I Don’t Usually Listen, I Read: How Different Learner Groups Process Game Feedback

How Different Learner Groups Process Game Feedback

Andrea Gauthier*

UCL Knowledge Lab, Department of Culture, Communication and Media, Institute of Education, University College London, andrea.gauthier@ucl.ac.uk

Laura Benton

UCL Knowledge Lab, Department of Culture, Communication and Media, Institute of Education, University College London, l.benton@ucl.ac.uk

Leona Bunting

Department of Applied IT, University of Gothenburg, leona.johansson.bunting@ait.gu.se

Elisabeth Herbert

Department of Psychology and Human Development, Institute of Education, University College London, elisabeth.herbert@ucl.ac.uk

Emma Sumner

Department of Psychology and Human Development, Institute of Education, University College London, e.sumner@ucl.ac.uk

Manolis Mavrikis

UCL Knowledge Lab, Department of Culture, Communication and Media, Institute of Education, University College London, m.mavrikis@ucl.ac.uk

Andrea Révész

Centre for Applied Linguistics, Department of Culture, Communication and Media, Institute of Education, University College London, a.revesz@ucl.ac.uk

Asimina Vasalou

UCL Knowledge Lab, Department of Culture, Communication and Media, Institute of Education, University College London, a.vasalou@ucl.ac.uk

Outcome and elaborative feedback in games can scaffold learners to recognise errors and apply corrective strategies. However, there is little evidence that indicates how children process such feedback. Using an active intervention approach, this study empirically evaluated how three groups of primary-aged children with different profiles—novice readers, children with reading difficulties, and children learning English as a foreign language—attended to, understood, and acted upon feedback within a digital literacy game. Children’s gameplay and verbalisations across groups were compared through systematic video analysis. Our findings demonstrate that all readers benefited from *visual, non-verbal outcome* feedback, which supported accurate interpretations of their

* Corresponding author.

performance, but groups attended to it differentially. Older children noticed *auditory, verbal elaborative* feedback more than novice readers, but all children struggled to understand it, instead relying on implicit knowledge to correct future responses. We conclude by highlighting several contributions to games-based learning research, game design, and pedagogical practice.

Additional Key words and phrases: Learning games, game design, feedback, children, reading

CCS CONCEPTS • Human-centered computing • Human-computer interaction (HCI) • Empirical studies in HCI

ACM Reference Format:

First Author's Name, Initials, and Last Name, Second Author's Name, Initials, and Last Name, and Third Author's Name, Initials, and Last Name. 2018. The Title of the Paper: ACM Conference Proceedings Manuscript Submission Template: This is the subtitle of the paper, this document both explains and embodies the submission format for authors using Word. In Woodstock '18: ACM Symposium on Neural Gaze Detection, June 03–05, 2018, Woodstock, NY. ACM, New York, NY, USA, 10 pages. NOTE: This block will be automatically generated when manuscripts are processed after acceptance.

1 INTRODUCTION

Learning games have become a mainstay resource for the primary school classroom, teaching young children basic skills such as literacy and mathematics. When choosing games for classroom learning, teachers will often seek those that have alignment with the curriculum and can reinforce what is already taught in class [3]. Therefore, depending on their domain and content coverage, some learning games can appeal to a range of learner groups, and learning games have been found to be effective and engaging for a range of different learners [43, 77]. In this paper, we examine a game for literacy learning called '*Navigo*'. *Navigo*'s content was designed for three different young learner groups: primary school children learning to read, children with reading difficulties, as well as children learning to read in English as a second language [8].

Games can create a safe space for failure, where learners try out different ideas or hypotheses as part of the learning experience [36, 78], whilst also offering just-in-time *feedback* in the event of an error [20, 48]. Previous research has shown that feedback following an error increases attainment, highlighting that feedback is one of the most impactful education interventions in learning [39, 40]. However, despite the recognised value of outcome (summative) *and* elaborative (formative) feedback, commercial learning games for young children have been most often designed to prioritise the former, alerting the child about their error without supporting them to apply strategies or knowledge to recover [7, 58, 61]. Moreover, a range of design opportunities exist for the presentation of game feedback, in terms of its *content* (e.g., its complexity), *timing* (e.g., immediate or delayed), and *modality* (e.g., visual vs auditory, verbal vs non-verbal, and the interplay between and/or combination of these modalities) [7, 46]. Yet, despite significant research on the effectiveness of auditory, verbal feedback in multimedia in general, there is a recognised need for more research on boundary conditions, where the so called 'modality principle' applies ([57], p. 337). Furthermore, most frameworks and guidelines available to inform the design of feedback in learning games is based largely on research with adults, rather than children (e.g., [2, 23, 46, 56, 75]). Research has not yet examined how particular design characteristics embedded in game feedback may facilitate young children's learning [20, 48].

This research gap is critical to address, particularly in the case of learning games that target a range of young learner groups as different learner characteristics may mediate the effectiveness of this instructional support [47]. The aim of the present research is to understand how *Navigo*'s outcome feedback in the visual, non-verbal modality and elaborative feedback in the auditory, verbal modality supported the learning process of its three diverse learner groups. We ask, *does outcome feedback support children with different characteristics to evaluate their performance and recognise their* *errors? How does elaborative feedback support children to understand and recover from their errors?* Given the paucity of research in this area, we chose to focus on how children process feedback as part of their game-based learning process, particularly as it relates to their attention, awareness, understanding, and integration. By comparing this process between groups of learners with different characteristics, we can identify specific challenges and opportunities for support in each group, which makes this research distinctly unique.

This paper makes several contributions to games-based learning research, game design, and practice. First, we found that outcome feedback embedded within the task content is the most effective in raising awareness in the three learner groups whilst also accurately communicating that the child had made an error. Second, we demonstrated that the auditory, verbal modality of the elaborative feedback poses challenges for children's processing of the feedback. These findings have led us to identify incremental improvements for game design and pedagogical practice that could support children's processing, notably, that children need support that is extrinsic to the game when it comes to using elaborative feedback. We propose several pedagogical adaptations that education practitioners could make to support children's use of elaborative feedback, applicable to learner groups as well as differentiated based on the challenges each group faced. Finally, through the process-orientated lens of this research, we identify specific game features that warrant future research and suggest methodological implications for future research on children's gameplay.

2 RELATED LITERATURE

2.1 Cognitive processing of feedback

Providing feedback within learning games can support learning in several ways: (i) reducing cognitive load by bringing attention to key parts of a task; (ii) indicating to a learner that there is a gap between their performance and a given learning aim; and (iii) providing corrective information, so that the learner can correct their strategy and progress in their learning and the game [47, 75].

The cognitive processing of such feedback requires both external and internal attentional systems to work in tandem [19]. *External attention* refers to people's perception of external, modality-specific, sensory information (e.g., visual or auditory stimuli), whereas *internal attention* refers to the selection and manipulation of internally generated information (e.g., working and long-term memories). Through cognitive control, the internal system mediates how incoming perceptual information (received by the external system) is organised and integrated in working and long-term memory [19, 30].

Yet, *attending* to said feedback in the first place is necessary for it to be processed by this dual system [71, 73]. Therefore, manipulating the perceptual salience of the feedback, e.g., through choice of its content, timing, and modality, may increase the likelihood that the feedback is attended to by the external system and that its beneficial effects are exploited by the internal one [33, 67]. This internal exploitation process is facilitated if the learner has a higher *awareness* and *understanding* of the feedback [73], e.g., by ensuring that its content aligns with the learners' prior knowledge and expectations [56], so that the internal system can effectively *organise* and *integrate* it with working and long-term memory. However, it should be noted that literature on feedback in language learning acknowledges that simply *attending* to feedback, without deeper *understanding*, may be enough for learning to take place [72].

2.2 Game feedback design

Johnson et al. [46] defines two overarching types of feedback in games: (1) *outcome* feedback, which is mostly summative and functions to inform the learner about the correctness of their response, and (2) *elaborative* or *process* feedback, which aims to evolve the learners' understanding, to support recovery from errors, and tends to be more formative in nature. Elaborative feedback is generally considered the main instructional driver behind learning progression in games, by scaffolding thinking and providing additional information [2]. When designing outcome and elaborative feedback in games, choices must be made regarding its *content*, *timing*, and *modality*, which can be tailored to the game's target audience, objectives, and context, to facilitate its processing by players.

As demonstrated in section 2.1, the content and complexity of feedback—and, specifically, how closely it aligns with learners' prior knowledge—is known to have a significant impact on how it gets attended to, organised, and integrated in gaming and multimedia contexts [7, 40, 47, 56, 59]. Additionally, the timing of when feedback is presented to learners can influence its effectiveness [2, 4, 14, 47]. For instance, feedback that is presented immediately after a response may be easier to remember, whereas feedback that is delayed until the end of a task might allow learners more time to reflect on their learning process and, thus, be better prepared to integrate the feedback [14]. Research with young adults suggests that immediate feedback is given more attention from learners than delayed feedback [51].

However, of most importance to the current research is feedback modality. Both outcome and elaborative feedback can be delivered through different modalities in games [47]. Feedback can be visual, such as visual effects that are embedded into the gameplay, symbolic icons, or text/dialogue boxes. Feedback can also be auditory, such as sound effects, or hints and prompts that might be narrated aloud. Or feedback can be multimodal and simultaneously provide visual features reinforced by narration/audio cues and vice versa. Additionally, both visual and auditory feedback can be verbal (with written or spoken words) or non-verbal (without words). Previous research has shown that *auditory, verbal* elaborative feedback (i.e., that is spoken) is more effective than *visual, verbal* elaborative feedback (i.e., that is written) in multimedia environments, which are already highly visually stimulating, so that the visual processing system does not get overloaded [47, 56]. As described in section 2.1, the salience of both visual and verbal feedback will affect how it is perceived by the external attentional system and then subsequently coded into working memory by the internal attentional system. For instance, visual outcome feedback that is placed within the focal learning area on the screen is likely to be more salient than feedback found on the screen's periphery [35, 48, 49, 79]. Centrally placed outcome feedback features are commonly intrinsic to the learning task, represented by changes to the gaming environment that would indicate to the player that an error was made. Contrastingly, elaborative feedback, which often takes the form of narration by a non-player character or guide, is not as easily embedded into game narratives and so, by nature, is commonly extrinsic to the learning task. In effect, there is a natural confound of design variables in many learning games, wherein outcome feedback tends to be *visual*, *non-verbal*, and (often) *intrinsic* to the learning task, whereas elaborative feedback tends to be *auditory*, *verbal*, and *extrinsic* to the learning task. Whilst this confound of variables presents a challenge for research, investigating design-related research questions in the context of complex, real-world learning games is important to inform existing approaches to game design for children.

This challenge is enhanced when working with children because the design of feedback within multimedia environments has largely been investigated within post-secondary education contexts (e.g., [2, 47, 75]). Current guidelines for designing feedback in learning games and multimedia environments are also largely derived from research on adults (e.g., [23, 46, 56]), as identified by previous work in this area [7]. Given that children have been known not to attend to the same features on digital devices as might be expected by instructional designers [29], more research is needed to appreciate the intricacies of designing feedback for children as a heterogeneous group.

2.3 Game feedback considerations for different learner groups

Children's age, metalinguistic knowledge, and executive functioning abilities should be considered when designing feedback in learning games. For instance, these characteristics of children may inform the content and complexity of elaborative feedback. In their review on instruction-based feedback, Hattie and Gan [39] describe the importance of prior knowledge and experiences upon which feedback can act; the constructivist perspective is that, without the relevant prior knowledge, elaborative feedback will be ineffective, which relates to previously discussed research on the interaction between external and internal attentional systems [19]. This is a crucial consideration when developing learning games for children within a broad age-range, where younger children and children with reading difficulties may (i) not have the appropriate vocabulary with which to process complex feedback or (ii) lack the meta-linguistic knowledge to be able to act on feedback. Older children learning a foreign language may face such issues in terms of lacking the second-language vocabulary and processing skills needed to make use of the feedback [16, 25, 54]. Furthermore, metacognition only begins to develop in children around ages 5-7 and is only used consistently to inform learning in late adolescence [5, 62]. Therefore, primary school-aged children may struggle, in general, to reflect on how more complex elaborative feedback relates to their own thoughts and behaviours.

Children's metacognitive abilities may also have implications on the timing at which the feedback is presented. In adult learners, delayed feedback was found to be beneficial only in high ability learners [4], whereas novice and low-ability learners benefited from immediate feedback [4, 47], as they were more able to link the feedback to their previous behaviours. Based on the lower metacognitive abilities and working memories of children, immediate feedback may be most appropriate across groups of children with different learning profiles.

Characteristics of children may also influence the choice of feedback modality. Younger children (e.g., novice readers) have less well developed visual attentional capacities in comparison to their older peers [13, 24], which has been shown to significantly impact reading performance [13]. It is plausible that, for beginner readers, visual attention span may also affect processing of visual feedback in an already visually stimulating multimedia environment, like a game [56]. Of note, children who struggle to read have also been shown to present with difficulties in visuo-spatial attention and visual processing [12, 28]; thus a similar pattern may be expected of younger, beginner readers when processing visual feedback embedded in a gaming environment. In addition, children with reading difficulties, such as dyslexia, are consistently found to have poor phonological processing skills and verbal short-term memory, which may inhibit children's abilities to process verbal feedback [76]. These problems may be compounded by the complexity and modality of the feedback (e.g., number of words, whether auditory or visual). For foreign-language learners, there is some evidence that auditory feedback may not be useful, due to challenges in interpreting verbal utterances when not fluent in the foreign language [16].

Ultimately, the effectiveness of the support in learning games depends on its design and the appropriateness of such design for the target learners [49]. Yet, it remains inconclusive as to what, when, and how to best support learning through game feedback [49].

3 RESEARCH MOTIVATION AND QUESTIONS

The focal learning game in this research is *Navigo*. *Navigo* was designed to support literacy learning of three learner groups – novice readers (NR), children with reading difficulties (CwRD) and children learning English as a Foreign Language (EFL). To cater to these groups, the game was designed to personalise content to the prior knowledge of each child. *Navigo* also offered two types of game feedback in the event of an error (1) *visual, non-verbal outcome feedback*, informing the child about their performance, and (2) *auditory, verbal elaborative feedback*, informing the child how to correct their next response. This made *Navigo* an ideal stimulus through which to investigate questions surrounding the design of feedback in games for groups of learners with different characteristics. Specifically, we aim to answer the following research questions (RQ):

- **RQ1** – Does *outcome feedback* support children with different learning characteristics to evaluate their performance and recognise their errors?
- **RQ2** – How does *elaborative feedback* support these children to understand and recover from their errors?

4 METHODOLOGY

4.1 Participants and Context

Seventy-nine primary school children participated and belonged to one of three learner groups:

(1) Novice readers (NR): comprised typically developing children in Year 1 (aged 5-6) in England, from a single school, who were in the initial stages of learning to read. As data collection in this group took place toward the end of the school year, these children had approximately 1.5 years of literacy instruction from reception (kindergarten) on the mechanics of reading. In addition to following a systematic phonics programme, they were introduced to word-morphology, such as simple prefixes and suffixes.

(2) Children with reading difficulties (CwRD): included older children in Years 4-6 (aged 8-11) in England, sampled across four mainstream schools, who were considered to have persistent reading difficulties despite at least four years of literacy instruction. Identified by their school's special education needs coordinator (SENCo), this group received additional targeted literacy support in small groups or 1:1 outside of the classroom, but none required an in-class support worker. Policy in England stipulates that a formal diagnosis of a learning difficulty is *not* required for children to receive additional provision, and accordingly children did not have a formal diagnosis of reading difficulty, such as dyslexia [22, 69]. Moreover, none of the children had diagnoses of additional, related learning difficulties. The study design was shared with teachers in advance, and they selected children who had sufficient oral communication skills to participate in the study task.

(3) English as a Foreign Language learners (EFL): consisted of children in Year 4 (aged 9-10) in Sweden, from one school, who had been learning English as a Foreign Language for approximately two years in school, although most of them had encountered it extensively in out-of-school contexts. Children in this group were described by the Swedish teachers as 'typically developing' and did not struggle with literacy in their native language.

Since we were interested in how game feedback supported understanding and recovery from errors, *making an error* was the inclusion criterion. Therefore, 52 participants who made at least one error while playing the game during the study were included in the data analysis. The final composition of groups is reported in Table 1.

Table 1. Participant allocation

Group	Recruited	Included in analysis	Females / males*
Novice Readers (NR)	24	16	8 / 8
Children with Reading Difficulties (CwRD)	27	16	6 / 10
English as a Foreign Language (EFL)	28	20	13 / 7
Total	79	52	27 / 25

* of sample included in analysis (distribution is equal across groups, $\chi 2(2, N = 52) = 2.73, p = .256$)

To identify a literacy area that would be appropriately challenging for the NR group we consulted the national curriculum which provided detailed statutory learning objectives and chose a language area that the children were due to encounter shortly in their literacy lessons. For the other two groups the children's teachers, literacy leads and/or SENCOs were consulted to identify learning objectives from the curriculum that were known to cause some difficulty to the groups of children involved and were also age appropriate. This choice ensured children would make some errors during gameplay, allowing us in turn to observe how children recovered from these errors after receiving game feedback. These consultations allowed us to isolate the language area of 'morphology', which refers to the process of analysing the structure of a word and recognising units that can be added to a base (root) word to change the meaning. Within morphology, four different prefix and suffix language features were chosen in total: (1) *Prefixes: negatives non, de*, etc*;* (2) *Derivational noun suffixes: -ent/-ence* etc (3) *Suffix -ing with a change of letter* (4) *Comparative adjectives –er, - est* etc. Table 2 presents a breakdown of the language features each learner group received whilst playing the *Navigo* game.

Prior to analysis related to our research questions, we performed an initial check of task difficulty between groups. A Kruskal-Wallis test (*H*) test followed by Bonferroni-adjusted Dunn pairwise comparisons (*D*) was performed to examine whether the learner groups made similar numbers of errors. Eta-square (η^2) is provided for the significant *H* result, where 0.01 is considered a small effect, 0.06 a medium effect, and 0.13 a large effect [21]. We observed that children across groups made errors throughout the game, with NR averaging 3.94 (SD = 1.06) errors, CwRD averaging 2.06 (SD = 1.12) errors, and EFL averaging 2.15 (SD = 1.27) errors in total. This was different across groups, $H(2, 52) = 17.81$, $p < .001$, $\eta^2 = 0.32$. Pairwise comparisons showed that NR participants made significantly more errors than both CwRD participants, $D = 19.22$, $p = .001$, and EFL participants, $D = 18.34$, $p = .001$, but that CwRD and EFL participants made a similar number of errors, $D = 0.88$, $p = 1.00$. This initial check therefore revealed that the morphology feature was more difficult for NR as compared to the two other learner groups, a finding which we will return to in the Discussion section.

4.2 Navigo and game feedback

Navigo is a literacy game set in an ancient Egyptian narrative designed to immerse children in game challenges that support the development of their literacy skills. It contains over 900 game activities that cover a range of literacy skills, including phonics and phonemic awareness, exception words, reading for meaning, and reading fluency. Within this study the children played the morphology language features identified using a multiple-choice minigame called *Perilous Paths.* One play-through of *Perilous Paths* consisted of three rounds, wherein a different question about the same language feature is presented in each round.

The game activities contained in *Navigo* were designed based on the game feedback guidance developed by Benton et al [7]. Accordingly, each game offered a clear *learning aim* and a *tutorial* that instructed the player how to complete the activity. The game activities reinforced the *success criteria* through a fixed set of gems that were earned or lost. The gems also served as a reward and as *outcome feedback* that indicated the child's performance. Outcome feedback was further expressed through various non-verbal, visual cues that indicated that an answer was correct or incorrect, as well as allowing the child to attempt incorrectly answered tasks again with the same content. In addition to the outcome feedback, the game offered *elaborative feedback* upon an error, to guide the child toward correcting their answer. Given the children's young age, elaborative feedback was always provided *immediately* after the child's error [46]. Alongside the feedback guidance informing the game design, the sentences and elaborative feedback contained in the game were checked against the Common European Framework of Languages ensuring the vocabulary was appropriate for an Intermediate Language speaker (B1) aligning with the EFL group's language competence.

Figure 1 shows how the game feedback design principles were instantiated in *Perilous Paths*. The game presented the instructions and the question at the top-right of the screen. Children were tasked with filling in the blank by choosing to cross one of three bridges. Upon getting an incorrect answer, the game presented the child with *outcome feedback*, to indicate to the child that they got the answer incorrect, e.g., the border around the answer turns red, the bridge breaks, a red gem is lost (refer to Figure 1). Outcome feedback was followed immediately by auditory, verbal *elaborative feedback*, to help the child correct their answer. This choice impacts upon the intrinsic and extrinsic nature of the feedback to the learning task: two of the outcome feedback features are intrinsic and three are extrinsic (refer to Table 2), whilst the elaborative feedback is extrinsic by nature of its auditory-verbal modality.

Whereas outcome feedback in *Perilous Paths* was the same across all morphology features, the elaborative feedback presented conceptual knowledge by prompting the child to apply a metalinguistic rule as it applied to each morphology language feature. Schneider and Crombie [74] suggest that children should be encouraged to reflect on language and to engage in analysis, creating deeper learning. For instance, providing linguistic terminology (e.g., 'think of how the prefix will change the meaning of the word you are trying to complete') encourages the child to think about the meaning of prefixes, and to analyse the items in this way. Gombert [37] termed this 'linguistic decision-making' in his model of metalinguistic awareness and argued that this process was crucial when learning to read. Feedback statements in *Navigo* were written by a linguistic expert with specific expertise in feedback (Table 2). Whilst there was variation in syntactic and lexical *complexity* of the elaborative feedback depending on the given language feature, all feedback was passed through vocabulary difficulty tools to ensure that they were appropriate for NR, CwRD, and EFL children.

In contrast, upon answering a question correctly, the game presented the child with visual, non-verbal *and* auditory, verbal outcome feedback, to indicate that the child answered correctly. Specifically, the border around the correct answer turned green, the player's avatar crossed the bridge, a gem was earned, and the narrator stated, "That's correct; well done! Onto the next one". Given our research focus we did not assess children's attention to or understanding of feedback to correct answers.

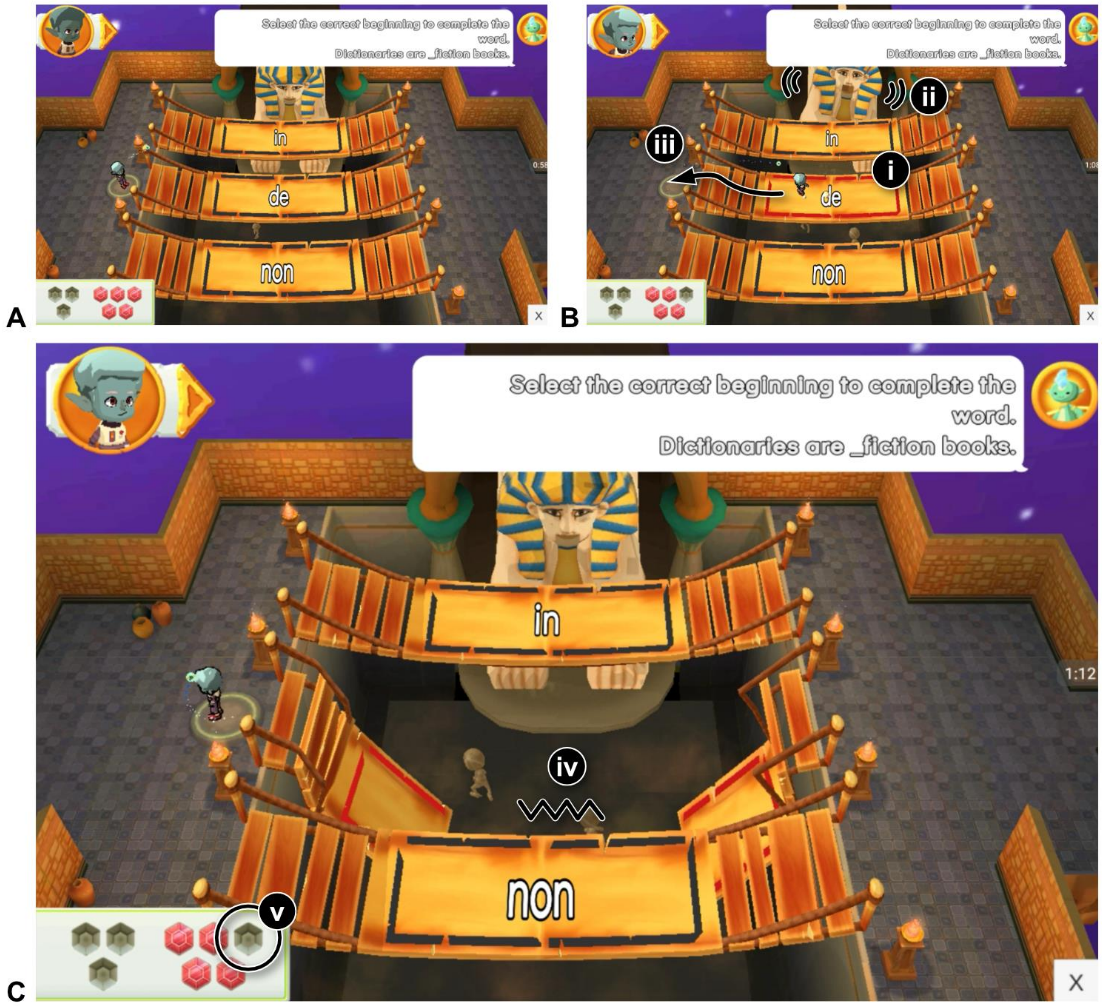

Figure 1. Outcome feedback in the *Perilous Paths* minigame in *Navigo*. (A) Learning task is narrated; (B) an incorrect answer (bridge) is selected; and (C) player prepares for another attempt. Visual, non-verbal outcome feedback features include: (i) bridge border turns red, (ii) sphinx shakes its head, (iii) player returns to starting position, (iv) the bridge breaks, and (v) a red gem is lost.

Table 2. Language features and feedback types in *Perilous Paths* minigame.

Game	Language feature	Elaborative feedback	Outcome feedback
Novice Readers (NR)	*Prefixes negatives*: non-, de- Example word: deconstruct	Game reads out incorrect answer HINT: “These prefixes are all related to negatives or opposites. Think of how the prefix will change the meaning of the word you are trying to complete.”	(i) Bridge border appears in red* (ii) Sphinx shakes (iii) Player is thrown back to starting position (iv) Bridge breaks* (v) Red gems lost
Children with Reading	*Prefixes negatives*: non-, de- Example word: deconstruct	Game reads out incorrect answer HINT: “These prefixes are all related to negatives or opposites. Think of how the	

Game	Language feature	Elaborative feedback	Outcome feedback
Difficulties (CwRD)		prefix will change the meaning of the word you are trying to complete."	
	Derivational noun suffixes: -ent/-ence/-ty/-ity/-ness Example word: royalty (pre-teaching)	Game reads out incorrect answer HINT: "Look for a noun."	
	-ing with a change of letter Example word: lie > lying	Game reads out incorrect answer HINT: "Think about when the events of the sentence took place."	
English as a Foreign Language (EFL)	*Comparative adjectives:* -er, -est, -ier, -iest	Game reads out incorrect answer HINT: "Consider the structure of the sentence and think of whether we compare one or two things."	

* feedback feature is intrinsic to the learning task

4.3 Procedure

All the children included in the study were familiar with *Perilous Paths* from previous participation in the research. Children had played *Perilous Paths* at least once during the preceding three-week period, for approximately 5 minutes. During this prior experience, they covered different language features to those presented in Table 2 but which were within the same word-morphology category (e.g., prefixes, but not negative prefixes), which ensured that any errors made in the current study were due to literacy knowledge, rather than usability of the game. Children completed the study individually with a research facilitator in a quiet room within their school. At the start of the session, the facilitator explained to each child that they would play *Perilous Paths*. To investigate their information processing, an *active intervention approach* was used, detailed by Van Kesteren [50]. Active intervention involves asking children about preceding plans, actions, and evaluations during interaction with technology. Compared to other verbal interventions such as retrospection, Van Kesteren [50] found that active intervention led to a higher number of verbalisations. When the child selected either a correct or incorrect answer, the facilitator intervened with questions 1 and 2 (below). In the event of an incorrect response, after the child made an attempt to correct their error, question 3 was additionally presented (parenthesis indicate what each question prompt intended to measure):

1. *Did you get that answer correct or incorrect?* (to identify if the child was made aware of their error)
2. *How do you know?* (to identify if the child noticed particular visual aspects of outcome feedback)
3. *How did you choose your answer?* (if child does not mention the hint) *Did you hear the hint and did it help you? If yes, how?* (to identify if the elaborative feedback was noticed and the child's understanding of it).

As previously mentioned, only children who made at least one error in any one of the three question rounds in *Perilous Paths* were included in subsequent analyses. It should be noted that, in the EFL group, these questions were posed to the children in Swedish, their native language.

4.4 Data collection and analysis

While children played the game, their screens and verbal utterances were recorded using screen recording software installed on each tablet. Each video was deductively coded using an analytic framework we developed to address the RQs. Table 3 summarises these codes and shows their alignment with the two RQs.

To establish statistical reliability for codes yielding binary and ratio variables, the recordings were analysed by two independent coders for each learner group. Inter-rater reliability was assessed using Krippendorff's alpha at the nominal measurement level for binary codes (C1-2, C5-6, C8) and at the ratio measurement level for C3 [41]. Across all codes, inter-rater agreement was considered moderate to excellent (Table 3). Any discrepancies between coders were resolved by re-watching the recordings and coming to a joint final decision about the value in question.

When children shared their understanding of elaborative feedback (C7) and strategy for recovering (C9), an inductive thematic analysis approach was additionally taken, which resulted in a set of codes capturing children's processing and integration of the conceptual knowledge presented in the feedback, as well as their coping strategy during error recovery. To ensure the coding approach was systematically applied, two of the authors collaboratively developed the initial codes and applied them to some of the videos. Subsequently, the first author coded the remaining videos upon repeated observations of the video data to ascertain the credibility of the coding. If the application of a code was not clear, a collaborative coding process was followed whereby the author previously involved in designing the coding framework discussed and reconciled the application of the code.

Table 3. Coding schema

Code	Code explanation	Options	Krippendorff's alpha
C1	RQ1: Outcome feedback: Does the child understand they made an error?	Yes/No	1.000
C2	RQ1: Outcome feedback: Does the child notice it?	Yes/No	0.952
C3	RQ1: Outcome feedback: Number of feedback features noticed	Maximum value of 5	0.945
C4	RQ1: Outcome feedback: Specific feedback features noticed	Coding according to the outcome features identified in Table 2	--
C5	RQ2: Elaborative feedback: Does the child notice it?	Yes/No	0.866
C6	RQ2: Elaborative feedback: Does the child understand it?	Yes/No	0.731
C7	RQ2: Elaborative feedback: Explanation of understanding	Inductive thematic coding of children's verbal responses to identify if they understood the feedback	--
C8	RQ2: Elaborative feedback: Recovery after feedback? (i.e., did the child answer correctly following the error, after the elaborative feedback was presented)	Yes/No	0.923
C9	RQ2: Elaborative feedback: Strategy for recovery	Inductive thematic coding of children's verbal responses to identify patterns of recovery strategies, e.g., used the hint.	--

To address the RQs, an exploratory statistical analysis of differences in the deductive codes was carried out between the three learner groups. SPSS v.27 [45] was used ($\alpha = 0.05$) and the choice of statistical tests appear in the results section. The qualitative findings generated through the inductive codes were triangulated with the quantitative results. Whereas the statistical analysis showed if the three groups of children understood the game feedback, the inductive coding offered deeper insight as to how children had processed the feedback and whether this feedback had informed a subsequent strategy to correct the error. It is noted that quotes from the EFL group appearing in the paper are translated into English.

5 RESULTS

5.1 RQ1: Does *outcome feedback* support children with different learning characteristics to evaluate their performance and recognise their errors?

Quantitative results related RQ1 are summarised in Table 4. A chi-square goodness of fit test (χ^2) was used to assess whether children, across the whole sample, were more or less likely to be aware of their error (C1) and to notice outcome feedback features (C2). An effect size, Phi (φ), is provided for significant contingency table tests, where 0.1 is considered a small effect, 0.3 a medium effect, and 0.5 a large effect [21]. Children across all groups (100%) **understood when they made an error** (C1). Most children (71.2%) stated that they **noticed visual, non-verbal outcome feedback features** in the game design that helped them to understand this (C2), whilst fewer (28.8%) stated that they "just knew" that their response was incorrect, $\chi^2(1, N = 52) = 9.31$, $p = .002$, $\varphi = 0.43$. A Chi-square test of independence (χ^2) was used to compare C2 between groups, using an exact-test p-value adjustment (p_{ex}) as a cell in the contingency table had an expected count of less than 5. The test revealed that a similar number of NR, CwRD, and EFL participants said **they noticed specific outcome feedback features** which helped them understand that they made an error, $\chi^2(2, N = 52) = 2.67$, $p_{ex} = .298$.

Next, a Kruskal-Wallis test (H) was used to compare the mean number of features noticed (C3) across groups. Children across learner groups were able to identify a similar number of outcome feedback features, $H(2, 52) = 1.23$, $p = .541$, approximately one out of five available features. When examining which features children noticed (C4) we found that **outcome feedback features within the focal learning area**, i.e., embedded within children's target response and intrinsic to the learning task, were most noticed by children: this included the bridge breaking (53.8%), followed closely by the bridge border turning red (40.4%). Other features not directly associated with their target response went relatively unnoticed, with 3.8% of participants stating that their character ran off the bridge, 1.9% that the Sphinx shook, and 1.9% that they lost a red gem. There was no indication that children from any one group attended to certain features more than those in other groups.

Table 4. Summative statistics related to visual, non-verbal outcome feedback (C1-C3).

	C1: Child understood they made an error		C2: Child noticed outcome feedback		C3: Number of outcome features noticed (max 5)	
Learner Groups	N	% within group	N	% within group	Mean	SD*
NR	16	100%	13	81.3%	0.88	0.50
CwRD	16	100%	9	56.3%	1.00	1.10
EFL	20	100%	15	75.0%	1.15	0.81

*SD = Standard Deviation

Whilst there were no significant differences in the overall number of features identified, when exploring the data, we observed that the distribution of these feedback features across participants appeared unequal across the groups. In particular, it appeared that, amongst CwRD, several children (n = 7) made no identification, whilst others (n = 5) made several identifications. Contrastingly, we observed that NR tended to identify only one feature (n = 12). To determine if this distribution was statistically relevant, we recoded C3 into a new variable "level of feature identification" with three ordinal values: (i) no features identified, (ii) one feature identified, and (iii) two or more features identified. We performed a post-hoc Chi-squares test of independence (with φ effect size) that plotted level of game feature identification by learner group as a 3x3 contingency table (Table 5). We found a significant difference between groups, $\chi^2(4, N = 52) = 10.97$, $p_{ex} = .026$, $\varphi = 0.46$. Follow-up comparisons were made using the adjusted standardised residuals comparison method and a Bonferroni-adjusted α based on the number of post-hoc tests [6, 32]. An analysis of adjusted residuals ($\alpha = .006$) shows that NR were significantly ***more likely* to only identify one feature**, $\chi^2(1, N = 16) = 8.87$, $p = .003$, $\varphi = 0.74$, and trended toward being significantly *unlikely* to identify two or more features, $\chi^2(1, N = 16) = 5.02$, $p = .025$, $\varphi = 0.56$. Secondly, CwRD trended toward being *unlikely* to identify only one feature, $\chi^2(1, N = 16) = 3.47$, $p = .063$, $\varphi = 0.47$, therefore, **being *more likely* to either identify no features at all or to identify several features**, as supported by our informal observations. Finally, there was a trend for EFL children to **identify two or more features**, $\chi^2(1, N = 20) = 2.83$, $p = .093$, $\varphi = 0.38$. No child noticed all five features.

Table 5. Identification of outcome features.

	No features identified		One feature identified		More than two features identified	
Learner Groups	N	% within group	N	% within group	N	% within group
NR	3	18.7	12	75.0	1	6.3
CwRD	7	43.8	4	25.0	5	31.3
EFL	5	25.0	7	35.0	8	40.0

5.2 RQ2: How does *elaborative feedback* support children to understand and recover from their errors?

Quantitative results related to RQ2 are summarised in Table 6. For RQ2 we again applied Chi-square goodness of fit tests to assess whether our sample of children were more/less likely, as a whole, to notice elaborative feedback (C5), to understand elaborative feedback (C6), and to recover after elaborative feedback (C8). In a similar way to RQ1, Chi-square tests of independence (including, where applicable, exact-test *p*-value adjustments, follow-up using adjusted residuals, and effect sizes) were used to assess differences in attention (C5), understanding (C6), and recovery (C8) between learner groups. Overall, children were **more likely to report that they noticed the auditory, verbal elaborative feedback** (C5: 64.7%) than that they did not notice it, $\chi^2(1, N=51) = 4.41$, $p = .036$, $\varphi = 0.29$. There was high intergroup variability in the number of participants who reported that they heard the hint given in the game, $\chi^2(2, N = 51) = 10.11$, $p = .006$, $\varphi = 0.45$, with fewer than half of NR noticing the feedback and nearly all EFL children noticing it (see Table 6). Follow-up analyses of adjusted residuals ($\alpha = .017$) show that **EFL participants were more likely to notice elaborative feedback**, $\chi^2(1, N = 20) = 9.22$, $p = .002$, $\varphi = 0.68$, whilst **NR participants were less likely to notice elaborative feedback**, $\chi^2(1, N = 16) = 5.68$, $p = .017$, $\varphi = 0.60$.

However, even though this elaborative feedback was widely noticed, this does not mean that it was understood (C6). Of the 35 children who noticed the feedback, only four of the total sample were coded as **having understood it**. Of these four, one was NR, two were CwRD, and one was EFL, $\chi^2(2, N = 35) = 1.40$, $p_{ex} = .795$.

The inductive analysis (C7) reveals a more nuanced appreciation of how children were (or were not) supported by the elaborative feedback and why. Only the above-mentioned four participants indicated that **the hint helped them select the correct answer on their next try**. For example, in answer to the prompt "How did you select your answer?", one NR child who recovered from an error on negative prefixes said she chose the correct answer because "*[the elaborative feedback] said something about negatives, so that's why I chose 'non-'*". One CwRD, who was completing derivational noun suffixes tasks, said he chose his correct answer because "it was the only noun", which relates directly to the elaborative feedback given (refer to Table 2). Yet, these children were in the minority. In answer to the prompt "Did you hear the hint, and did it help you? If yes, how?", many children reported that they heard/noticed it (C5) but were **not able to recall what it said nor suggest how it helped them** (88.5%). Some of these children expressed that the elaborative feedback was "difficult to hear", with some specifying that it was either too fast (5.9%), e.g., "*I did hear it, but it was a bit too fast, and I could not understand*", or not loud enough (3.9%), e.g., "*the volume was to low*", and others simply that they "*heard it, but not what it said*". One EFL child explained that "*I don't usually listen, I read instead*", while another said it would be "*better if the hint was in writing because then you could read it if you didn't get it the first time*", suggesting a general preference for visual (written) forms of verbal feedback. In a few cases, the elaborative feedback may not have been heard because the child **continued to move and interact in the game while the hint was being narrated** (7.7%). This was noted to have happened with two NR and two CwRD, which may have impeded their processing of the verbal feedback. Despite not being able to recall or explain the elaborative feedback, a few children professed that the **elaborative feedback was helpful by using it as outcome feedback** (9.8%). For example, one child said that "*[the elaborative feedback] said it was incorrect*", whilst another said, "*it told me to try a different bridge*", which are both inaccurate, yet served to support the child in understanding that their first answer was wrong. So, some children still benefitted from the feedback even if they were not able to understand it and apply it systematically.

It is also possible that some children, particularly novice readers, **did not have the adequate background knowledge for the elaborative feedback to be of any help**. It appeared that several of the NR participants were unable to understand problems concerning negative prefixes (the chosen language feature), with coders identifying this as a potential issue in 43.8% of NR participants. In several instances, the study facilitator had to help children understand that they needed to "*choose the correct beginning of the word*" (i.e., the prefix) during gameplay, pointing out the gap in the sentence that needed to be filled and suggesting that they could press a button to hear the problem again. Beyond the issue of language feature, some NRs had difficulty with the vocabulary presented in the game; some children repeated the problem out loud in an inquisitive manner or inaccurately, which prompted the coder to suggest that this vocabulary was perhaps beyond their knowledge. For example, for the prefix problem "*Sign language is [non]verbal*", one NR child repeated "*Sign language*?", suggesting the child was in doubt. Another NR child, for the problem "*The driver had to [de]frost the window*", repeated the completed sentence aloud once they got it correct, but incorrectly said "*decrost*", twice, instead of "*defrost*", which similarly indicated a possible lack of familiarity with the vocabulary embedded in the task. Therefore, given the lack of underpinning vocabulary knowledge, the elaborative feedback would not have helped, regardless of whether it was perceived or not. In support of this conclusion, the number of errors made by NRs showed that they struggled the most with the overall task (refer to section 4.1). CwRD and EFL did not seem to have the same issues with understanding the game problems/content; yet, they still were not process the elaborative feedback.

So, if children were not able to process the elaborative feedback, how did they recover from their errors? We found that children were **neither likely nor unlikely to recover (C8) after their first exposure to elaborative feedback**, $\chi^2(1, N = 52) = 1.23$, $p = .267$. This probability was equal across groups, $\chi^2(2, N = 52) = 0.84$, $p = .657$. Yet, based on the findings presented above, we can suggest that **those who *did* recover likely did so through different strategies**, without integrating the elaborative feedback. In answer to the researcher's prompt "*How did you choose your answer?*", several NR children (56.3%) reported applying a random-selection or process-of-elimination strategy to recover from their errors, further supporting the assumption about comprehension difficulties. For example, several children reported that "*I just guessed*" or "*it was the last bridge*". Contrastingly, this was not as common in other groups, with 12.5% of CwRD and 15.0% of EFL participants having reported applying this strategy. Other attempted bespoke strategies reported by children included choosing the same bridge (top, middle, or bottom) as the last round, choosing the same prefix as the last round, or choosing a *different* prefix from the last round under the assumption that a game would not supply the same correct answer twice in a row. However, several other children applied effective strategies to recover from the errors, the most notable being an implicit learning strategy that relies on the semantics of the constructed sentence (i.e., what "makes sense"). Children across groups (38.5%) reported that, e.g., "*it made a lot of sense when I chose it*" (NR participant), "*some words are wrong with some sentences and don't look or sound good with some sentences*" (CwRD), or "*it sounds logical*" (EFL participant). This strategy was identified in 18.9% NR, 37.5% CwRD, and 55.0% EFL. Another strategy applied by one EFL participant (who seemed to understand the content, despite not hearing/understanding the elaborative feedback), was to translate the problem into their native language, to better reason about the language feature (comparative adjective endings): "*[he's] compared with his sister and [so] it's -er at the end*".

Table 6. Summative statistics related to verbal elaborative feedback (C5, C6, C8).

Learner Groups	C5: Child noticed elaborative feedback		C6: Child understood elaborative feedback		C8: Child recovered after elaborative feedback	
	N	% within group	N	% within group	N	% within group
NR	6	40.0%*	1	6.7%*	8	50.0%
CwRD	9	56.3%	2	12.5%	9	56.3%
EFL	18	90.0%	1	5.0%	13	65.0%

*The study facilitator did not explicitly prompt one child in relation to C5 and C6, so % are from a total of N=15.

6 DISCUSSION

The present work aimed to understand if and how game feedback, specifically *visual, non-verbal outcome feedback* and *auditory, verbal elaborative feedback*, embedded in a literacy game activity fostered children's learning process and if there were processing variations across different learner groups (NR, CwRD and EFL). Our analysis indicates the following overarching findings: (i) visual, non-verbal outcome feedback that is intrinsic to the game task fosters a child's understanding of an error; and (ii) there is mixed evidence on children's attention to and understanding of auditory, verbal elaborative feedback. Below we reflect on each of these themes and present implications for future research methodology, game design, and pedagogical practice, notably, that children may benefit from extrinsic support to process elaborative feedback.

6.1 Outcome feedback intrinsic to the game task fosters understanding of error

Children from all three learner groups recognised making an error. This finding suggests that the outcome feedback was effectively designed for the diverse learner groups involved. Nonetheless, we found learner group differences in relation to *how many* features of outcome feedback children reported identifying. NRs were more likely to identify a single feature and EFL children were more likely to detect more than two features. CwRD exhibited interindividual differences; children either identified more than two features (similar to their EFL counterparts who were of similar age), or they were not able to articulate which features supported their understanding. Whilst we did not use cognitive measures in this study, these findings are supported by literature demonstrating the poorer visual working-memory capabilities of novice learners [13, 24] and children with reading difficulties [12, 28, 76]. Though differences in noticing outcome feedback features were found between learner groups, the number of outcome feedback features noticed did not seem to have an impact on children's understanding of their performance.

Despite the *Perilous Paths* minigame offering five outcome feedback game features, children, on average, tended to report between one to two features that appeared in the centre of the screen. These features were embedded in the gameplay and the child's response (i.e., bridge breaking and bridge border turning red), rather than appearing peripheral to the learning task (i.e., gems lost, Sphinx shaking, character being thrown off the bridge and returned to the starting position). This supports recommendations made by Ke and colleagues about **integrating game feedback within the central focal area of play** [48, 49], so that it is intrinsic to the learning task. Ke [48] also argues that this design recommendation could minimise cognitive demands. However, visual outcome feedback features that were not reported as noticed, such as the *Sphinx shaking* or the *child's character returning to the start of the bridge*, but may also have functioned to reinforce the aesthetics and narrative of the game, as well as the child's understanding of what to do next following their error. It is also possible that the multiple visual-non-verbal outcome feedback features worked to *collectively* inform the child's understanding of their performance, but only features intrinsic to the learning task attracted attention and conscious decoding [10, 11, 60, 72]. Alternatively, it could be that children experienced high cognitive load when processing these multiple visual game features and, thus, their external attentional system did not select features outside the focal area of play [48, 64]. Given the prevalent use of multiple visual outcome feedback features in learning games, future research could investigate this question by **triangulating findings from the active intervention method with methods that measure children's unfolding attention, such as eye-tracking** (e.g., [35]).

Previous research has shown that rewards can play a critical role in motivation whilst also acting as outcome feedback [7, 80]. In contrast to past research that shows children of this age are generally familiar with learning games and their reward systems [78], children across all learner groups did not notice the gems earned or lost. This might be because such rewards only become meaningful over an extended period (e.g., over several weeks), so that children can develop a deeper appreciation for their value within the game [49]. This is similar to what was found by Gauthier et al. [35], wherein a scoreboard feature (also appearing in the periphery of the screen) was largely ignored by 7- to 8-year-olds who played a one-off session of a mathematics and science game. The short timeframe of the current study did not allow children to engage in activities that would promote meaning-making with the scoring mechanic, e.g., by creating an avatar and customising the avatar with new clothing received based on their performance in the game. This type of performance-based customisation mechanic has been associated with high levels of motivation [65]. Given the pervasive use of rewards in learning games, it is important for future work to **examine if children learn to attend to rewards despite their peripheral screen position over a longer period of gameplay, giving them time to attach meaning to scoring and performance**.

6.2 Mixed evidence on children's attention and processing of auditory, verbal elaborative feedback

The literature suggests that a spoken modality for elaborative game feedback may be more effective for learning in visually stimulating environments (e.g., [47, 56]), as the different modality allows learners to *attend to*, mentally *organise*, and *integrate* feedback via a second (auditory) processing system, thereby reducing cognitive load on the visual processing system [56]. However, empirical research in support of this recommendation has been largely based on studies from adult learners (e.g., [2, 23, 46, 56]). Investigating this process of attending to and understanding feedback with three groups of primary school children, we found that the extent to which children tended to *pay attention* to the spoken elaborative feedback varied by learner group. Compared to NR and CwRD who noticed the feedback 40% and 56% respectively, 90% of the EFL children reported hearing the feedback. Although our study did not include cognitive measures, drawing on past research, these differences could be due to the profiles of NR and CwRD such as their developing attentional skills and poor verbal and auditory working memory [18, 42]. This could explain why some NR and CwRD ignored the elaborative feedback and continued to play during the narration. Future research could examine **whether interruptive feedback that forces the child to pause until the elaborative feedback is fully narrated can serve as a mechanism to focus children's attention** [38]. Moreover, another attentional barrier reported by a few children was the volume, or speed, of the auditory modality suggesting that game design could **offer children the ability to replay the feedback**. An alternative explanation is that the complexity of the elaborative feedback that NR received (on negative prefixes) was higher than for participants practicing other language features (see Table 2). The shorter, less complex feedback for other language features may be responsible for higher rates of attention to elaborative feedback in the CwRD and EFL groups [52, 63], suggesting that **short, simple elaborative feedback may be better at attracting children's attention**. And yet, children across all three groups did not understand the feedback, regardless of differences in feedback complexity, which suggests that the **modality of feedback delivery was the driving factor behind lack of understanding** in this study.

As discussed above, and in contrast to empirical work with adult learners, our findings show that most of the children were not able to *organise* and *integrate* elaborative feedback in the auditory, verbal modality within their existing knowledge; instead, **children applied the elaborative feedback as outcome feedback** to correct their response. This is akin to findings by Schmidt [72], who acknowledged that simply noticing feedback—without full awareness or understanding of it—was enough for implicit learning to take place. Whilst the findings of this study indicate that children are challenged to employ *auditory* verbal (spoken) elaborative feedback in their learning, there is currently no evidence generated with children to suggest that a *visual* verbal (written) modality would be more effective; for instance, it is possible that written elaborative feedback may have increased children's cognitive load, as observed in adult learners (refer to [56]). Yet, some EFL children stated a preference for written forms of verbal feedback (e.g., "I don't usually listen, I read."). In the case of our EFL children, this gap in processing spoken feedback may have been due to children's slower processing speed in the second language (e.g., [16, 31]) and, thus, visual feedback could be beneficial. Game researchers specifically addressing second language learners may need to **explore if a visual modality or multimodal approach (e.g., text and narration) enables children time to process elaborative feedback more effectively**.

In line with this, and given our finding that visual outcome feedback features intrinsic to the learning task garnered the most attention, it may be worth exploring whether elaborative feedback could also be designed to be intrinsic to game-based learning tasks through a multimodal approach. In the current version of *Navigo*, like in many other learning games, the auditory, verbal elaborative feedback is extrinsic to the learning task by nature of its non-visual modality. However, by combining the auditory, verbal hint with visual cues in the focal area of play, the elaborative feedback might be more effectively integrated into the learning task. For example, for the spoken hint "look for a noun", the suffixes of the remaining word options could be highlighted, thereby linking the spoken hint to the learning task. This is in line with [26] who demonstrated the importance for learners to notice what the target of the feedback is to appropriately correct their response. A similar multimodal pedagogical approach was found to be effective when captioning videos for EFL learners in Korea, wherein captions were enhanced by highlighting key areas of speech related to verb conjugation [53].

6.3 Pedagogical implication: Processing of elaborative feedback requires extrinsic support

Given the findings we have reported so far, we propose that children's use of elaborative feedback in their learning may require support by an adult. In line with this perspective, previous research has discussed the equally crucial role of *intrinsic* (within the game) and *extrinsic* (outside the game) support, with the latter intended to direct children on how to use the intrinsic features [9, 17, 79]. Note that this contrasts with the *Navigo*'s feedback that we have described as either intrinsic or extrinsic *to the learning task* – but all outcome and elaborative feedback features described thus far were *intrinsic to the game* itself. In this section we propose recommendations for support that is *extrinsic to the game* by drawing on our findings.

As evidenced earlier, more than half of NR and half of the CwRD did not pay attention to the elaborative feedback. Extrinsic support could be offered during the early period of children's gameplay to **train them to pause and listen to the elaborative feedback they receive following an error**. In support of this, research with 7-10-year olds demonstrates that training children to "stop and think" while playing learning games leads to increased counterintuitive reasoning skills and academic performance in science and maths [70, 81]. This would be particularly beneficial for NR whose impulse was to immediately engage in trial-and-error strategies. Additionally, across the three learner groups, most children were not able to recall the content of the feedback, whilst some children's limited processing of the feedback led them to treat it as an indication of their performance. This finding was particularly surprising in the case of CwRD, given the explicit teaching they receive in their additional literacy provision [22, 69], as well as the metacognitive training in English primary schools, where self-regulated learning strategies (e.g., receiving and applying oral feedback) are explicitly trained from Year 1 onward, and are thought to be exhibited reliably by children at Year 4 (ages 8-9) [66, 69]. Children across groups did not apply the elaborative feedback to correct their next attempt and relied on a variety of other strategies [44]. As such, in addition to training children to listen for feedback, they might also be **trained on how to apply elaborative feedback to improve their game performance**. This is supported by recent research [15], which found that scaffolding elaborative hints *prior to gameplay* increased learning outcomes. Providing **pre-teaching instruction to introduce the linguistic terminology before gameplay** could foster children's ability to then use this information in the task when prompted by the elaborative feedback to analyse word categories. Given EFL children's difficulties to access the metalinguistic concepts in their second language, teachers could **introduce these concepts in their native language prior gameplay to create mappings between L1 and L2**. This may be more or less feasible depending on the L1. Swedish shares many similarities with English, so this approach may be feasible for Swedish EFL learners [68].

Crucially our study showed that children, such as NR, who are learning the game content through practice, may require the most pedagogical guidance outside the game. Within the NR group we observed a variation of abilities. From the originally sampled 24, 8 NR children did not make any errors at all suggesting that some of the children had prior knowledge of negative prefixes, whereas the remaining children made more errors than the older learner groups. This finding shows the importance of **identifying which children would benefit the most from adult support**. We also found that many NR children needed assistance with key vocabulary presented in the game content. Thus, extrinsic support for games that stretch learning for this young group could include the **introduction of key vocabulary appearing in the game prior to children's gameplay**. Additionally, NR struggled to relate the linguistic concept to the game task indicating that **task modelling by an adult** could strengthen children's understanding.

Finally, it is worth mentioning here that research in the learning analytics field has demonstrated that the analysis of interaction data from games and the targeted design of tools for teachers can support classroom orchestration, e.g., through increased awareness of areas that children find challenging [27, 55]. Access to a learning analytics dashboard has been shown to support teachers in identifying areas where extrinsic support is needed, both in real-time or in preparing for an upcoming class session [1, 34]. Learning analytics could also be used to **introduce reflection activities** for children, to consolidate their digital experience with the learning task and the feedback beyond the game [55]. This would be particularly beneficial for older children (e.g., CwRD and EFL), who are beginning to develop metacognitive capacities [5]. Table 7 summarises the implications for extrinsic support as they apply to individual as well as all learner groups.

Table 7. Summary of proposed extrinsic support.

External support	Learner group
Train children to attend to auditory, verbal game feedback	NR, CwRD
Train children to apply auditory, verbal game feedback as a game strategy to improve performance	All
Pre-teach the linguistic concept from the outside and its connection to the content of the game feedback	All
Pre-teach the linguistic concept from the outside and its link to children's native language	EFL
Pre-teach new vocabulary appearing within the game task	NR
Model the game task	NR
Identify and target students who will benefit from the most support	NR
Introduce reflection activities with learning analytics to consolidate task and feedback	CwRD, EFL

6.4 Limitations

To elicit comparisons between three learner groups, this study triangulated analyses from quantitative measures of children's self-reports on attention and understanding with qualitative analysis of their processing of game feedback. Despite the strength of triangulating quantitative and qualitative analysis, there were some methodological limitations. Even though the language features selected were carefully chosen, several children from each group did not make task errors. This reduced the sample size of the study and thus limited the investigation to non-parametric analyses that did not allow us to account statistically for possible moderating characteristics of children, such as gender, age (within groups), or familiarity with gaming. Moreover, to investigate children's information processing, we used the active intervention method, which required us to interrupt children's gameplay at designated moments. This choice may have directed children's attention to the game feedback, though our study showed that children did not notice the entirety of feedback cues, nor did many of them process the elaborative feedback. Despite this possible limitation, the active intervention method allowed us to overcome known limitations associated with other methods such as post-game interviews which would rely on children's memory, or the think-aloud method which would require children to process the game task and verbalise their actions at the same time. Additionally, our study took place over a single session, and it is possible that children of this age only benefit from game feedback after repeated exposure, so future work may consider investigating these research questions longitudinally. Finally, EFL participants in this study were Swedish, which we do not claim to be representative of children learning EFL more broadly; future work may want to replicate these findings with other L1 EFL learners to establish the transferability of these findings.

7 CONCLUSION

Feedback is a main driver for knowledge and skills development in learning games. Digital learning games can offer dynamic, multimodal feedback through both audio and visual prompts and cues to (i) let children know if their ideas are correct or incorrect (outcome feedback) or, importantly, (ii) help children adopt new ideas and strategies to advance their learning (elaborative feedback). Yet, most research on game-based feedback has been performed with adult learners, and little is known about how to design effective feedback in learning games for children. For instance, long-standing guidance suggested that elaborative feedback in multimedia learning tools should be delivered through an auditory, verbal modality, to avoid overburdening the visual processing system in a visually intensive environment [56]. The use of such elaborative feedback in games for children is relatively untested. Moreover, the learning characteristics of children can be diverse, so questions arise about how these characteristics, e.g., age, learning (dis)abilities, language comprehension, might impact children's perception and interpretation of feedback. The conflated nature of outcome vs elaborative feedback in multimodal environments with other design factors (e.g., whether feedback is visual vs auditory, verbal vs non-verbal, intrinsic vs extrinsic to the learning task, and intrinsic vs extrinsic to the gaming environment) brings an extra layer of complexity to research around this topic, and it is crucial that we begin to unpack these complexities, to make meaningful contributions in this domain.

This study used the context of a real-world literacy and reading game, called *Navigo*, for primary school children with diverse learning characteristics, to explore how the design of feedback in the game impacted their learning. The research empirically evaluated how three groups of children with different profiles—primary-aged novice readers (NR), children with reading difficulties (CwRD), and children learning English as a Foreign Language (EFL)—attended to, understood, and acted upon *visual, non-verbal outcome feedback* and *auditory, verbal elaborative feedback* in the game. By comparing three groups of learners with different characteristics, e.g., in terms of age, abilities, and language familiarity, we aimed to pinpoint whether these characteristics resulted in differential processing of feedback, which might, in turn, have implications on how we design game feedback for diverse learners. We implemented an active intervention approach with mixed-methods analysis, that supported significant quantitative findings with rigorous qualitative interpretations. Our findings informed methodological considerations for future research, as well as recommendations for incremental improvements in game design that could improve children's processing of feedback.

Specifically, our results revealed that visual, non-verbal outcome feedback embedded within the focal learning task is most effective in attracting children's attention across the three learner groups, whilst also accurately communicating that the child had made an error. Features peripheral to the learning task were not often identified by children, even for the gain/loss of rewards, which are intended to be a key motivational element in the game. This has implications for future research which might investigate (e.g., through eye-tracking methods) whether children could not attend to peripheral visual outcome feedback features due to cognitive load, or whether they attended to these features but were not consciously aware that they did so, as well as whether they become more appreciative of these features after repeated exposure to the learning game.

Additionally, we found that the verbal modality of the elaborative feedback posed challenges for children's processing. Several NR and CwRD claimed not to hear the feedback, suggesting that replayability of feedback may be important in the auditory, verbal modality. Some of these children ignored the feedback completely and continued playing while the feedback was being narrated, which suggests that introducing interruptive feedback (e.g., that pauses play) may draw more attention to it. Furthermore, we can imply from these findings that enhancing elaborative feedback in the visual modality might help learners make connections between unfamiliar, verbally spoken words and their existing vocabulary. Specifically, future work might investigate the efficacy of either (i) a visual, verbal (i.e., written) modality to accompany auditory, verbal hints (particularly for EFL children) or (ii) the integration of visual, non-verbal cues with the spoken hint, which could make the elaborative feedback more intrinsic to the learning task; these directions have yet to be explored. A notable implication for pedagogical practice is that children may need extrinsic support when it comes to using elaborative feedback in games, and we make several recommendations on how extrinsic support might be implemented in the classroom and beyond.

Finally, we believe that our methodological approach—that is, an active intervention protocol with mixed-methods analyses, undertaken in the context of a real-world learning game—also serves as a contribution to the domain. This approach, in combination with additional techniques like eye-tracking, might help other researchers demonstrate how individual game features and design decisions impact children's game-based behaviours, which we expect to improve existing approaches to game design for children.

In summary, the primary contributions of this research are that it advances our understanding of how *diverse children* (rather than adults) process and act upon visual and verbal feedback in digital learning environments, which is an area that is sorely understudied in the human-computer interaction design domain. In addition, our findings challenge mainstream game design recommendations about the best modality for elaborative feedback, and we discuss different perspectives on potential design solutions and pedagogical implications. Methodologically, our work has implications for the evaluation of technology design with diverse children and suggests future directions for research in this area.

8 ACKNOWLEDGEMENT

We would like to thank Rachel Finapiri, Nelly Joye, Yvonne Vezzoli, and Seray Ibrahim for contributing to the data collection. This work was funded by iRead (project no: 731724) H2020 Innovation Action EU Project.

References

[1] Aleven, V. et al. 2016. Developing a Teacher Dashboard For Use with Intelligent Tutoring Systems. *Proceedings of the 4th International Workshop on Teaching Analytics* (Lyon, France, 2016), 44–50.

[2] Attali, Y. and van der Kleij, F. 2017. Effects of feedback elaboration and feedback timing during computer-based practice in mathematics problem solving. *Computers and Education*. 110, (2017), 154–169. DOI:https://doi.org/10.1016/j.compedu.2017.03.012.

[3] Baek, Y.K. 2008. What hinders teachers in using computer and video games in the classroom? Exploring factors inhibiting the uptake of computer and video games. *Cyberpsychology and Behavior*. 11, 6 (2008), 665–671. DOI:https://doi.org/10.1089/cpb.2008.0127.

[4] Bangert-Drowns, R.L. et al. 1991. The Instructional Effect of Feedback in Test-Like Events. *Review of Educational Research*. 61, 2 (1991), 213–238. DOI:https://doi.org/10.3102/00346543061002213.

[5] Bares, C.B. 2011. Emerging Metacognitive Processes During Childhood: Implications for Intervention Development with Children. *Child and Adolescent Social Work Journal*. 28, 4 (2011), 291–299. DOI:https://doi.org/10.1007/s10560-011-0233-1.

[6] Beasley, T.M. and Schumacker, R.E. 1995. Multiple Regression Approach to Analyzing Contingency Tables: Post Hoc and Planned Comparison Procedures. *Journal of Experimental Education*. 64, August (1995), 79–93. DOI:https://doi.org/10.1080/00220973.1995.9943797.

[7] Benton, L. et al. 2018. A critical examination of feedback in early reading games. *CHI Conference on Human Factors in Computing Systems - Proceedings*. 2018-April, (2018). DOI:https://doi.org/10.1145/3173574.3173947.

[8] Benton, L. et al. 2021. Designing for "challenge" in a large-scale adaptive literacy game for primary school children. *British Journal of Educational Technology*. 52, 5 (2021), 1862–1880. DOI:https://doi.org/10.1111/bjet.13146.

[9] Benton, L. et al. 2019. What's Missing: The Role of Instructional Design in Children's Games-Based Learning. *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019)* (Glasgow, Scotland, May 2019), 11-undefined.

[10] Bias, R. et al. 2012. Usability/User-Centered Design in the iSchools: Justifying a Teaching Philosophy. *Journal of Education for Library and*

Information Science. 53, 4 (2012), 274–289.

[11] Billingsky, P.A. 1993. Reflections on ISO 9241: Software usability may be more than the sum of its parts. *StandardView*. 1, 1 (1993), 22–25.

[12] Boden, C. and Giaschi, D. 2007. M-stream deficits and reading-related visual processes in developmental dyslexia. *Psychological Bulletin*. 133, 2 (2007), 346–366. DOI:https://doi.org/10.1037/0033-2909.133.2.346.

[13] Bosse, M.L. and Valdois, S. 2009. Influence of the visual attention span on child reading performance: A cross-sectional study. *Journal of Research in Reading*. 32, 2 (2009), 230–253. DOI:https://doi.org/10.1111/j.1467-9817.2008.01387.x.

[14] Butler, D.L. and Winne, P.H. 1995. Feedback and Self-Regulated Learning: A Theoretical Synthesis. *Review of Educational Research*. 65, 3 (1995), 245–281. DOI:https://doi.org/10.3102/00346543065003245.

[15] Callaghan, M.N. and Reich, S.M. 2021. Mobile app features that scaffold pre-school learning: Verbal feedback and leveling designs. *British Journal of Educational Technology*. 52, 2 (2021), 785–806. DOI:https://doi.org/10.1111/bjet.13055.

[16] Carroll, S.E. 1995. The irrelevance of verbal feedback to language learning. *The Current State of Interlanguage: Studies in Honor of William E. Rutherford*. L. Eubank et al., eds. John Benjamins Publishings. 73–88.

[17] Carvalho, M.B. et al. 2015. An activity theory-based model for serious games analysis and conceptual design. *Computers and Education*. 87, (2015), 166–181. DOI:https://doi.org/10.1016/j.compedu.2015.03.023.

[18] Chabani, E. and Hommel, B. 2014. Effectiveness of visual and verbal prompts in training visuospatial processing skills in school age children. *Instructional Science*. 42, 6 (2014), 995–1012. DOI:https://doi.org/10.1007/s11251-014-9316-7.

[19] Chun, M.M. et al. 2011. A Taxonomy of external and internal attention. *Annual Review of Psychology*. 62, (2011), 73–101. DOI:https://doi.org/10.1146/annurev.psych.093008.100427.

[20] Clark, D.B. et al. 2016. Digital Games, Design, and Learning: A Systematic Review and Meta-Analysis. *Review of Educational Research*. 86, 1 (2016), 79–122. DOI:https://doi.org/10.3102/0034654315582065.

[21] Cohen, J. 1988. *Statistical power analysis for the behavioral sciences*. Lawrence Erlbaum Associates.

[22] Department for Education and Department for Health 2015. *Special educational needs and disability code of practice: 0 to 25 years*.

[23] Dunwell, I. et al. 2011. Four-dimensional consideration of feedback in serious games. *Digital Games and Learning*. (2011), 42–62. DOI:https://doi.org/978-1-4411-9870-9.

[24] Dye, M.W.G. and Bavelier, D. 2010. Differential development of visual attention skills in school-age children. *Vision Research*. 50, 4 (2010), 452–459. DOI:https://doi.org/10.1016/j.visres.2009.10.010.

[25] Edele, A. and Stanat, P. 2016. The Role of First-Language Listening Comprehension in Second-Language Reading Comprehension. *Journal of Educational Psychology*. 108, 2 (2016), 163–180.

[26] Egi, T. 2010. Uptake, modified output, and learner perceptions of recasts: Learner responses as language awareness. *Modern Language Journal*. 94, 1 (2010), 1–21. DOI:https://doi.org/10.1111/j.1540-4781.2009.00980.x.

[27] van Es, E.A. and Sherin, M.G. 2002. Learning to Notice : Scaffolding New Teachers ' Interpretations of Classroom Interactions. *Journal of technology and teacher education*. 10, April 2014 (2002), 571–596.

[28] Facoetti, A. et al. 2006. The relationship between visuo-spatial attention and nonword reading in developmental dyslexia. *Cognitive Neuropsychology*. 23, 6 (2006), 841–855. DOI:https://doi.org/10.1080/02643290500483090.

[29] Falloon, G. 2013. Young students using iPads: App design and content influences on their learning pathways. *Computers and Education*. 68, (2013), 505–521. DOI:https://doi.org/10.1016/j.compedu.2013.06.006.

[30] Fan, J.E. and Turk-Browne, N.B. 2016. Incidental biasing of attention from visual long-term memory. *Journal of Experimental Psychology: Learning Memory and Cognition*. 42, 6 (2016), 970–977. DOI:https://doi.org/10.1037/xlm0000209.

[31] Field, J. 2013. Cognitive validity. *Examining Listening: Research and Practice in Assessing Second Language Listening*. A. Geranpaye and L. Taylor, eds. Cambridge University Press. 77–151.

[32] García-Pérez, M.A. and Núñez-Antón, V.V. 2003. Cellwise Residual Analysis in Two-Way Contingency Tables. *Educational and Psychological*

Measurement. 63, 5 (2003), 825–839. DOI:https://doi.org/10.1177/0013164403251280.

[33] Gass, S.M. et al. 2017. Salience in second language acquisition and related fields. *Salience in second language acquisition*. S.M. Gass et al., eds. Routledge. 1–18.

[34] Gauthier, A. et al. 2022. Adoption and usage challenges of a Learning Analytics Dashboard for game-based learning : design and implementation implications. *Companion Proceedings 12th International Conference on Learning Analytics & Knowledge (LAK22)* (2022), 1–4.

[35] Gauthier, A. et al. 2022. Manipulating interface design features affects children' s stop-and-think behaviours in a counterintuitive-problem game. *Transactions on Computer-Human Interaction*. 29, 2 (2022), in press. DOI:https://doi.org/http://dx.doi.org/10.1145/3485168.

[36] Gauthier, A. and Jenkinson, J. 2018. Designing productively negative experiences with serious game mechanics: Qualitative analysis of game-play and game design in a randomized trial. *Computers & Education*. 127, 2018 (2018), 66–89. DOI:https://doi.org/10.1016/j.compedu.2018.08.017.

[37] Gombert, J.E. 1992. *Metalinguistic development*. Harvester-Wheatsheaf.

[38] Grawemeyer, B. et al. 2015. Light-Bulb Moment? Towards Adaptive Presentation of Feedback based on Students' Affective State. *Proceedings of the 20th International Conference on Intelligent User Interfaces* (Atlanta, GA, 2015), 400–404.

[39] Hattie, J. and Gan, M. 2015. Instruction Based on Feedback. *Handbook of Research on Learning and Instruction*. 11237 (2015). DOI:https://doi.org/10.4324/9780203839089.ch13.

[40] Hattie, J. and Timperley, H. 2007. The power of feedback. *Review of Educational Research*. 77, 1 (2007), 81–112. DOI:https://doi.org/10.3102/003465430298487.

[41] Hayes, A.F. and Krippendorff, K. 2007. Answering the call for a standard reliability measure for coding data. *Communication Methods and Measures*. 1, (2007), 77–89.

[42] Hitch, G.J. et al. 1989. Visual and phonological components of working memory in children. *Memory & Cognition*. 17, 2 (1989), 175–185. DOI:https://doi.org/10.3758/BF03197067.

[43] Holmes, W. 2011. Using game-based learning to support struggling readers at home. *Learning, Media and Technology*. 36, 1 (2011), 5–19. DOI:https://doi.org/10.1080/17439884.2010.531023.

[44] Iacovides, I. et al. 2014. Player strategies: Achieving breakthroughs and progressing in single-player and cooperative games. *CHI PLAY 2014 - Proceedings of the 2014 Annual Symposium on Computer-Human Interaction in Play*. (2014), 131–140. DOI:https://doi.org/10.1145/2658537.2658697.

[45] IBM Corporation 2016. SPSS Statistics. IBM Corporation.

[46] Johnson, C.I. et al. 2017. Designing Effective Feedback Messages in Serious Games and Simulations: A Research Review. *Instructional Techniques to Facilitate Learning and Motivation of Serious Games*. P. Wouters and H. van Oostendorp, eds. Springer International Publishing Switzerland.

[47] Johnson, C.I. et al. 2017. Designing Effective Feedback Messages in Serious Games and Simulations: A Research Review. *Instructional Techniques to Facilitate Learning and Motivation of Serious Games*. P. Wouters and H. van Oostendorp, eds. Springer. 119–140.

[48] Ke, F. 2016. Designing and integrating purposeful learning in game play: a systematic review. *Educational Technology Research and Development*. 64, 2 (2016), 219–244. DOI:https://doi.org/10.1007/s11423-015-9418-1.

[49] Ke, F. et al. 2019. *Interdisciplinary Design of Game-based Learning Platforms*. Springer.

[50] Van Kesteren, U.E.H. et al. 2003. Assessing usability evaluation methods on their effectiveness to elicit verbal comments from children subjects. *Proceedings of the 2003 Conference on Interaction Design and Children, IDC 2003*. January (2003), 41–49. DOI:https://doi.org/10.1145/953536.953544.

[51] Van Der Kleij, F.M. et al. 2012. Effects of feedback in a computer-based assessment for learning. *Computers and Education*. 58, 1 (2012), 263–272. DOI:https://doi.org/10.1016/j.compedu.2011.07.020.

[52] Kulhavy, R.W. et al. 1985. Feedback complexity and corrective efficiency. *Contemporary Educational Psychology*. 10, 3 (1985), 285–291.

DOI:https://doi.org/10.1016/0361-476X(85)90025-6.

[53] Lee, M. and Révész, A. 2020. Promoting grammatical development through captions and textual enhancement in multimodal input-based tasks. *Studies in Second Language Acquisition*. 42, 3 (2020), 625–651. DOI:https://doi.org/10.1017/S0272263120000108.

[54] Long, D.R. 1990. What you don't know can't help you: An exploratory study of background knowledge ad second language listening comprehension. *Studies in Second Language Acquisition*. 12, 1 (1990), 65–80.

[55] Mavrikis, M. et al. 2019. Intelligent analysis and data visualisation for teacher assistance tools: The case of exploratory learning. *British Journal of Educational Technology*. 50, 6 (2019), 2920–2942. DOI:https://doi.org/10.1111/bjet.12876.

[56] Mayer, R.E. and Moreno, R. 2003. Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*. 38, 1 (2003), 43–52. DOI:https://doi.org/10.1207/S15326985EP3801_6.

[57] Mayer, R.E. and Pilegard, C. 2014. Principles for Managing Essential Processing in Multimedia Learning: Segmenting, Pre-training, and Modality Principles. *The Cambridge Handbook of Multimedia Learning*. R.E. Mayer, ed. Cambridge University Press. 316–344.

[58] McLaren, B.M. and Nguyen, H. 2021. AIED Digital Learning Games: Where We Are and How We Might Make a Bigger Impact. *Handbook of Artificial Intelligence in Education*. B. Boulay et al., eds.

[59] Narciss, S. et al. 2014. Exploring feedback and student characteristics relevant for personalizing feedback strategies. *Computers and Education*. 71, (2014), 56–76. DOI:https://doi.org/10.1016/j.compedu.2013.09.011.

[60] Nelson, H.G. and Stolterman, E. 2003. *The Design Way: Intentional Change in an Unpredictable World*. Educational Technology Publications.

[61] Nikolayev, M. et al. 2021. Review of feedback in edutainment games for preschoolers in the USA. *Journal of Children and Media*. 15, 3 (2021), 358–375. DOI:https://doi.org/10.1080/17482798.2020.1815227.

[62] Papleontiou-Louca, E. 2003. The concept and instruction of metacognition. *Teacher Development*. 7, 1 (2003), 9–30. DOI:https://doi.org/10.1080/13664530300200184.

[63] Phye, G.D. and Bender, T. 1989. Feedback complexity and practice: Response pattern analysis in retention and transfer. *Contemporary Educational Psychology*. 14, 2 (1989), 97–110. DOI:https://doi.org/10.1016/0361-476X(89)90028-3.

[64] Plass, J.L. et al. 2003. Cognitive load in reading a foreign language text with multimedia aids and the influence of verbal and spatial abilities. *Computers in Human Behavior*. 19, 2 (2003), 221–243. DOI:https://doi.org/10.1016/S0747-5632(02)00015-8.

[65] Proulx, J.-N. et al. 2017. Learning Mechanics and Game Mechanics Under the Perspective of Self-Determination Theory to Foster Motivation in Digital Game Based Learning. *Simulation & Gaming*. 48, 1 (2017), 81–97. DOI:https://doi.org/10.1177/1046878116674399.

[66] Quigley, A. et al. 2018. *Metacognition and Self-regulated Learning: Guidance Report*.

[67] Révész, A. et al. 2022. Using eye-tracking as a tool to develop L2 lexical knowledge. *Language Learning and Technology*. (2022), 1–47.

[68] Ringbom, H. and Jarvis, S. 2009. The Importance of Cross-Linguistic Similarity in Foreign Language Learning. *The Handbook of Language Teaching*. M.H. Long and C.J. Doughty, eds. Wiley-Blackwell. 106–118.

[69] Rose, J. 2009. *Identifying and Teaching Children and Young People with Dyslexia and Literacy Difficulties*.

[70] Roy, P. et al. 2019. *Stop and Think: Learning Counterintuitive Concepts*.

[71] Schmidt 2001. Attention. *Cognition and second language instruction*. P. Robinson, ed. Cambridge University Press. 3–32.

[72] Schmidt, R. 2010. Attention, Awareness, and Individual Differences in Language Learning. *Proceedings of CLaSIC 2010*. 4, (2010), 721–737.

[73] Schmidt, R. 1994. Deconstructing consciousness in search of useful definitions for applied linguistics. *Consciousness in second language learning*. J.H. Hulstijn and R. Schmidt, eds. 11–26.

[74] Schneider, E. and Crombie, M. 2003. *Dyslexia and foreign language learning*. David Fulton Publishers.

[75] Shute, V.J. 2008. Focus on formative feedback. *Review of Educational Research*. 78, 1 (2008), 153–189. DOI:https://doi.org/10.3102/0034654307313795.

[76] Snowling, M.J. et al. 2020. Defining and understanding dyslexia: past, present and future. *Oxford Review of Education*. 46, 4 (2020), 501–513.

DOI:https://doi.org/10.1080/03054985.2020.1765756.

[77] Takita, T. et al. 2017. Reading Aloud Training Game for Children with Auto Evaluation of Oral Reading Fluency. *Proceedings of International Conference on Entertainment Computing* (Tsukuba City, Japan, 2017), 404–408.

[78] Vasalou, A. et al. 2017. Digital games-based learning for children with dyslexia: A social constructivist perspective on engagement and learning during group game-play. *Computers and Education*. 114, December (2017), 175–192. DOI:https://doi.org/10.1016/j.compedu.2017.06.009.

[79] Vasalou, A. et al. 2021. Do children with reading difficulties benefit from instructional game supports? Exploring children's attention and understanding of feedback. *British Journal of Educational Technology*. June (2021), 1–15. DOI:https://doi.org/10.1111/bjet.13145.

[80] Wang, F. and Hannafin, M.J. 2005. Design-Based Research and Technology-Enhanced Learning Environments. *Educational Technology Research and Development*. 53, 4 (2005), 5–23.

[81] Wilkinson, H.R. et al. 2019. Domain-Specific Inhibitory Control Training to Improve Children's Learning of Counterintuitive Concepts in Mathematics and Science. *Journal of Cognitive Enhancement*. 4, (2019), 296–314. DOI:https://doi.org/https://doi.org/10.1007/s41465-019-00161-4.