What's Missing: The Role of Instructional Design in Children's Games-Based Learning

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ABSTRACT

Learning games that address targeted curriculum areas are widely used in schools. Within games, productive learning episodes can result from breakdowns when followed by a breakthrough, yet their role in children's learning has not been investigated. This paper examines the role of game and instructional design during and after breakdowns. We observed 26 young children playing several popular learning games and conducted a moment-by-moment analysis of breakdown episodes. Our findings show children achieve productive breakthroughs independently less than half of the time. In particular, breakdowns caused by game actions are difficult for children to overcome independently and prevent engagement with the domain skills. Importantly, we identify specific instructional game components and their role in fostering strategies that result in successful breakthroughs. We conclude with intrinsic and extrinsic instructional design implications for both game designers and primary teachers to better enable children's games-based learning.

CCS CONCEPTS

• **Applied computing** → **Computer games**; Computer-assisted instruction.

KEYWORDS

Learning games; instructional design; children; reading.

CHI 2019, May 4–9, 2019, Glasgow, Scotland UK

ACM ISBN 978-1-4503-5970-2/19/05…$15.00
https://doi.org/10.1145/3290605.3300812

ACM Reference Format:
Laura Benton, Asimina Vasalou, Wolmet Barendregt, Leona Bunting, and Andrea Révész. 2019. What's Missing: The Role of Instructional Design in Children's Games-Based Learning. In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019), May 4–9, 2019, Glasgow, Scotland UK*. ACM, New York, NY, USA, 11 pages. https://doi.org/10.1145/3290605.3300812

1 INTRODUCTION

Learning game use in schools is increasing [34, 35], with many games aimed at younger students [24]. Learning games often target development of foundational skills and knowledge, e.g. mathematics or literacy, to support teacher delivery of the statutory curriculum [3, 9, 37]. Children's learning in the context of games has been broadly theorised across a continuum, ranging from *generic skills* such as creativity or media literacy to *domain-specific skills* like geometry or reading [21]. Learning games designed for the classroom tend to prioritise the latter, in particular by targeting academic knowledge/skill acquisition and practice [20, 21].

Empirical studies reporting classroom technology use have shown children often play games without external scaffolding, e.g. in [25] a case study of Swedish preschools when teachers provided children with a computer game they then took a backseat role in its use. Similarly (in the US) Inan et al. found that practice-based digital apps, such as games, were often used by children without extensive peer or teacher support [15]. These findings are hardly surprising when situated in the broader context of teaching. Managing increasingly busy and diverse classes, teachers often lack time to develop new scalable pedagogical approaches [32]. Among other implications, these observations highlight the ever more critical role of quality in-game instructional design to facilitate children's learning during game play experiences [3, 6, 20, 37].

Challenge is a central dimension of game play, and thus children are likely to experience conceptual or systemic contradictions, i.e., *game breakdowns*, as part of their game interactions. The potential of game breakdowns to foster children's learning depends on their ability to overcome them through *game breakthroughs* [14]. Learning can occur through the player applying one or more different strategies to achieve a subsequent breakthrough [14, 28, 33]. There are multiple types of learning within games: the player typically learns about *how to play the game*, but learning games provide the opportunity to also learn *domain-specific knowledge* and *skills*, facilitated by the instructional design [2, 20, 38].

The goal of the present work is to understand children's breakdowns and breakthroughs during these learning episodes. Specifically, we ask: *why do young children (age 5-7) experience breakdowns in learning games? Are they able to achieve breakthroughs independently, and how?* We apply a wide lens on game design to pick out the different instructional game design elements that facilitate game breakdowns and breakthroughs. We examine these research questions in an empirical study involving the observation of 26 young primary school children (age 5-7 years) playing existing commercial reading games currently being used in UK schools. In the UK, a large number of children struggle with learning to read, with around 25% of young adults growing up with poor literacy [22]. At the same time, there is a proliferation of learning games that target the 5-7 age group and are typically designed for independent play. Children of this age are just starting to develop independent learning strategies and there is thus a need to explore how games can facilitate this development. Therefore, focusing on a population and an area of knowledge where there is a known difficulty as well as a gap in knowledge around appropriate game design allows us to approach this context as a critical case study [27] that has strategic importance to our broader research focus.

We make three contributions intended to inform learning game designers as well as teacher pedagogy. First, we present a methodological approach to support learning game designers in evaluating possible breakdown causes during children's game play as well as in understanding how instructional design choices can interact with learning breakthroughs. Second, we identify usability as an avoidable cause to children's breakdowns suggesting common issues that can be easily addressed by the commercial sector to improve early learning game usability. Third, we highlight key instructional, learning and game components that may foster children's independent breakthroughs and propose suggestions for how extrinsic teacher instruction can help address gaps in current game design.

2 RELATED LITERATURE

Bogost [4] defines play as "a way of operating a constrained system in a gratifying way" in which these design constraints offer possible spaces for play. Within games, players experience and overcome failure [18, 30, 31], with the existence of "opportunities for success and overcoming difficulties" being one of the defining features of games [17]. Bogost [4] goes on to suggest that rather than overcoming this in-built structure that instead play is in how the player operates within it. The role of these breakdowns within games-based learning has been an area of focus for games researchers [14, 28].

Iacovides et al. [14] provide further clarity on the reasons for game breakdowns, explaining breakdowns may follow from issues related to (i) *player actions* when a player undertakes the required game action unsuccessfully; (ii) *player understanding* when a player does not know what to do next; or (iii) *player involvement* when a player becomes bored or frustrated. However, despite the potential significance of breakdowns for learning, not all lead to learning [14]. Learning is likely to occur only when a breakdown is followed by a breakthrough in *understanding* [14]. To ensure that understanding is achieved and subsequent progress made, the game mechanics and learning outcomes should be linked [10, 19]. This prevents players from circumventing the learning by finding other ways to progress (i.e. through *action* breakthroughs) which do not require breakthroughs in understanding [14]. In further research, Iacovides et al. [13] identified five strategies (trial + error; experiment; repetition; stop + think; take the hint) that adult players utilise to achieve breakthroughs in games. They evidence how game design directs breakthroughs e.g. by providing hints, but also how the player and possibilities for game actions interact in different ways. For example, whereas some players engage in trial and error to progress, others take more strategic actions where hypotheses are tested and game outcomes evaluated.

In the context of learning games, this relationship between the learner and the game design toward achieving a game breakthrough is particularly significant. Aiming to facilitate specific learning outcomes, learning game design is characterised by several instructional dimensions and as Wouters and van Oostendorp [38] show well-designed instructional support (e.g. modeling, modality of explanations and feedback) are more effective for learning. Carvalho et al. [5] highlight a need to further examine these instructional dimensions to understand precisely *how* they can support better learning outcomes. They propose the ATMSG model which can be used to analyse how learning happens in these games. It specifically considers the *actions, tools* and *goals* relating to the game, learning and instructional design components, each of which may have different subjects (game designer/teacher/player) and motives (have fun/fulfil course requirements/raise learner's interest), but share the same tool (learning game). The ATMSG model also subdivides the instructional component into *intrinsic* (instructional design within the game and how it supports learning) and *extrinsic* activity (overall learning context and how a teacher supports learning before, during and after game play). They present a

Table 1: Overview of school and child demographics

School	Description	No. of Students
School A	Rural, high SES, non-fee paying primary school	4 students (1 girl, 3 boys)
School B	Suburban, high SES, non-selective fee-paying girls primary school	14 students (all girls)
School C	Inner city, low SES, non-fee paying faith primary school	8 students (4 boys, 4 girls)

'unified vocabulary' which can be used to support identification and classification of components e.g. **entity manipulation** is a *game action* category manifesting through game interactions such as 'match', or 'select' (among others).

3 RESEARCH MOTIVATION

In this paper, we examine young children's breakdowns and subsequent independent breakthroughs when playing games that target reading skill development. We take a holistic approach, considering aspects of the game, learning and instructional design that may affect the potential for productive breakdowns and/or support successful breakthroughs that advance a child's learning. Our research questions include: **RQ1** - What are the common causes of young children's learning game breakdowns? **RQ2** - How often are breakdowns followed by breakthroughs and what strategies do children use to independently achieve these breakthroughs?

4 METHODOLOGY

Participants

Twenty-six children from three UK primary schools participated. As Table 1 shows, schools were selected to cover a broad spectrum of contexts (i.e. location, socioeconomic status (SES) and school type). The children were aged 5-7 years old (Years 1 and 2 of primary school). While year group was our main selection criterion, we also ensured participants did not have a suspected or formal learning difficulty diagnosis.

Games Selection

We selected four mini-games to focus on through three systematic steps. First, we reviewed the learning aims of early reading, and identified that phonology (phonemic awareness and phonics), morphology and exception words were skills taught across the early primary years [8]. These reading skills formed criteria for game selection. We focused on mini-games which are typically preferred by teachers as they fit more easily within their many extrinsic constraints, such as short lessons and specific skill focus. Furthermore they are seen as low risk as they are quick to learn and also inexpensive [9, 31]. Second, to identify suitable games, we consulted teachers and other reading technology experts. Through this process, two widely used reading games that included mini-games targeting these reading skills were selected: Teach Your Monster to Read (TYMTR)[1] and Reading Eggs (RE)[2]. TYMTR is an online and app-based series of mini-games integrated in a broader game world focusing on the first key stages of reading (age 5-7 years). It teaches phonics, exception words, and reading for meaning. The content and game sequencing also complements the UK government's Letters and Sounds programme. It is freely available to play via the website as well as through a paid-for app, and has been used by over 1.5 million children. RE is an extensive online and app-based reading programme of mini-games and activities (2-13 years). It covers a range of reading skills, including phonics and phonemic awareness, exception words, vocabulary, reading for meaning, and fluency. It has been used by over 10 million children worldwide. The widespread use of these two games suggested that primary school children were likely to encounter these games either in school or at home. In a final step, four mini-games from TYMTR and RE were chosen in consultation with the teachers in each school to ensure the game learning aims and content were appropriate to the level expected in the year groups involved. This ensured that the children had some prior knowledge of the linguistic concepts being practiced, but that the mini-game would still present some level of challenge. This contributed to some differences between the mini-games and the choice of reading content level that the Y1 (ages 5-6) and Y2 (ages 6-7) participants played. Table 2 provides a full overview of the mini-games including a description of the overall implementation in terms of the gaming, learning and intrinsic instruction components, following the template set out in Carvalho et al. [5] as part of the ATMSG game design analysis model.

Procedure

The children participated in mixed ability pairs (total 13 pairs) chosen by their teachers. This ensured the children felt more comfortable and allowed the researcher to better understand the rationale behind particular actions and decisions through their discussions. After explaining the study and obtaining their informed consent, the researcher asked the children to take turns playing on a shared tablet. Each child played two mini-games (10-15min game play time per pair) and the

[1]https://www.usbornefoundation.org.uk/teachyourmonstertoread/
[2]https://readingeggs.co.uk/about/

Table 2: Mini-game component description based on [5] *same game mechanics with differently levelled content.

Mini-Game	Gaming	Learning	Intrinsic Instruction
Parachute Teach Your Monster to Read phonology mini-game **Participants:** Year 1 For screenshot see: https://bit.ly/2TAkm3w	For each presented word the player has to choose a series of two balloons that match those attached to their avatar. The game mechanics alternate between balloons with letters (tapped once) and audio balloons (tapped once to listen and twice to select). The aim is build all words correctly, with unlimited attempts for each word.	Each target word is constructed by selecting individual graphemes (letters) or phonemes (sounds) that together make that word. The game supports the acquisition of word blending and segmenting skills.	Verbal instructions are provided once for each word but not repeatable. Errors are implicitly communicated by repeating the same word and successes result in progress to the next word, no explicit feedback is given. The skill practiced alternates between sounds and letters adding to the complexity.
What's Missing (WM) Reading Eggs phonology mini-game **Participants:** Year 2	Matching pairs are selected by tapping on two cards in turn. There are two types of card (letters only and image + word with gap) with a match being one of each type, however the game allows two cards of the same type to be selected. All cards need to be matched (with less than 2 incorrect matches) to complete the game.	The full word should be deduced from the picture and constructed by finding the letters that correctly fill the gap. The game supports the acquisition of word blending and segmenting skills.	Verbal and written instructions are provided once at the start of the game but are not repeatable. Errors are communicated through losing a 'life' and successes are explicitly communicated through the cards changing to a green tick. The game reduces in complexity as cards are paired and the number of possible options is reduced.
Write the Banner (WtB) Reading Eggs exception words mini-game **Participants:** Year 1/2*	The spoken sentence is recreated by dragging tiles into gaps in the banner. Each banner gap has three possible options (positioned underneath and highlighted) but it is possible to drag any tile to a gap. Each gap should be filled in turn, with an unlimited number of attempts at each.	The sentence needs to be remembered through identifying each correct word tile in turn. The game supports whole word recognition practice, particularly the reading of common exception words.	Verbal and written instructions are provided once at the start of the game but are not repeatable. The target sentence is read aloud once but is also not repeatable. Errors cannot be made as incorrect words snap back to their starting position.
Buzzy's Word Machine (BWM) Reading Eggs morphology mini-game **Participants:** Year 1/2*	For each word a series of two tiles should be dragged onto the 'word machine', one for the root word and one for the suffix. 2-3 tile options are presented at each selection point. Each option can be tried until the correct tile is dragged into the correct position.	The word spoken aloud should be remembered, with the root word firstly identified and then the suffix from the available options. The game supports reading words that contain suffixes (i.e. common word endings).	Verbal and written instructions are provided once at the start of the game but are not repeatable. The target word can be heard again by pressing the 'listen' button. A picture also provides a hint to the word. Incorrect selections disappear from the screen until only the correct option is left to choose.

session was audio and screen recorded. The researcher set up and verbally explained how to play each mini-game, reinforcing the game instructions e.g. "you need to drag the correct words up to the banner to make the sentence you hear", to avoid breakdowns due to obvious usability problems. The children were then asked to try to complete the mini-game independently. To mitigate any emotional risks they might experience through making errors the researcher intervened with additional guidance if the child appeared distressed or completely stuck and unable to progress. At the end of each session we asked the children to reflect on their performance in each mini-game.

Analysis

Identification of Breakdowns. Given our research goals, the critical incidents analysed in this study were game breakdowns as defined by [14, 28]. Through an analysis of screen/audio recordings of children's gameplay, we documented 46 game breakdowns (defined below) across the 13 child pairs.

Analytic Framework. Within these 46 breakdowns, we analysed the micro-level unfolding of a child's gameplay using an analytic framework based on [28], as it supports game breakdown identification, is useful for "establishing how players develop strategies" [14] and has been highlighted as particularly appropriate for observing novice learners [28]. Though the original framework was initially couched in Activity Theory, given the goals of our research, we adapt it to use as an observational tool to capture the relationship between game design and children's moment-by-moment game play. The adapted framework included the following: (1) Game actions and operations (2) Rationale of operations which lead to breakdowns (3) Observable evidence of breakthroughs.

Table 3 illustrates these dimensions through an example from *WtB*, which requires first listening to a sentence and subsequently choosing the correct words to place in a banner with five gaps. Each banner gap has three multiple-choice options underneath, which are visible on screen. Here the child has forgotten the fourth word and so tries another adjective (still meaningful in the sentence). It is also operationally possible to drag an option from a different set, which the child then tries. In offering a systematic way to document children's moment-to-moment actions, this framework allowed us to observe how game actions led to breakdowns, what actions followed, and if these actions subsequently led to a breakthrough contributing toward **RQ2**. The game actions taken also allowed us to identify particular contradictions between game and child contributing to the development of a rationale for these breakdowns and thus informing **RQ1**. However, to fully address our research questions, it was necessary to extend the framework with three additional dimensions: breakdown type and strategy, and extrinsic intervention.

Breakdown type reflects the recent theoretical account of breakdowns developed by Iacovides et al [14]. We distinguish between *action breakdowns* (a result of the player not performing a game action e.g. dragging a correct answer to an incorrect hotspot) and *understanding breakdowns* (related to the player not knowing where to go, or what to do because of a conceptual issue e.g. a child voicing out "how should I spell the word 'share'?" when the target word is 'fair'.). We found no evidence in our data of *involvement breakdowns* and therefore this type was not included within our analysis. There were 3 cases of an understanding and action breakdown occurring as part of the same action (e.g. dragging an incorrect word to an incorrect position). These cases were initially coded as a breakdown in understanding. If the child selected the correct answer but continued to miss the correct position it would then be coded as an understanding breakthrough and an action breakdown.

Strategy was added to further inform **RQ2**, capturing how children independently achieved game breakthroughs. To examine the strategies the children used following a breakdown, we used a taxonomy of strategies game players employ to overcome breakdowns and achieve breakthroughs, developed by [13]. Given our focus, we concentrated on five strategies used by players to independently overcome breakdowns: (1) Trial + Error (exploring possible actions and outcomes); (2) Experiment (forming hypothesis on basis of prior knowledge or trial + error, test out then reflect and reform if needed); (3) Repetition (rehearsing, refining or repeating same action several times); (4) Stop + Think (pausing, reflecting or not acting within the game) (5) Take the Hint (using in-game feedback to inform subsequent action).

Extrinsic intervention was included in our analysis to document the guidance offered by the researcher or peer. By observing whether external guidance contributed to subsequent breakthroughs, we better understood the breakdown rationale. In the Table 3 example the other child suggests what the word could be, helping the player successfully complete the sentence, and providing evidence that the breakdown occurred due to forgetting the specific word.

Reliability strategies. The two researchers that collected the data undertook the initial analysis phase using the framework in Table 3. The researchers met regularly to discuss their analysis to ensure a consistent coding approach. This led to the application of the 'trial + error' code being refined, for when there was evidence of a systematic sequence of actions (e.g. selecting each available option in turn). Furthermore, within our interpretive analysis (indicated in Table 3), two techniques were used to establish reliability. As highlighted in [28], it can be difficult to understand player

Table 3: Coding excerpt for WtB mini-game following [28] including: *new dimensions +interpretive analysis required.

Action	Operation	Rationale	Breakdown type*+ (Strategy*+)	Evidence of Breakthrough	Extrinsic intervention
Choosing one card to fill 4th gap on the banner	Drags incorrect word **blue** to 4th banner gap *(Incorrect feedback)*	Forgets 4th word, so tries alternative adjective	Understanding		
	Drags incorrect word **mice** to 4th gap from other column *(Incorrect feedback)*	Remembers 5th word so tries this in 4th gap	(Experiment)		
	Drags correct word **icy**		(Child guidance: understanding)	(Fills gap correctly)	Other child suggests word

intentions and to identify whether a breakdown occurred. To address this in our study, we triangulated our own interpretations of each breakdown with children's post-game reflections. In some cases, this contributed to a better articulation of the breakdown rationale. Additionally, the rationale was inferred through the 'extrinsic intervention' coding. When the breakdown rationale could not be identified, we did not proceed in further coding the data.

To further ensure the reliability of breakdown type and strategy codes a different approach was used. A subset of the data was coded by a third researcher (and paper co-author) not involved in data collection. This coder examined 30% (suggested as acceptable in previous research [26]) of the breakdowns (covering one breakdown per pair spread across all mini-games) and coded both breakdown type and the strategies used. The value for Cohen's Kappa [7] was 0.71, indicating a substantial agreement between the coders [23]. The rest of the breakdown types and strategies was therefore analysed by a single coder (one of the initial researchers).

5 RESULTS

Common causes of breakdowns (RQ1)

Our analysis showed that children experienced both action and understanding breakdowns. We identified four primary causes, presented below with supporting examples.

Disconnect between action and expected outcome. Children experienced action breakdowns across all mini-games. These were characterised by a misalignment in children's expectations of how the game should react to their actions and their actual experience of the game. *WtB* and *BWM* in particular required words or word segments to be dragged to an onscreen hotspot. In *WtB*, although the hotspot was visually indicated on the banner, it was also highly sensitive. This resulted in children dropping correct word tiles in the right position, yet these tiles bounced back. Within *BWM*, the instructions verbally guided the player to 'drop the word' into the machine. Given its shape, children interpreted the ellipse on top of the machine to be the appropriate hotspot instead of the bottom of the machine. *Parachute* alternated between segmenting (selecting letters representing each sound in a word) and blending (selecting each individual sound in a word), with balloon options displaying different letter(s) or containing a sound that the player tapped to hear. In the segmenting mode, the child tapped one of three balloon options each displaying a letter to make their choice. Within the blending mode, the game required the child to tap twice, first to hear the sound the balloon represented and then to make their choice. Having started the game in the segmenting mode, when proceeding to blending, some children tapped the balloon only once expecting the game to progress. In summary, a diverse set of usability issues underpinned a disconnection between the child's game action and the expected outcome. In *WtB* there was an incongruence between children's prior knowledge of touch interfaces and the high sensitivity of the mini-game in question. In *BWM* the hotspot did not correspond to the instruction and the game visuals. Parachute presented two different input conventions within the same mini-game.

Misunderstanding game rules. With games governed by rules, some of the observed breakdowns showed that children misunderstood the (implicit) rules underpinning two mini-games. An awareness of these rules served to limit the number of possible game options, thus reducing the task complexity. For example in *WM* there were two card types, one displaying word part with a gap and a picture (e.g. "Fl_"), and another with 1-2 letters that could fill the gap (e.g. "ag"). If the player selected a first card type, only half the remaining cards would be possible options despite all cards being available to select. Evidencing a lack of understanding of these rules, some children attempted to combine cards of the same type. Similarly in *WtB*, for each of the five banner gaps there were three word tile options underneath. Even though many children correctly started the task in the first gap, they went on to select word tiles associated with other banner gaps.

Table 4: Overview of breakdown types and % breakthroughs by mini-game.

Mini-game	No. action breakdowns (no. pairs experiencing breakdown)	% breakdowns followed by a breakthrough	No. understanding breakdowns (no. pairs experiencing breakdown)	% breakdowns followed by a breakthrough
Parachute	2 breakdowns (2/8 pairs)	0%	6 breakdowns (4/8 pairs)	67%
WtB	3 breakdowns (3/13 pairs)	33%	9 breakdowns (7/13 pairs)	11%
BWM	7 breakdowns (6/13 pairs)	29%	11 breakdowns (6/13 pairs)	55%
WM	1 breakdown (1/5 pairs)	0%	7 breakdowns (3/5 pairs)	57%
Total	**13 breakdowns**	**23%**	**33 breakdowns**	**45%**

This enlarged the scope of possibilities from 1/3 to 1/15, as a result also increasing the task complexity.

Difficulties with underlying pedagogic approach. All mini-games relied on particular pedagogical approaches guiding how reading skills should be taught. During children's game interactions, there were several occasions where these pedagogic approaches proved challenging for children. As described earlier, *Parachute* combined two different modes, the segmenting and blending. Alternating between sounds and letters within the same activity, however, posed difficulties for some children who could not understand why there were no letters on the balloons in the blending mode. Additionally, both *Parachute* and *BWM* drew from a pedagogic approach that moves from smaller letter units to the whole word. These games guided the child to focus on individual parts of the word in turn (i.e. individual grapheme/phoneme or morphemes) to construct the whole word. Though children often successfully selected the first word part, for the second part (the suffix) they did not understand it was still the same target word, expressing surprise when they saw just suffixes.

Difficulty with necessary cognitive strategy. The instructional game design promoted the use of certain cognitive strategies for success. Breakdowns may have in part stemmed from children not realising the importance of using these strategies, or from the strategies introducing an excessive cognitive load. Several mini-games required children to initially listen to and remember a word/sentence, which in two mini-games (*WtB* and *Parachute*) could not be replayed. Having failed to focus their attention on the initial part of the task, children were left not knowing what options to choose next. Furthermore, some mini-games (*WM* and *Parachute*) may have required additional cognitive effort to manipulate word parts, e.g. in *Parachute* on hearing "lair" the children had to segment this word into sounds (i.e. "l-air") and then translate each part to the related letter(s). Given children's requests for help in these games it was clear they were struggling to remember whole or part of words/sentences.

To summarise our RQ1 findings, action breakdowns were mostly caused by usability issues, resulting in children misunderstanding the game mechanics. Understanding breakdowns followed from a child's interaction with instructional game design dimensions. Having presented an analysis that considers causes of children's game breakdowns, Table 4 provides an overview of the two breakdown types occurring per game and pair. Overall, understanding breakthroughs were more frequent than action breakthroughs with the exception of *WtB*, demonstrating the impact of this action breakdown on children's game play.

Breakthrough frequency and strategies used (RQ2)

Across the 13 pairs there were 46 breakdowns in total, an average of 3.54 per pair (SD = 2.15) although two pairs experienced 7 and 9 breakdowns respectively. From these breakdowns 37% resulted in subsequent independent breakthroughs. Table 5 indicates that most breakthroughs made were following breakdowns in understanding. When it came to action breakdowns children were able to overcome their breakdown only around a quarter (23%) of the time. Moreover, in two mini-games (*Parachute* and *WM*) no children were able to overcome the action breakdown, though it is also noted that such breakdowns were relatively few in these two games. Due to the low number of action breakthroughs (3), we focus our analysis on understanding breakthroughs. Having presented a general overview of children's breakdowns and breakthroughs, we now focus on the kind of strategies the children used to overcome breakdowns related to understanding, with the aim to show if and how particular instructional dimensions of the game design promoted these strategies. As Table 5 shows, the strategies children successfully employed to achieve breakthroughs in understanding varied between mini-games. Our findings highlight that the mini-games tended to privilege certain strategies. The three themes below show how each game appeared to support these different strategies.

Space for exploration. Some mini-games created space for exploration and in turn supported the use of experimentation

Table 5: No. pairs successfully using each strategy to achieve a breakthrough after an understanding breakdown.

Mini-game	(1) Trial and Error	(2) Experiment	(3) Repetition	(4) Stop + Think	(5) Take the Hint
Parachute	0	4 pairs	1 pair	0	0
WtB	0	1 pair	0	0	0
BWM	6 pairs	0	0	0	0
WM	1 pair	3 pairs	0	0	0
Total	**7 pairs**	**8 pairs**	**1 pair**	**0**	**0**

strategies. For instance, *WM* presented all of the word parts to the player at the same time. The child was subsequently free to select the order in which to attempt to form each word. When children struggled forming a word they moved on to experiment with another word before coming back to their initial attempt, having now reduced the number of card options in the solution space. While *WM* facilitated exploration through the available number of options, within the segmenting mode of *Parachute* children could listen to each phoneme multiple times before making their choice. This resulted in children experimenting with tapping each balloon (to hear the phoneme). The ability to tap and listen helped them to determine whether it was the correct sound, which was reinforced by several children through voicing out the whole word before selecting their final response.

Meaningful learning content. Only one mini-game (*WtB*) required children to decode individual words before selecting an option. They then had to place the words in the right order to construct a sentence. As described earlier, this game required children to listen to, remember and replicate a sentence. However, many children either did not listen to or forgot the sentence, particularly when it used less frequent words, or was less plausible e.g. "Catty cake caught icy mice". In attempting to construct a plausible sentence, children used semantics to explore the combination of different word possibilities. For example, several of the children forgot the correct word 'icy' and experimented with other adjectives that could be used to form a meaningful sentence.

Trial and error followed by outcome feedback. All mini-games allowed children to use a trial and error strategy, the effectiveness of which was indicated through outcome feedback (i.e. information about the correctness of the response). This strategy achieved more breakthroughs in some games than others due to the differences in instructional design. Trial and error was most successful in *BWM* as each of the 2-3 options could be tried in order (left to right) until the correct response was identified through a process of elimination. Children used this strategy most frequently when unsure what word part to select. By contrast, in *WM* the child had a limited number of lives which made it more difficult to use trial and error. Each time the game restarted to use this strategy children had to remember the options they had previously gotten correct as well as those that were definitely incorrect. Similar demands on cognitive processing and memory were potential issues in *Parachute*. Several children had successfully progressed in partially building a word by choosing the correct sounds/letters. Following an incorrect answer, however, the entire word reset and they had to start again from the first letter/sound. Whilst the options remained the same, children could not always remember which letter or sound choices they had previously made errors on to employ an effective trial and error strategy on a single response.

6 DISCUSSION

Technology in the classroom can be approached as a self-directed activity that students engage in, introduced by a teacher whose role then becomes facilitative. The present work set out to characterise the nature of young children's breakdowns with education gaming technology by examining the type of breakdowns occurring (action or understanding), and investigating what game and instructional design decisions cause them. Given the context within which these games are commonly used we have then explored if children have the strategies to *independently* resolve these breakdowns, focusing on how the instructional game activity facilitates particular strategies. Below we revisit our findings. We use the unified vocabulary of the ATMSG game design analysis model [5] to scaffold our discussion and implications by connecting our findings to the gaming, learning and instructional design dimensions of the model (in bold).

Gaming and Learning Design: Avoiding Unproductive Breakdowns

Although there were substantially fewer action (than understanding) breakdowns, the children were less likely to independently recover from these, preventing them from making progress within the game. Games-based learning encompasses both learning content as well as *how to play the game* [2], in our study sometimes the latter did not occur.

Our analysis highlights specific implications for both gaming actions and tools to ensure that unproductive action breakdowns are mitigated in these areas. One primary game action issue the children experienced related to **entity manipulation**, where they struggled to drag words or word segments to the correct hotspot. Young children can struggle with actions requiring fine-grained motor skills [11], therefore it is unsurprising that games involving dragging actions with precise positioning caused challenges. Additionally, another issue arose with the **segmentation of gameplay** in *Parachute*, which incorporated alternating mechanics resulting in confusion around how to input a response. In line with previous recommendations that learning games should avoid complex game mechanics [29], we reiterate that early learning games should have simple input mechanisms and focus on a single set of mechanics within each mini-game.

Our findings also pose implications for learning actions, with the children having problems attending to and **remembering** (i.e. recalling word/sentences during *WtB* and *Parachute*) as well as **applying** (i.e. constructing words through matching appropriate cards in *WM*). Without additional instructional support to facilitate learning actions, games involving these learning actions may prevent the player from achieving a productive breakthrough in understanding. Although a 'listen again' feature is one way to support remembering (utilised in *BWM*), our results highlighted the choice of learning content can also have an impact. For example, within a reading context children were more likely to recall frequent and meaningful sentences such as "It's good to have friends". This has implications for the 'developmental fit' of learning content for the target age group [12]. These findings together suggest learning games should provide scaffolds for potentially challenging cognitive processes such as attention, memory or manipulation of learning content to avoid unproductive breakdowns due to a lack of developmental fit.

The ways in which the gaming and learning actions manifested in the games under examination, and the design implications drawn, have the potential to inform broader learning game design practice. For example, prior research on learning games for mathematics [19] showed players can require additional scaffolding when undertaking arithmetic calculations. This may result in unproductive breakdowns if performing these calculations is not the primary learning goal. Alongside their design implications, our findings also allow us to characterise an unproductive breakdown for learning. Researchers have discussed the importance of balancing the 'usability' and 'fun' elements of a game, highlighting the need for challenge within a play context that might be unwanted within other contexts [1]. While entertainment games often embed challenge into their gaming actions, the authors recognise that challenge can be due to usability problems that cause frustrations. In our case, action breakdowns occurred as a result of trivial usability problems embedded in gaming actions. Given the diversity of children's profiles it is challenging to predict and address the many potential usability issues that could occur. We selected games that are widely-used and tested in the classroom. Yet our study highlights that usability issues remain and there is thus a need for game designers to continue to engage in ongoing usability evaluation. Furthermore, usability problems were introduced through learning actions that assumed prior existence of certain cognitive skills such as memory. As we have discussed, these learning actions were not linked to learning goals, so appropriate in-game learning scaffolds were not available. Thus, both gaming and learning actions impeded children's progress in game play and created an insurmountable barrier in their ability to achieve a breakthrough.

Instructional Design: Fostering Appropriate Intrinsic and Extrinsic Strategies

Overall, our study showed that game breakdowns occurred frequently and were followed by learning breakthroughs less than 50% of the time. Whereas this might suggest that the instructional design did not scaffold independent learning, it also highlights the importance of teacher or peer-led extrinsic instruction support outside the game, the implications of which we consider next.

As Table 5 shows, children predominantly relied on two strategies, *trial and error* and *experimentation*. Iacovides et al [13] report that *trial and error* enables progress through action breakthroughs, but does not always facilitate understanding breakthroughs. In our study children used *trial and error* to circumvent their engagement with the learning content. Whilst in some cases children made progress, these actions did not evidence learning connected to the learning goal. In contrast, through *experimenting* children were able to, for example, choose initially to focus on familiar content before replicating the same learning actions with more challenging content making it a more productive learning strategy. Thus, although several strategies were used to achieve successful breakthroughs, certain strategy use may be more beneficial for learning.

In examining how instructional design encouraged strategy use, we found that *trial and error* was enabled or inhibited through the instantiation of a **limited set of choices** and **multiple chances**. In *BWM* the set of choices reduced after each incorrect response, until only the correct choice remained. This design motivated children to use just *trial and error*. The other games either allowed unlimited chances without removing incorrect options (*WtB*) or reset after a certain number of errors (*Parachute* and *WM*). This made it more challenging to use a *trial and error* strategy. By showing precisely how instructional design can facilitate *trial and error* game designers could employ these techniques to limit this strategy. Furthermore, our analysis shows that less structured instructional design provides more space for exploration, enabling opportunities for *experimentation*.

Our findings also highlight the limited use or absence of certain strategies. Whereas, *repetition* has been defined as the player repeating the same action to gain proficiency, in the context of understanding breakdowns children's ability to employ *repetition* required learning actions on their part that recalled and reproduced previously correct answers. The games that reset options (*Parachute* and *WM*) functionally enabled the use of *repetition* where the child could first repeat the responses that were correct. However, this strategy was rarely used successfully as children forgot the responses they had previously gotten correct, thus approaching the task from scratch each time. *Stop and think* and *take the hint* both required the child to apply learning actions to **evaluate** their current performance against the game learning goal. Given the basic intrinsic instructional design, e.g. no provision of elaborative feedback [17], children did not engage in these higher-order thinking processes.

In summary, our study demonstrates that children have a limited and impoverished repertoire of strategies to independently overcome their understanding breakdowns, and in many cases are not able to progress in the game on their own. So far we have identified gaps for future game design research (e.g. the need to support taking the hint) and improvements in instructional game design (e.g. design techniques for avoiding trial and error). The same results, however, can indicate a need to develop extrinsic forms of instruction outside the game. As Marklund [3] highlights, "the teacher's ability to manage gaming activities is crucial in the use of a learning game". Our findings suggest several implications for the overall extrinsic instructional design, often overlooked in previous learning game research [19, 36]. To foster the use of the *stop and think* strategy teachers could support learners in undertaking problem analysis [19] to identify the problematic aspect(s) of the activity, e.g. by making the underlying game rules more explicit. Furthermore, pre-teaching may help children build on prior learning making concrete the underlying game pedagogic approach through familiar examples, and upon which children can draw on at moments of impasse. For learning games with more extensive instructional support teachers can encourage a *take the hint* strategy by indicating how children can independently seek in-game help as well as discussing how to use the available feedback to guide further game play. Teachers could also ask prompting questions [19] to encourage *experimentation* within learning games that provide the space for this.

Limitations and Reflections

The qualitative insights and their design implications are our main contribution. The numeric data provided further context for interpreting a predominantly qualitative inquiry. The generalisability of our quantitative findings should be interpreted against the modest sample of children participating in the study, its particular demographic make up, and the games we considered. Specifically, our study included 26 participants of which there were only 7 boys. This was due in part to one of the participating schools being a girl's school. Boys in this age group may have had earlier exposure to games [16] than girls. It is thus possible that these prior literacies may have limited boys' experiences of action breakdowns. In addition, the sample of the mini-games chosen was a small subset within each of the broader reading games we initially identified. Despite this, we believe our findings are of relevance to broader early learning games; not only did these mini-game mechanics (i.e. multiple-choice and matching) present themselves repeatedly throughout the main game, albeit with different 'skins' and content, but also these are common mechanics found in early learning games. In summary, further research with a larger sample and other early learning games can examine the extent to which these findings generalise to early learners and games, for instance by exploring the transference of the breakthrough strategies we identified in other subjects such as Mathematics.

7 CONCLUSION

This paper examined the role of game and instructional design in children's breakdowns and breakthroughs within early learning games. We reported an empirical study involving 26 primary school children (aged 5-7 years) who played four existing mini-games targeting reading skills. To answer our research questions, we combined and extended existing analytic frameworks to scrutinise game play actions and to infer children's learning. Game designers may use this methodological approach to evaluate causes of children's in-game breakdowns as well as understand the interaction between specific instructional design components and learning breakthroughs. Our findings reveal apparent widespread usability issues within popular learning games, suggesting a need for the commercial sector to further engage with formative evaluation of game play and child development needs. Most importantly, we identify the instructional, learning and game components that productively support children's independent breakthroughs, while we locate gaps in current game design to facilitate higher-order strategies, also introducing new opportunities for planned extrinsic instruction.

8 ACKNOWLEDGEMENTS

We thank all the participating children as well as their teachers for supporting this research. This work is part of the iRead project which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731724.

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