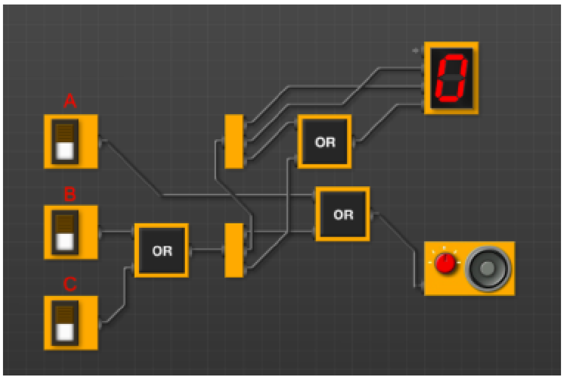
Input A	Input B	Output Z
0	0	1
0	1	1
1	0	1
1	1	0

- ☐ P is a NOT gate; Q is a NOT gate
- ☐ P is an AND gate; Q is a NOT gate
- ☐ P is a NOT gate; Q is an AND gate
- ☐ P is an AND gate; Q is an AND gate
- ☐ Given data is insufficient to reach a conclusion.

Study the logic gate given below and answer the next 2 questions.

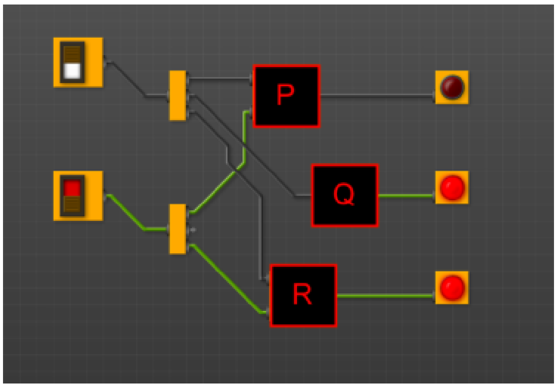


7. Look at the figure below and choose the correct statement.



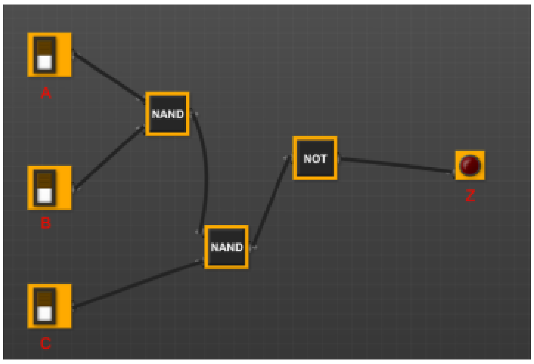
- ☐ If Switch A is OFF and Switch B is OFF, the alarm is ON
- ☐ If Switch B is ON and Switch C is OFF, the alarm is OFF.
- ☐ If no switch is ON, the alarm is ON
- ☐ If all switches are ON, the alarm is OFF.
- ☐ If any switch is ON, the alarm is ON.
- ☐ I don't know.

8. In the figure below, what logic gates (NOT/AND/OR) are represented by P, Q and R?



Enter your answer

9. A NAND gate gives the opposite of an AND gate and can be seen as an AND gate followed by a NOT gate. For the figure below, mark whether this statement is true or false:Z=0 for A=0, B=0, C=1



- ☐ True
- ☐ False
- ☐ I don't know.

10. Kara will go on the ski-trip on **any** of the following conditions:
a) Both Dani and Jon go

and

Lola goes and Sally does not.

b) Both Rita and Tom go

and

Fifi does not.

c) Maurice goes.

Everyone except Maurice and Tom (who have come down with a flu) will be going on the ski-trip. Will Kara go?

- ☐ Yes
- ☐ No
- ☐ The data given is insufficient to answer this question.
- ☐ I don't know.

11. Halloween is here and as usual, clown-costumes are very popular. Unfortunately, my dog fears clowns. What is funnier is that it only barks when it sees **two** clowns in the room.

a) It did not bark when Fifi and Maurice entered the room.

b) It did not bark when it saw Maurice and Dani together.

c) It barked when it saw both Dani and Jo together.

d) It did not bark when it saw Fifi and Lola walk in together.

Select all the correct statements

- ☐ Fifi is in a clown-costume.
- ☐ Fifi is not in a clown-costume.
- ☐ Given data is insufficient to reach a conclusion about Fifi's costume.
- ☐ Lola is in a clown-costume
- ☐ Lola is not in a clown-costume
- ☐ Given data is insufficient to draw a conclusion about Lola's costume.

Scoring Key

1. 0.25 pts for each row (if all rows entered are correct), i.e. 0 pts if there are wrong entries. Max: 1 pt.

For example,

Input A	Input B	Output
0	0	0
0	1	0
1	0	0
1	1	1

= 1 pt

Input A	Input B	Output

0	1	0
1	0	0

= 0.25pts + 0.25 pts = 0.50 pts

Input A	Input B	Output
0	0	0
0	1	0
1	1	0
0	0	1

= 0 pts (Because we assume that the test-taker is simply employing guesswork and writing different combinations of the digits.)

2. 1 pt for answer: NOT gate
3. 1 pt for answer: 'The fan will turn on' ONLY. 0 pts if other options have been selected.
4. 1 pt for answer: 'This is not possible' ONLY. 0 pts if other options have been selected.
5. 1 pt for answer: NOT gate
6. 1 pt for answer: 'P is an AND gate; Q is a NOT gate' ONLY. 0 pts if other options have been selected.
7. 1 pt for answer: 'If any switch is ON, the alarm is ON' ONLY. 0 pts if other options have been selected.
8. [Total pts for this Q= 0.99 pts] 0.33 pts for each correct answer: P is AND gate; Q is NOT gate; R is OR gate.
9. 1 pt for answer: False. 0 pts if other options have been selected.

10. 1 pt for answer: No. 0 pts if other options have been selected.
11. 0.50 pts for each correct answer: ‘Given data is insufficient to reach a conclusion about Fifi’s costume.’; ‘‘Given data is insufficient to reach a conclusion about Fifi’s costume.’

Appendix D. Researcher's Guide

Preparation for the study (sufficient number of days before the study):

Arrange the following:

1. A quiet room with at least 1 functional electrical charging point.
2. Laptops and chargers (the number you are able to procure will determine the maximum size of your participant group).
3. The software 'Adobe Flash Player' installed on each laptop.
4. Login page for each testing condition bookmarked on web browsers for quick access.
5. Sheets of paper and pens for participants.
6. At least one set of extra earphones in case a participant forgets to bring their own.

24 hours before the study:

Send an email or message to participants to remind them of the study and to bring earphones, and to confirm the venue and time.

Study set-up:

Keep each laptop plugged in, switched on and the login page open. Write the participant's login ID (a randomly generated number) on the top of the sheet of paper. Keep the paper and a pen beside the laptop (for participant's use).

Participant-orientation:

1. Welcome the participant(s). Ask them to take a seat and give them a moment to settle down, keep their phones on silent and get ready. Confirm that they are 18 years of age or above.
2. Explain the agenda: They would play a game (maximum 50 minutes), take a test (time-limit is 10 minutes) and then answer a few questions in an interview.
3. Ask participants to inform you before they start the test so that you can time it.
4. Tell participants to plug in their earphones, check the laptop's volume and screen brightness, start when they're ready and turn to you in case of technical difficulties, system glitches, questions about the game or instructions.
5. Tell participants in the experimental condition to watch all videos.

Close-out:

Thank the participant for their participation and request them to not disclose the details of the study to other participants so as not to affect the internal validity of the study.

Up to 12 hours after the study: Send a follow-up thank you message to participants.

Note: It is important to maintain a positive connection with participants to encourage them to a) participate in future scientific studies and b) motivate their social network to participate as well.