International Journal of Child-Computer Interaction 40 (2024) 100635

Contents lists available at ScienceDirect

International Journal of Child-Computer Interaction

journal homepage: www.elsevier.com/locate/ijcci

Research Paper

Children's approaches to solving puzzles in videogames

Ekta Shokeen [a,*], Anthony J. Pellicone [b], David Weintrop [c], Diane Jass Ketelhut [b], Michel Cukier [d], Jandelyn Dawn Plane [e], Caro Williams-Pierce [f]

[a] College of Information Studies, University of Maryland, College Park, MD, USA
[b] College of Education, University of Maryland, College Park, MD, USA
[c] College of Education, College of Information Studies, University of Maryland, College Park, MD, USA
[d] Department of Mechanical Engineering, University of Maryland, College Park, MD, USA
[e] Computer Science, University of Maryland, College Park, MD, USA
[f] College of Information Studies, University of Maryland, MD, USA

ARTICLE INFO

Keywords:
Videogames
Puzzle solving
Children
Experience
Information

ABSTRACT

Puzzles are a core component of many videogames. While research has explored the potential of using puzzles in games to provide players with challenges they enjoy, little is known about how children seek information *while* solving puzzles in videogames. Using a constructivist grounded theory method, this study examines children's (ages 11–14) puzzle-solving approaches within a game titled *GEM of the Forest* [name anonymized]. The results show that children relied on two sources of information to solve puzzles: (1) information from the out-of-game world including players' prior game experiences, and (2) information within the game world including instructions, hints, inventory, and feedback. We present an empirically grounded theoretical model to understand children's information seeking behaviors while solving in-game puzzles. This paper contributes a theoretical understanding of children's information seeking behavior and strategies to solve puzzles in games. Additionally, we provide a description of the utility of this framework through design implications for the design of information in technologies that seek to engage children in puzzles.

1. Introduction

One of the most popular technologies children use are videogames (NPD Market Report). According to the Entertainment Software Association (ESA) 2021 report, 76% of children in the United States (under 18 years) are videogame players (Essential Facts About the Video, 2021). Videogames are becoming central to youth culture (Ito et al., 2013; Play In The NECL, 2021; Youth eSports League). This calls for the attention of different stakeholders including parents, game designers, and educators to make children's interactions with videogames a positive experience (Berger, 2017; Gee, 2005; Shaffer & Gee, 2006). Videogames hold great promise as contexts to introduce children to new concepts in fun ways (Koster, 2013; Maloney et al., 2015; Prensky, 2001; Shaffer & Gee, 2006). The experience of playing a game depends largely on the player's interaction with the game mechanics (Christou, 2014; Maloney et al., 2015; Michailidis, Balaguer-Ballester, & He, 2018). Traditionally studies on game design focus on the player's affective (e.g., emotional) responses and their conceptual knowledge changes (e.g., what they learned) e.g., (Iacovides, Cox, McAndrew, Aczel, & Scanlon, 2015; Mekler, Iacovides, & Bopp, 2018; Shute, Wang, Greiff, Zhao, & Moore, 2016). Recent studies on successful commercial puzzle games emphasize on the importance of understanding the design of challenges balancing the element of learning and enjoyment for players e.g., (Iacovides, Cox, Avakian, & Knoll, 2014; Linehan, Bellord, Kirman, Morford, & Roche, 2014; Visani Scozzi, Iacovides, & Linehan, 2017). There are many previous studies explaining player experiences in terms of how they engage with gameplay and what strategies are employed and how game design should be shaped around those behaviors e.g. (Linehan et al., 2014; Schell, 2008; Visani Scozzi et al., 2017). In our prior research, we found that the same puzzle designs can provide completely different experience for different children (Gainer, 2010; Prensky, 2005; Shokeen et al., 2020; Turner & Lapan, 2005). To best of

Abbreviations: Human-centered computing, Human computer interaction (HCI); Interaction paradigms, Empirical studies in HCI; Applied Computing, Computer games.

* Corresponding author.
E-mail addresses: eshokeen@umd.edu (E. Shokeen), apellico@umd.edu (A.J. Pellicone), weintrop@umd.edu (D. Weintrop), djk@umd.edu (D.J. Ketelhut), mcukier@umd.edu (M. Cukier), jplane@umd.edu (J.D. Plane), carowp@umd.edu (C. Williams-Pierce).

https://doi.org/10.1016/j.ijcci.2024.100635
Received 7 June 2022; Received in revised form 27 November 2023; Accepted 10 February 2024
Available online 28 February 2024
2212-8689/

our knowledge, we didn't find the literature addressing *why* the same puzzle design can lead to different experiences for different children. This motivated us to examine *what* led to different emergent experiences for children with the focus on understanding *how* we can better design puzzles in educational games for children. We focus specifically on *how* children engaged in playing in-game puzzles, and theorize *why* – that is, what their gameplay strategies and information-seeking behaviors were, and what led different players to engage differently (Shokeen et al., 2020).

Problem solving is considered a key skill for future schooling and careers (Cairns, Li, Wang, & Nordin, 2014; Deterding, 2016; Vanbecelaere et al., 2020; Visani Scozzi et al., 2017).. Research on the design of technology for children suggests they must receive certain in-game support from the technology to nurture their experience of informed problem solving (Mekler et al., 2018; Michailidis et al., 2018), but the field lacks a comprehensive understanding of *how* the designed support and problem-solving experiences are related. We focus here on *puzzles* within videogames, as puzzles are a rich problem solving environment and one of the common ways for designing challenges in games (Linehan et al., 2014; Prensky, 2001). As mentioned above, problem solving is seen as an important life skill, and the field of child-computer interaction has a well-established corpus of literature on the relevance of problem solving in digital contexts (Michailidis et al., 2018; Verenikina & Herrington, 2009; Wise & Kong, 2005). Puzzles are a playful way to design problem solving opportunities, encourage players to take an active role in gameplay (Williams-Pierce, 2019; Juul, 2008; Shaffer & Gee, 2006) and can provide 'pleasantly frustrating' experiences that both challenge and reward the player (Gee, 2007). Designing the right level of difficulty is essential as games that are too difficult or too easy for the players can lead to negative experiences (Calado, Alexandre, & Griffiths, 2014; Swartout & van Lent, 2003). Puzzles provide a motivating and enjoyable experience to players if designed with appropriate levels of in-game support accommodating differences among players (Christou, 2014; Dostál, 2015; Juul, 2008; Tsvyatkova & Storni, 2019). Designing the right level of difficulty for children in puzzles is especially challenging as they have varying levels of cognitive maturity and content knowledge to draw upon (Vanbecelaere et al., 2020; Verenikina & Herrington, 2009; Voulgari, Zammit, Stouraitis, Liapis, & Yannakakis, 2021).

Building on prior work on puzzles, we define a puzzle as a *constrained environment that require players to find a solution to a given challenge*. In particular, puzzle solving requires players to put different pieces of information together. Thus, understanding the ways in which children find, interact with, and utilize the information to solve a puzzle (collectively termed as *information seeking behaviors*) can provide useful insights into *how* and *where* to design in-game support information for children (Beck & Stolterman, 2016; Berger, 2017). Therefore, we pursue the following primary research question:

How do young players seek information while solving puzzles within videogames?

While pursuing the primary research question and reflecting on its implications with respect to how it interacts with the puzzle design and players' prior gaming experiences, we added two secondary research questions that attend to the ways that children used information from multiple sources to solve puzzles (hereby referred to as *information seeking strategies*). These two questions are.

i) *How do puzzle designs affect young players' information seeking strategies?*
ii) *How do young players' prior gaming experience influence their information seeking strategies?*

To answer these questions, we used the constructivist grounded theory approach to develop a theory about children's information seeking behaviors in puzzles through inductive analysis of 17 children's (11–14 years old) experience of puzzle solving as they play tested an under-development puzzle-based educational videogame, titled *HEX of the Turtle Islands* (hereby referred to as *HEX*). We collected and analyzed multiple forms of data including observations, responses to in-game prompts, video recordings, and semi-structured interviews. This work is part of a larger design project seeking to introduce youth to the field of cybersecurity in a game-based context. The focus of this paper is limited to providing a theoretical understanding of children's information seeking behaviors and strategies while solving puzzles embedded within the game.

The primary contribution of this paper is the theoretical model that improves our understanding of children's information seeking behaviors by identifying the different sources of information available to them to solve puzzles, and their information seeking strategies around those different sources. Our theoretical approach is aligned with Beck and Stolterman's (Beck & Stolterman, 2016) description of *theory as an analytical tool* – one that both supports our understanding of how children problem solve in puzzles, and contributes back to the overall theory by providing a model for better design. We also discuss how puzzle designs and players' prior gaming experiences directly influence children's puzzle solving in games. Lastly, we provide practical design recommendations based on our theoretical model.

2. Related work

2.1. Children's problem solving in technology-mediated contexts

Problem solving is considered a key skill to be developed among children that can greatly benefit them as they find themselves in new situations (Dostál, 2015; Mayer, 2011) and for their future integration into society (Binkley et al., 2012; Csapó & Funke, 2017; Keen, 2011; Rahman, 2019). Keen (Keen, 2011) argues that we need to design environments that encourage and enhance problem solving from a young age. One of the designed environments that has been found useful to provide affordances for enhancing children's competency in problem solving skills is that of videogames (Alkan & Cagiltay, 2007; Among Us; Cox, Cairns, Shah, & Carroll, 2012; Hamlen, 2018; Ito et al., 2013; Shute, Ventura, & Bauer, 2009, pp. 317–343).

While developing solutions to specific problems in videogames, children are required to understand, use, and evaluate the way the game is designed and structured (Apperley & Walsh, 2012). These problem-solving abilities to navigate the way information is accessed, processed, and distributed in games are considered game literacies (Buckingham & Burn, 2007). Problem solving skills are related to cognitive development of children, and the middle-school age group (roughly 11–13 in the United States) is a critical point for cognitive development. In particular, they start to think about different perspectives and influence on the actions on their future, and begin to develop interest in different career domains and pay more attention to decision making, organizing ideas, and information (Christou, 2014; Gee, 2005; Youth eSports League). This critical transition is occurring individualistically, however, so middle-school age children have varying levels of cognitive maturity and content knowledge to draw upon while solving problems in videogames (Vanbecelaere et al., 2020; Verenikina & Herrington, 2009; Voulgari et al., 2021).

Research on children's problem solving in videogames identifies strategies such as *guessing* (Wise & Kong, 2005) and *informed problem solving* (Bruce, 2008). Previous work has employed various parameters to automatically detect children's behaviors while they engage in problem solving, such as response times, number of attempts to respond correctly, and the response itself (Chuang and Chen, 2007a, 2007b; Joseph, 2011). Related studies have examined ways of detecting children's behaviors by utilizing different features derived from system-generated data which identify the various stages of their experiences (Giannakos, Papamitsiou, Markopoulos, Read, & Hourcade, 2020; Henrie, Halverson, & Graham, 2015; Shute et al., 2009). For example, Shute et al. (Shute et al., 2016) designed a stealth assessment model to assess players' problem solving competency based on their sequence of actions in the game using system logs. Lee & Ke (Lee & Ke, 2019) suggested that symbolic representations are better than iconic representations in facilitating players' learning, reflection, and promote their problem solving in videogames. These are useful insights about children's problem solving, but these prior studies did not sufficiently account for the wide range of prior experiences that players bring to the gameplay experience, and therefore cannot account for how different players with different backgrounds may need differing in-game supports.

Few studies to date have examined children's interactions in-game using qualitative methods for characterizing their experiences of problem solving (Tsvyatkova & Storni, 2019). Notable exceptions include Shin et al. (Shin, Kim, & Gweon, 2020) distinguishing guessing from problem solving. Csikszentmihalyi (Csikszentmihalhi, 2020) suggests that when a problem difficulty exceeds the scope of a child's prior domain knowledge and problem solving ability, they engage in guessing. In such scenarios, children must receive certain support (e.g., a hint) from the system to proceed in the game (Lee-Cultura, Sharma, & Giannakos, 2021). However, there are no existing models in game literature to guide the design of puzzles for children (Beck & Stolterman, 2016; Berger, 2017).

2.2. Defining puzzle solving in videogames

Puzzles are a crucial component of educational videogames as they provide players with opportunities to interact with domain specific content knowledge in fun and engaging ways (Clark, Tanner-Smith, & Killingsworth, 2016; Dasgupta, Ferebee, & Michalewicz, 2013; Deterding, 2016). The use of puzzles serves as a mechanism to turn conventional gameplay into learning experiences as the puzzles can motivate players to explore and employ productive practices (Weintrop & Wilensky, 2014; Schell, 2008). Schell (Schell, 2008) describes a puzzle as "a game with a dominant strategy" which means that puzzle games require players to search for a particular way of playing. On the other hand, Brock and Fraser (Brock & Fraser, 2018) describe games as puzzles that can be challenging to solve. For this study, we draw on Schell's (Schell, 2008) description of puzzles as "anything that makes players stop and think" within a videogame context. Building on prior work on puzzles, we conceptualize a puzzle as *a constrained environment based on specific rules defined by the designer that guide players to find a solution to a given challenge*. We define puzzle solving as *players employing strategies to put different pieces of information together to solve a given in-game challenge*. Despite advances in technology, it is still challenging to design appropriate levels of support for in-game puzzle solving (Hoggan & Brewster, 2010) as there is a fine balance to strike between too easy and too hard, while also accommodating players with varying levels of skills and differing prior experiences (Carvalho, Duarte, & Carriço, 2012).

We draw upon Squire's (2006) framing of games as an emergent experience which characterizes the larger context of a player interacting with a game, implying that playing the same game can give a different experience to different players. We view puzzle solving as an emergent experience that takes place when a player interacts with a puzzle. In this paper, we will incrementally develop a theoretical model based on the foundation shown in Fig. 1 that define a player's interaction with the puzzle as the emergent puzzle solving experience.

2.3. Players' strategies to overcome in-game challenges

There has been an increase in research focusing on players' gameplay experiences, much of which argues that challenge is an important gameplay component (Cairns et al., 2014; Cox et al., 2012; Nordin et al.). Challenges, and the need to overcome them in gameplay, serve as learning mechanisms (Koster, 2013). From prior research on design of in-game challenges, we know the importance of breaking complex challenging into simpler components and introducing them gradually (Apperley & Walsh, 2012; Linehan et al., 2014; Schell, 2008). These guidelines support the design of challenges in the game for children, however it does not provide us the comprehensive understanding of children information seeking behavior and information seeking strategies for solving puzzle. The design of information in puzzle for children in more complex than simplifying the information in small components and introducing it gradually. For example, we can design hints in the form of inventory, but the child might not refer to the inventory at all. In other scenario, we can design information in the text form, but the child might ignore reading the text at all. As puzzle designers, we need to understand children's interaction in the game play to better understand their behavior and strategies.

Few studies emphasized that players learn from failures to move ahead in gameplay (Pelletier & Oliver, 2006; Ryan and Siegel). Novice players have been shown to use a variety of strategies to solving gameplay challenges, such as "trial and error" and using "friends as sources of information" while playing games (Alkan & Cagiltay, 2007). Blumberg et al. (Blumberg, Rosenthal, & Randall, 2008) indicate players with frequent gaming experience refer to the in-game insights and hints more than players with infrequent gaming experiences while solving in-game challenges. Iacovides et al. (Iacovides et al., 2015) examined adult players' breakdowns, breakthroughs, and identified strategies (such as Trial & Error; Stop & Think; Take the Hint) that they rely on to progress within commercial puzzle games. Prior work suggests that learning, and especially handling failure, are key elements of designing information available to players in puzzle-based game play. However, it is still unclear how and when a player chooses a specific strategy (Iacovides, Cox, & Knoll, 2014).

Feedback and failure mechanisms are recognized as crucial in determining whether a player is experiencing productive or unproductive frustration while solving in-game puzzles (Beck & Stolterman, 2016; Berger, 2017). There are various tensions associated with designing feedback to support players; for example, the use of multi-modal feedback can be challenging to fit in the narrative metaphor and aesthetics of the game and the use of a direct "hint" button can reduce difficulty of puzzles but might impact self-efficacy and identity formation opportunities for players (Beck & Stolterman, 2016). In this study, we leverage our previous research on failure and feedback mechanism as a way to conceptualize the experience of being challenged during puzzle solving (and its role in encouraging players in information seeking).

3. Methodology

3.1. Selection and participation

The study was designed to examine the information seeking behavior of children between the ages of 11–14 while they engage in solving puzzles within a game. The participants from the target age range were recruited through a list-serve associated with the University of Maryland, and a recruitment pamphlet was included in a STEM resource

Fig. 1. Puzzle Solving as an emergent experience between the player and the puzzle.

packet distributed via the local public library during the COVID-19 pandemic. A parental consent and child assent were received from each participant, and participants in the study received a $15 Amazon gift card. We collected a demographic survey from participants' parents to gather additional information about the participants. A total of 17 youth participated in the study (see Table 1 for information on each participant). Before starting each data collection session, participants were informed about the protocol of the study. In addition to their written assent, verbal consent was taken before starting the recording of the session. Also, each participant was told that they could discontinue the gameplay session or interview at any time, and still receive the gift card.

Table 1 provides the demographic of the participants in the study (all names are pseudonyms). Players' prior gaming experience was categorized into three levels – *Seldom* (rarely played games), *Occasional* (played games 1 or 2 days a week), and *Frequent* (played games daily). All procedures were approved by the University of Maryland Institutional Review Board.

3.2. Data collection

We collected data in multiple forms including observations, in-game prompts, video recordings, and semi-structured interviews. Data collection sessions were conducted virtually using Zoom with participants sharing both their cameras and their screens. These sessions were recorded creating a video that captured what was happening on screens in addition to the players' facial reactions, body language, and verbal responses. The duration of each data collection session was approximately an hour long consisting of about 40 min of gameplay and a 20-min post-gameplay semi-structured interview. During each data collection session 2 or 3 researchers were present, consisting of one researcher leading the session and the other(s) observing.

For getting players' perspectives, we leveraged a novel form of the think-aloud protocol that leverages the authentic gameplay practice of streaming (Fonteyn, Kuipers, & Grobe, 1993). Participants were encouraged to imagine they were livestreaming their gameplay to their friends, and thus naturally encouraged to provide commentary on what they were doing, what was happening in the game, and their own naturalistic reactions. Additionally, the game had embedded prompts that would appear on screen for players to respond to specific in-game transitions (such as when moving from one section of the game to another) to get more structured in-game reflections. These prompts include questions such as "What have you done so far?" and "What do you like and what should we change?" Players responded to these prompts by sharing their thoughts aloud before resuming their gameplay.

Table 1
Demographic details about participants (provided by parents) with duration of their gameplay during the study and level of their prior gaming experiences (provided by participants).

Participants	Age	Gender	Racial Identity	Gameplay Duration	Prior Gaming Experience
Mike	12	M	Black or African American	40	Occasional
Kate	13	M	White	25	Frequent
Briana	13	F	Black or African American	70	Seldom
Naman	13	M	Asian or Pacific Islander	35	Occasional
Elisa	13	F	Asian or Pacific Islander	33	Occasional
Ethan	13	M	Not Reported	46	Occasional
Jack	13	M	Not Reported	38	Occasional
Ava	13	F	Asian or Pacific Islander	25	Frequent
Matthew	13	M	Not Reported	36	Frequent
Rohit	13	M	Not Reported	34	Occasional
Alex	13	M	Black or African American	27	Frequent
Lauren	13	F	White	31	Frequent
Ben	13	M	White	33	Occasional
Susan	14	F	White	27	Frequent
Shelly	14	F	White	57	Seldom
Adam	14	M	White	22	Frequent
Olivia	14	F	White	30	Occasional

3.3. Data analysis

We applied qualitative analysis to develop a constructivist grounded theory, where 'constructivist' represents the evolving nature of theory, 'grounded' represents how theory is grounded in the participants' own words and experiences, and 'theory' represents a more nuanced and deeper understanding of a phenomenon (Charmaz, 2006). It is an interpretive practice of engaging with the data and constructing an abstract understanding of it (Charmaz, 2006). This method of analysis uses an inductive approach to generate a new theory from data collected from participants' observations and interviews (Charmaz, 2006). As discussed above, there are no existing theories explicitly about children's plan of actions to solve puzzles (hereby referred to as *puzzle solving strategies*) in videogames. Therefore, we developed a constructivist grounded theory based on an inductive analysis of data collected from participants.

Based on the guidelines provides by Charmaz (Charmaz, 2006), our data analysis process took place over four phases using the qualitative Data Analysis software - MAXQDA. Table 2 provides the list of open coding and focused coding system developed during the analysis process. *First*, we open coded the data characterizing each line, or segment of data from all cases. For example, here is a data segment:

> Randomly connected wires expecting them to work, he said "*Maybe, Maybe*". Then he carefully looked at the rules in the wire library and said out loud, "*that's why they say it's important to read*". He clapped when he got his wire connection correct.

During open coding the above data segment was coded as Puzzle Solving - Strategy. *Second, we* used these open-codes to build focused codes (Charmaz, 2006). For example, during focused coding the above

Table 2
Open and focused coding system for this study from MAXQDA file.

Open Coding System	**Focused Coding System**
▸Thinking about puzzle	▸Puzzles
•Medium	▸Door Puzzle
•Design	•Recognition of code
•Challenging/Hard	•Reaction to Cipher
•Easy	•Understanding
▸Prior Experience	•Productive Frustration
▸Favorite Puzzle	•Prior Experience/Comparison
•Like all	•Approach Description
•Box Puzzle	▸Wire Puzzle
•Wire Puzzle	•Understanding
•Pigpen Cipher	•Productive Frustration
▸Puzzle game experience	•Prior Experience/Comparison
▸Learning Element	•Approach Description
•Problem Solving	▸Box Puzzle
•Thinking	•Understanding
•Puzzle Solving	•Productive Frustration
•Strategy	•Prior Experience/Comparison
•Logic	•Approach Description
▸Game Description	
▸Gaming Experience	
•Gaming Interest	

data segment was coded as Productive Frustration/Wire Puzzle – Approach Description. *Third*, we applied analytical memoing with focused coding to refine and organize the emerging coding scheme. *Fourth*, axial coding using the resulting set of codes was conducted on the data (Birks, Chapman, & Francis, 2008; Charmaz, 2006). The iterative process of analysis allowed the research team to take a deep dive into their information seeking behavior while solving puzzle and discuss the emerging theme of the data throughout the process including the development of focused and axial codes.

4. GAME: HEX

HEX is a puzzle-based game designed for players between the ages of 11–14 years. The overall goal for the development of *HEX* is to introduce players to the field of cybersecurity, however, in this study, the analytic focus is limited to players' approaches to solving puzzles in the game. Puzzles are an important part of *HEX* and used as a mechanism to introduce basic cybersecurity skills (e.g., critical thinking, decrypting codes) which makes it a good fit for pursuing the stated research questions. The version of the game used in this study includes three types of puzzles: Door Puzzles, Wire Puzzles, and Box Puzzles. Below, we provide a brief description of these puzzles.

4.1. Door Puzzle

The Door Puzzle (Fig. 2) is based on a simple form of cryptography where information is arrayed spatially into a grid commonly known as a Numeric Pigpen Cipher. The objective of this puzzle is to introduce players to the idea of decryption of a message based on a cipher key. This puzzle is situated in the game as a means of unlocking a door. To do so, the player needs to locate an encrypted 4-digit passcode in the game world and then use it as a cipher key to decode the puzzle and unlock the door. The cipher in this puzzle uses a 3-by-3 grid containing the numbers 1 through 9 (Fig. 2 - A) that must be found by the player in another building in the game before they are able to unlock the door. The encrypted form of the lock's code is engraved on the wall (Fig. 2 - D) next to the keypad (Fig. 2 - C).

To solve the puzzle and open the door, the player needs to figure out the association between the sequence of symbols given on the top (Fig. 2 - D) and the spatial position of specific numbers from the grid (Fig. 2 - A). The puzzle has only one correct four-digit password to unlock the door (7391) – if other answers are given, the player is given another chance. The visual feedback is designed in the puzzle to support players in finding the correct solution of the puzzle. For instance, when a player added an incorrect code 7352 (Fig. 2 – B) and hit the RUN. The interface of the turns into flashing red from green, highlighting the code is engraved on the wall (Fig. 2 - D). This visual feedback redirects the player to notice and use the code engraved on the wall.

4.2. Wire puzzle

The player encounters a series of Wire Puzzles of increasing difficulty at four different locations in the game. To solve these logic puzzles, the player must connect colored wires adhering to a set of rules (e.g., Same color wires CANNOT be in neighboring ports). The wire rules are discovered by the player as they explore the world and are displayed in the Wire Library (Fig. 3 - A). To do this, the player drags wires from the bottom of the screen (Fig. 3 - B) and connects these to the top sockets (Fig. 3 - C). The number in the center (Fig. 3 - F) tells the player how many wire connections need to be made. As the player progresses, new rules are added. On a failed attempt, the background turns into flashing red color and a red Error Log (Fig. 3 - E) provides text-based feedback describing errors in the current connections (e.g., colors do not match). Thus, the Wire Puzzle provides direct visual and text-based feedback to players on a failed attempt to support them in finding the correct solution of the puzzle.

4.2.1. Box Puzzle

The player encounters several Box Puzzles as they explore the game world. Box Puzzles separate the user from an in-game object they desire, thus the player must solve the Box Puzzle to retrieve the object. To solve these puzzles, players need to use spatial reasoning to plan a path by which they can reach the object and then push the boxes (Fig. 4 – D) into strategic locations to create that path (Fig. 4 - A). Since there are no instructions within the game related to this puzzle type, the player needs to figure the puzzle out on their own by interacting with the boxes and exploring different possibilities. The design of feedback in Box Puzzle is hidden when players attempt to move objects such as bookshelves (Fig. 4 – C) and open boxes filled with material (Fig. 4 – B) to create the path, the puzzle mechanisms restrict such movements and redirect the player to interact with movable boxes (Fig. 4 – D). These restrained actions provide feedback to the player to interact with other objects.

4.3. GEM inventory

A final game design element that informs the puzzle solving strategies is the in-game Inventory. The inventory screen (Fig. 5) shows players the items they have collected, a quest log that details progress the player has made, and their current goals. The player can access the inventory at any time by clicking the on-screen inventory icon (shown in the top left of Fig. 4).

To summarize, there are multiple ways in which information is designed in the game to support players in solving puzzles correctly. All three puzzles have feedback mechanisms embedded; however, the design of the feedback differs. As described above, the Box Puzzle provides hidden feedback in the form of restricting players from taking certain actions, the Door Puzzle provides visual feedback on a failed

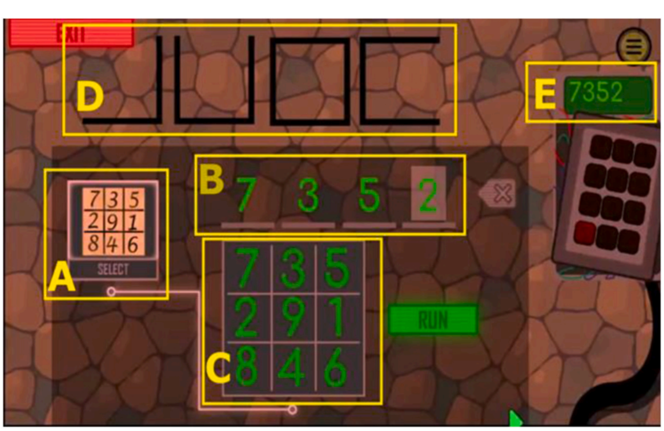

Fig. 2. The Door Puzzle, marked with parts A, B, C, D and E in yellow.

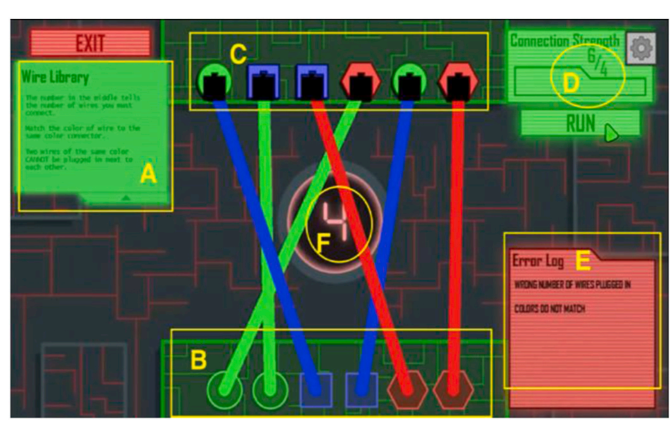

Fig. 3. The Wire Puzzle, marked with parts A, B, C, D and E in yellow.

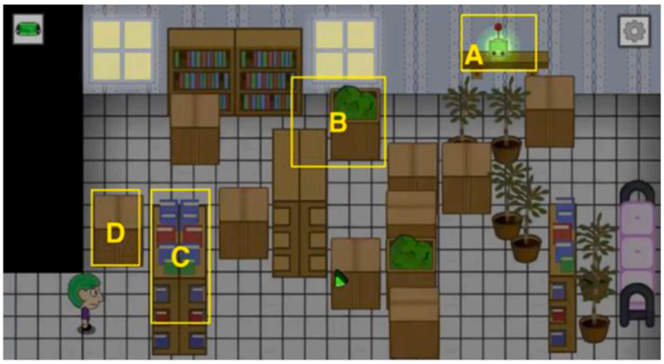

Fig. 4. The Box Puzzle. = , marked with parts A, B, C, and D in yellow.

Fig. 5. Gem universal device interface.

attempt, and the Wire Puzzles provide visual and text-based feedback.

5. Findings

In response to our primary research question - *How do young players seek information while solving puzzles within videogames?* We incrementally built our theoretical model of players' information seeking sources to solve puzzles, starting with the foundation shown in Fig. 1 based on the inductive analysis of children's experiences. In response to our secondary research questions: *How do puzzle designs affect young players information seeking strategies?* and *How do young players' prior gaming experience influence their information seeking strategies?* We demonstrate the influence of game design and prior gaming experiences on children's information seeking strategies in the game.

5.1. Use of out-of-game world information

Our analysis reveals that while solving puzzles, children draw information from their past experiences, which we label as *use of out-of-game world information*. Findings show that if players had prior experiences of solving similar puzzles, they use information from those experiences to guide their current puzzle solving strategies. For example, during the interview, Adam explicitly described his strategy as "If I have already solved some similar puzzle before then I kind of draw from that, like I just remember how I did it last time". His approach to solving puzzles was based on his memory of past experiences solving similar puzzles. Likewise, in Mike's interview, he described his approach to solving puzzles as an analogy between brain and storage, saying "I think my brain has a sense of storage where I put the information that I have learned, so I went back to that information and realized what I have to do next". His response showcased how even younger players (ages 11–14) recognize their prior knowledge and memories as valuable resources to draw upon when encountering challenges in gameplay contexts. The information from past experiences differed widely for players - some may have information that is applicable to solve the puzzle at hand whereas others may not have any relevant prior knowledge to draw on. We found that depending on the presence or absence of relevant prior knowledge, their emerging experience of solving puzzles varied. Some players experienced consistencies in the information that they have from their past experiences and information that was required to solve the puzzle in the game, whereas others experienced inconsistencies. Next, we provide descriptive examples demonstrating consistent and inconsistent puzzle solving strategies based on past experiences identified in the focal cases.

5.1.1. Consistent past experience

For some participants in the study, previously used ways of solving puzzles were applicable to solve puzzles in *HEX*. We coded these contexts as a *consistent past experience*. In such scenarios, players may not need to discover new information since their attempt to solve the presented puzzle is consistent with their previous experience. For example, while sharing her Box Puzzles approach, Lauren in her interview response said, "I have seen those [Box Puzzles] in other games. I generally knew how to do it. I really like how some of those boxes you could not move. I tried to remember that". Her response emphasized that her prior experience with Box Puzzles influenced her approach to solve the Box Puzzle in this game. Similarly, during her gameplay, she was observed solving the Door Puzzle in her first attempt without exploring the interface for clues. This observation from the gameplay session was further reinforced by her interview response when she said, "I really knew the code; I was pretty sure what to do. So, I knew that the shape … was related to whatever number …". Here, she was referring that she already knew the cipher code based on past experiences. In this example, observation of her gameplay session and her interview response confirmed that she relied on the information from her past experiences as a source to approach the Door Puzzle. Moreover, her being able to solve the puzzle completely based on her past information signified that her this experience was consistent with her prior experiences.

5.1.2. Inconsistent past experiences

While many players were able to draw on prior gameplay experience to solve puzzles in *HEX*, not all such attempts to draw on prior experience were successful. An experience where the player previously learned an approach to solving a puzzle that was not applicable in *HEX* or interfered with solving the *HEX* version of the puzzle was coded as an *inconsistent past experience*. In such scenarios, players attempted to apply information from their past experiences, but when their attempt failed, they realized that their prior experience was not as applicable to the puzzle as they had initially thought. After realizing that their previously learned approaches failed, players had to pursue other ways to solve the puzzle. Often, the player figured out that they needed to modify the approach that was used in their past experiences to solve the puzzle. For example, Shelly, in her first attempt of solving the Wire Puzzle, was observed connecting all six wires across without referring to any rules from the Wire Library. While playing the game she commented that "there is a game called Among Us (Among Us) and they have the same puzzles and it's like the opposite of that, that's what I was trying to do at first". Combining data from her commentary and observation of her puzzle solving strategies we found the information from her past gaming experiences informed her current experience of solving wire puzzles but in a way that was insufficient or counter to the approach needed to solve the *HEX* version of the puzzle. After a failed attempt, feedback from the puzzle directed her attention towards the instructions given on the interface of the wire puzzle and she was able to solve the puzzle using the information given in the game. Similarly, Mike was observed commenting, "[w]hat I have noticed when I have played games, in most of the games you can just walk through the boxes, but in this game, you can actually push them" while solving a Box Puzzle. He was making a comparison that the information he had from his past experiences was different than this game. In these examples, both participants' prior experiences were inconsistent with their current experiences, which led them to seek information within in the game to solve the puzzle correctly.

5.1.3. Expanding the theoretical model: information out-of-game world

Players draw on their prior game experience when trying to solve in-game puzzles, however the utility of these prior experiences varies. Some prior experiences may be inconsistent with the current puzzles being solved. We added these two sources of information from players having or lacking relevant past experiences to our model (the yellow boxes in Fig. 6). The prior experiences information is further divided into consistent and inconsistent information to capture whether the prior knowledge is useful in the puzzle at hand.

5.2. Use of information within the game world

Our analysis also identified that players use information within the game to help solve in-game puzzles. The information within the game world can also be further divided into two categories – 1) game-initiated supports which includes instructions and inventory and 2) player-initiated support which includes exploration and feedback. We observed that the types of in-game information used depended on whether players had frequent, occasional, or seldom prior videogame experience as well as the individual prior experiences they had while solving a particular puzzle.

5.2.1. Game-initiated supports

In the game world there are sources of information that are initiated by the game to support players' experiences of solving the puzzle. Game-initiated supports are provided directly to players in the game and the player is not required to do any specific task to access that information (although they could choose to revisit that information later). For instance, information in the form of instructions is given to the player to solve each puzzle, and information in the inventory is available but players must choose to refer to it to see the information again.

5.2.1.1. Instructions. The first in-game information seeking strategy we identified in the data is to use the game-provided instructions to solve puzzles. While this may sound obvious, many players do not read the instructions and many games are designed to not require text-based instructions. In the case where a game or puzzle has very particular rules, instructions serve as a key information source. For example, while sharing her approach to solving the Wire Puzzles during the interview, Lauren mentioned, "[f]or the Wire Puzzle, I made sure that I read all the rules first so that I don't mess up". Her response pointed towards the benefits of reading rules and instructions carefully to solve puzzles in game-based contexts. Similarly, other participants also indicated that reading the instructions usually helped them to solve unfamiliar puzzles or to help players when they got stuck or confused. For instance, in Adam's interview, he emphasized the importance of reading the information given in the game when he encountered a novel puzzle, saying "… but if it's a new puzzle that I haven't solved before then I carefully read instructions and look for hints". Mike was observed struggling to connecting wires as he was solving the Wire Puzzle without referring to the instructions and hoping his guessing approach to work. After a few failed attempts, he looked at the rules in the wire library and said out loud, "that's why they say it's important to read!" In his next attempt, he solved the wire puzzle correctly and clapped for himself. Here observation of Mike's gameplay and his commentary during gameplay suggests that reading the information given in the game helped him clear his confusion by focusing his attention on certain aspects of the puzzle. Across these players, we found that explicit in-game instructions, especially for novel or information-dense puzzles, can serve as important in-game puzzle solving supports for players.

5.2.1.2. Inventory. Another source of information for players from inside the game is the *inventory* (Fig. 5). Our analysis reveals that some players refer to their inventory to get information that could be used to solve in-game puzzles. For example, during the interview Naman shared, "It had an inventory, that was really helpful". During his gameplay, he was observed referring to the inventory multiple times in different locations to seek help in finding out what key items were available to him, what was the objective of the next puzzle, and what information he needed to collect. Similarly, other participants were also observed referring to the inventory during the gameplay to get information such as where they are in the game and/or the objective of the next puzzles. Although the inventory provided useful information to the player, not all players were observed using it. The use of the inventory as an in-game information source was observed more frequently among players with more experience playing games. Participants who rarely played videogames were not observed referring to the inventory as a source of information for solving puzzles.

5.2.2. Player-initiated supports

In the game world there are two sources of information – *exploration* and *feedback* - that are available to players when they take the initiative to explore the game world and attempt to solve puzzles. When players initiate *exploration* in the world, they get information in the form of clues based on their interactions with non-playing characters in the game which could help them to solve the puzzles. Similarly, players need to initiate an attempt to solve the puzzle and, when their attempt fails, they get information from the game in the form of *feedback* which can then help them solve the puzzle.

5.2.2.1. Exploration. A strategy we observed players employing to gather information within the game world was through *exploration*. This was found to be done by players for two reasons: either the player felt the information they had was not sufficient to solve the puzzle or the player wanted to collect all the pieces before starting the puzzle. Both strategies led players to explore the game world to collect information that could be used to solve the in-game puzzles. For example, while playing, Adam commented, "there is one thing I do in every videogame that I look back on and see if I am not missing anything because there [are] goodies and other hidden stuff which is helpful to solve puzzles". Exploration served as a useful source of information for Mike as he found

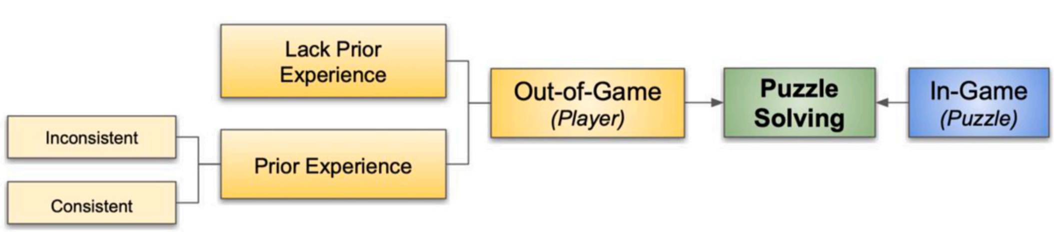

Fig. 6. The expanded theoretical model that incorporates player's prior knowledge, including prior experiences (either consistent or inconsistent with the current game) and players with no prior knowledge.

the first wire puzzle in the game before collecting all the required modules. When he interacted with the electric panel, an error displayed stating, "Proper wire module not found. Please install the required module and try again". In response to this message, Mike responded, "Oh, it's just giving me an idea" and then he proceeded to leave the wire puzzle interface and look for the remaining wire modules before returning to solve the puzzle.

5.2.2.2. Feedback. The feedback provided by the puzzles themselves because of failed attempts is another in-game information retrieval strategy our analysis identified. We found that puzzle feedback helped players by focusing their attention on specific aspects of the puzzle and helped them succeed in solving it. In some cases, we observed players not reading or misinterpreting information provided by the game, leading to a failure to solve the puzzle on the first attempt. In such scenarios, players could be found correcting their approaches after receiving feedback directly from the puzzle. For example, we observed Shelly correcting her approach to solve the Wire Puzzle using the feedback in the error log. In her third failed attempt to solve the Wire Puzzle, she made the error of connecting two wires of matching colors next to each other, which led to the puzzle giving her direct text-based feedback, "Same color wires are plugged next to each other" in the error log. Using this feedback, on the next attempt she changed the wire arrangement and successfully solved the puzzle.

5.2.3. Expanding the theoretical model: information within the game world

Having found children using different sources of information support from within the game world, we now expand our theoretical model to include these sources (refer to blue boxes of Fig. 7). Here, we present a theoretical model that theorize the ways in which children found utilizing different sources of information in-game. We sub-categorized in-game information into game-initiated sources of information - *instructions* and *inventory*; and player-initiated sources of information - *feedback* and *exploration*. Adding these dimensions gives us an expanded model of sources of information that children relied on while solving puzzle in games.

5.3. Influence of puzzle design

One of our secondary research questions asked: *How do puzzle designs affect young players' information seeking strategies?* To answer this question, we coded the information retrieval strategies used by players for each of the puzzles included in *HEX*: the Wire Puzzle, Door Puzzle, and Box Puzzle. Wire Puzzles had the direct text-based instructions, whereas the design of instructions in Door Puzzles was both visual and text-based which players were required to collect during the exploration. There were no explicit text-based instructions designed in the Box Puzzle which required players to explore different interactions with the boxes in order to see what could be done to solve the puzzle. These differences in the design of instructions and feedback were found to influence players' puzzle solving strategies. For example, players were found exploring for instructions to solve the Box Puzzle. Briana tried to jump over the boxes and other objects, but the constrained design of the Box Puzzle did not allow her to do so and forced her to figure out a solution to the puzzle by rearranging the location of boxes to clear a path for her character. Similarly, Alex was observed figuring out the affordances of the Box Puzzle as he tried different actions: "I can't push those [filled boxes], I can get here and if I do this [moved an empty box], I can get through there". This exploration for instruction was enjoyed by some players and made other players frustrated. For example, Shelly was observed getting frustrated with the design of the Box Puzzle; in her interview she suggested to improve the design of the Box Puzzle by adding direct instructions for solving, she said "It should tell you [player] the direct message on what to do." Whereas Briana in her interview expressed that she liked the design of the Box Puzzle.

The design of the feedback incorporated into the puzzles also varied. The design of feedback in the Wire Puzzles was given to the player in a text form which was perceived by players as "straightforward" [Shelly, interview]. The design of feedback in the Door Puzzle was in a visual form and required players to make connections between different pieces of visual information. In the interview, while describing the approach to solve the Door Puzzle, Mike was observed making hand gestures to represent the visual information provided in the game for solving the puzzle. His use of hand gestures during the interview response suggests that he utilized the visual information implicit in the design of the Door Puzzle to solve it. Players were found to be attempting to solve Wire Puzzles without reading the instructions and during failed attempts, the text-based feedback guided them to correct their solutions. For example, Shelly was observed correcting her approach to solve the Wire Puzzle using the feedback in the error log.

To summarize, these findings suggest that different modalities of instruction and feedback in which information was designed in puzzles influenced players' information seeking strategies to solve them. In particular, we saw three distinct patterns, one for each puzzle design: lack of text-based instructions led players to initiate exploration (Box Puzzle); text-based instructions were initially ignored until repeated failure led the players to actually seek that information (Wire Puzzle); and players had to explore in order to gather the visual and text-based instructions (Door Puzzle).

5.4. The impact of prior gaming experience

The last of our secondary research questions asked: *how do young players' prior gaming experience influence their information seeking strategies?* We found that players' expectations about how puzzles work and should be solved varied based on their prior gaming experiences. Players with frequent experience stated that they enjoyed exploring different possibilities within the game whereas those with less prior gaming experience expressed that they expected to get direct instructions from the puzzle interface design. For instance, Adam, a frequent player of videogames, expressed in his interview that he liked exploring and interacting with objects to figure out what to do in the Box Puzzle. This contrasted with Shelly, a player with little gaming experience, who expressed in her interview that having a message on boxes filled with rocks that says "you can't move it" would have made her gameplay experience better. Another example of connecting beyond game to in-game was the use of inventory to find the information. We found frequent and occasional players [e.g., Alex, Naman, Mike] referred to

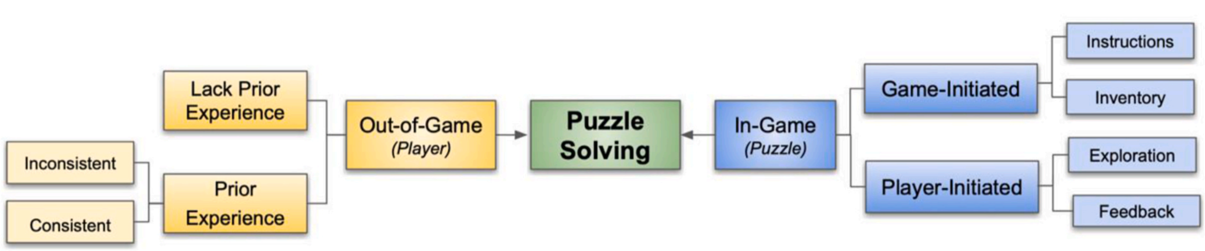

Fig. 7. The expanded theoretical model that now includes sources of in-game supports.

the inventory for information whereas seldom players [e.g., Shelly, Briana] did not refer to the inventory at all. This indicates players' prior gaming experiences with common game features such as an inventory can influence where they look for in-game support to solve puzzles. This has direct implications for game designers, especially for games that are seeking to support players with varying levels of prior gameplay and puzzle solving. We discuss these implications for design in detail in the following section, as the impact of prior gaming experience is tangled up with the different forms of information available to players.

6. Discussion

This study aimed to provide a theoretical understanding of children information seeking behaviors and strategies for solving puzzles in a game-based setting. To accomplish this, we examined children's information seeking behaviors while they solved three different kinds of puzzles in a videogame. We found they leverage multiple sources of information to solve in-game puzzles (see Fig. 7). Out-of-game sources consisted of players' background information that they brought with them to the game, which can be consistent or inconsistent to in-game information. If children have experienced a similar puzzle before then they may find it too easy, and if they lack information to solve the puzzle than it may be too difficult for them to proceed. To avoid such scenarios, designers need to balance the design of information provided to players in the game. Some basic information designed in-game can be categorized as *game-initiated*; it is presented to players in the form of instructions and inventory. These pieces of information introduce player to the goal of the puzzle and what to do next. Another set of information design in-game can be categorized as *player-initiated*; these pieces of information are accessed by players based on certain actions, such as when feedback is received based on a failed attempt, or clues are received by on exploring the game world. On the macro level, it may seem obvious the players either use their past experiences or the information in the game for solving the puzzle, but this paper findings explain the complexities of their micro-interaction with information in the game. This study findings support the design guidelines from the prior research on designing in-game challenges for players (Apperley & Walsh, 2012; Linehan et al., 2014; Schell, 2008) and expands on it by examining children's empirical experiences to provide a comprehensive understanding of what form of information may or may not work while designing puzzles for children. Our theoretical model in response to our primary research question maps out the information sources that support children's puzzle solving in games, and can serve as a future analytical tool to expand the field's understanding of designing for productive problem solving. This theoretical model can be useful for all game designers particularly the ones interested in using educational puzzles in games a tool for enhancing children problem solving skills.

In response to our secondary research questions, our findings suggest that the design of information in puzzles directly influence children's puzzle solving strategies. Puzzles with indirect instruction and feedback required players to try different actions to find the correct solution, and while some children expressed that they like the exploratory nature of such puzzle design, others expressed their desire to have direct indicators for solving puzzles. In addition, we found some sources of information are only accessed by players with certain levels of prior gaming experience, such as the information from the Inventory, as players who rarely play games did not use the Inventory when seeking information. These findings support claims from prior research on game design that novice and experienced players employs different strategies for overcoming in-game challenges (Alkan & Cagiltay, 2007; Blumberg et al., 2008). In additions to supporting guidelines of breaking complex challenging into simpler components at micro and macro level and introducing them gradually (Apperley & Walsh, 2012; Linehan et al., 2014; Schell, 2008), we suggest game designers should consider improving the accessibility of in-game support information to address the varying game literacies of children. Below, we discuss implications on how our theoretical model can guide the design of accessible in-game information supports in future puzzle games, and then discuss limitations and future work.

6.1. *Implications for puzzle design*

6.1.1. *Design for multiple game literacies*

Our findings suggest children interact differently with the same puzzle based on varying information from their past experiences, the yellow boxes in our theoretical model (Fig. 7). This implies that designers need to consider the differences in gaming literacies of children. While designing any puzzle, playtesting with target demographics is well known as a best practice in the design of game-based learning (Fullerton, 2019), however our theoretical model highlights varying level game literacies among children within the same age-group that are often treated as having homogenous experiences with games and gameplay (Buckingham & Burn, 2007). Therefore, we recommend designers make sure to playtest their puzzles with varying levels of game literacies within the targeted age-range. This will help to identify the varying baselines of game literacy to build on.

However, our recommendations go further: we specifically encourage designers to develop in-game support structures for multiple game literacies. Such design is a careful balance: how do we support novice gamers in accessing informational structures they may not otherwise remember to access (e.g., the Inventory), while also not frustrating expert players are well aware of those structures already? Our model provides specific types of informational structures that should be included within educational games, and future research needs to include a deeper consideration of how to design game-initiated structures to better support across different levels of game literacy. While sometimes the need for game-initiated support can be easily identified and designed for – such as a player failing repeatedly at a puzzle and finally receiving a reminder to look in their inventory – there is considerable work to be done regarding other types of support. For example, a novice player engaging in unproductive exploration because they have forgotten that the inventory can help them may need a game-initiated reminder; whereas an expert player engaging in productive exploration may find their enjoyable experience disrupted by such reminders.

6.1.2. *Accessibility of in-game support information*

In addition, due to these varying game literacies, children have differing expectations from puzzles design, ranging from preferring direct instructions to preferring exploration. To balance this, we recommend designers to break the information into different elements represented in the yellow boxes in our theoretical model (Fig. 7) in order to increase information accessibility to players of different levels. However, designers need to consider what information seeking strategies they wish to promote within their puzzles – perhaps, like the Box Puzzle, they want players to just explore, using trial and error to discover the puzzle solution. In this case, whereas labeling the boxes as suggested by Shelly may not support the desired player-initiated exploration, the designers could consider other ways to support players with low levels of gameplay literacy in confidently engaging in trial and error. Or perhaps they want players to pay close attention to text-based instructions, such as with the Wire Puzzle. In that case, developing multiple feedback types could be productive: a player who reads the instructions and is struggling with the puzzle could benefit from different feedback than a player who just jumps in and starts connecting wires randomly (and needs to be directed back to the instructions). In other words, children need different levels or forms of support to promote certain kind of strategies (Beck & Stolterman, 2016; Buckingham & Burn, 2007), which begins with determining the desired strategies and then designing the pieces of the model appropriately. Our division of information into game-initiated and player-initiated elements provides a practical tool for understanding how different players seek information in different ways.

6.1.3. Multi-modality of in-game support information

Our proposed theoretical model demonstrates the various ways that puzzle designers can consider providing information within the game – instruction, inventory, feedback, and exploration. Based on these in-game information seeking sources, we suggest designers to balance the complexity and accessibility of information across these game-initiated versus puzzle-initiated support designs. We suggest that adding game-initiated information to the puzzle interface about how to solve the puzzle (e.g., instructions, inventory) is crucial for introducing players to the goals of various puzzles in game. In situations, a player may or may not use game-initiated information depending on their game literacies. Therefore, we suggest providing the opportunity for player-initiated feedback after failed attempts (e.g., error log) to direct players towards necessary information in order to support players in having positive gameplay experience. If multiple failures occur and the player is not taking advantage of player-initiated support, then there should be game-initiated support. To avoid negative experiences of children with puzzle solving, designers should provide scaffolding information to players in multiple forms and locations of the game to support players' puzzle solving.

6.2. Limitations & future work

The results of this study are limited based on the empirical study of 17 participants aged 11–14 years located in a specific geographic area, so players who are younger or older and located in different geographic regions may respond differently. In addition, we do not have the data to examine the full trajectory of gameplay experience, ranging from truly novice players (e.g., never played a video game) to truly expert (e.g., nationally competitive for their age group in a particular e-Sport). Furthermore, we focused on gameplay experience generally – perhaps examining more closely their literacies in puzzles and/or educational games in particular would reveal crucial insights. Expanding the range of gameplay expertise and developing a more fine-grained assessment of background experience will likely add to and nuance the design implications of our work.

The results of this study are also limited by the specifics of the game, namely the three types of puzzles. Crucially, as these puzzles only offered the information structures described above, it is highly likely that other information structures are absent from our model. For example, commercial game players often engage in online information seeking – perhaps other types of educational puzzle games could productively leverage such external information structures (Martin, 2012). Examining different types of puzzles and/or educational games more broadly will likely expand our model in powerful ways.

Lastly, our model insufficiently accounts for the multimodal nature of gameplay, and future studies should examine potential differences rigorously. For example, while the Door Puzzle provided visual and text-based instructions, our puzzle design conflated the potential increase in usefulness of such multimodality with the fact that players had to explore in order to find those instructions. It is possible that player-initiated exploration that results in instructions makes those instructions more important to players – and thus they are more likely to read them before solving the puzzle. Or perhaps the combination of text and visual led to better understood instructions and would have even if the instructions were fully game-initiated. Examining the different impacts of modality and the different initiators of information separately would more deeply inform our understanding of how children engage in information seeking during gameplay.

7. Conclusion

This work presents a theoretical model by breaking down children's information seeking sources, offering theoretical and practical insights into balancing the design of information to scaffold children's puzzle solving in technology-based environments. Puzzle designers need to consider the different game literacies that exists among children while designing information in-game. It is crucial to provide support for children within the game so all players can succeed regardless of prior gaming experience. We suggest distributing the information in player-initiated and game-initiated categories to help children overcome the challenge of puzzle solving, as having the right pieces of information in the right form at the right place can help improve players' emergent experiences while they solve puzzles. In addition, we posit that our model can provide a richer way to think about how to design information structures to support specific strategies of play, and that designers will benefit from considering how information should be included in multiple forms to increase access for novice players (while carefully avoiding disrupting experts). This work contributes to the field's understanding of how children solve puzzles and *when* and *where* they look for information while solving puzzles in game. In particular, we have contributed to the child-computer interaction knowledge base by identifying specific design influences on children's problem solving experiences and suggesting future research to nuance the analytical tool of our model to further support productive design for information seeking behaviors.

Place the footnote text for the author (if applicable) here.

CRediT authorship contribution statement

Ekta Shokeen: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Anthony J. Pellicone:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. **David Weintrop:** Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Diane Jass Ketelhut:** Formal analysis, Funding acquisition, Investigation, Project administration, Supervision, Writing – review & editing. **Michel Cukier:** Funding acquisition, Resources, Software, Supervision, Writing – review & editing. **Jandelyn Dawn Plane:** Resources, Software, Supervision, Writing – review & editing. **Caro Williams-Pierce:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgments

We acknowledge the support of the US Department of Defense. The views and conclusions expressed in this paper are those of the authors and do not necessarily represent those of the Department of Defense or U.S Government. Most of all, we thank the students who participated in this study for sharing their experiences.

References

2021 Essential facts about the video game industry: https://www.theesa.com/resource/2021-essential-facts-about-the-video-game-industry/. Accessed: 2022-01-05.

Alkan, S., & Cagiltay, K. (2007). Studying computer game learning experience through eye tracking. *British Journal of Educational Technology, 38*(Apr. 2007), 538–542. https://doi.org/10.1111/j.1467-8535.2007.00721.x

Among Us - Apps on Google Play: https://play.google.com/store/apps/details?id=com.innersloth.spacemafia&hl=en_US&gl=US. Accessed: 2022-01-17.

Apperley, T., & Walsh, C. (2012). What digital games and literacy have in common: A heuristic for understanding pupils' gaming literacy. *Literacy, 46*(3), 115–122, 2012.
Beck, J., & Stolterman, E. (2016). Examining practical, everyday theory use in design research. *She Ji: The Journal of Design, Economics, and Innovation, 2*(2), 125–140 (2016.
Berger, A. A. (2017). *Video games: A popular culture phenomenon*. Routledge.
Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., et al. (2012). Defining twenty-first century skills. In *Assessment and teaching of 21st century skills* (pp. 17–66). Springer.
Birks, M., Chapman, Y., & Francis, K. (2008). Memoing in qualitative research: Probing data and processes. *Journal of Research in Nursing, 13*(1), 68–75. https://doi.org/10.1177/1744987107081254. Jan. 2008.
Blumberg, F. C., Rosenthal, S. F., & Randall, J. D. (2008). Impasse-driven learning in the context of video games. *Computers in Human Behavior, 24*(4), 1530–1541. https://doi.org/10.1016/j.chb.2007.05.010. Jul. 2008.
Brock, T., & Fraser, E. (2018). Is computer gaming a craft? Prehension, practice, and puzzle-solving in gaming labour. *Information, Communication & Society, 21*(9), 1219–1233. https://doi.org/10.1080/1369118X.2018.1468920. Sep. 2018.
Bruce, B. C. (2008). *Learning at the border: How young people use new media for community action and personal growth*. Department of Education, University of Cyprus.
Buckingham, D., & Burn, A. (2007). Game literacy in theory and practice. *Journal of Educational Multimedia and Hypermedia, 16*(3), 323–349, 2007.
Cairns, P., Li, J., Wang, W., & Nordin, A. I. (2014). The influence of controllers on immersion in mobile games. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 371–380). New York, NY, USA, Apr. 2014.
Calado, F., Alexandre, J., & Griffiths, M. D. (2014). Mom, dad it's only a game! Perceived gambling and gaming behaviors among adolescents and young adults: An exploratory study. *International Journal of Mental Health and Addiction, 12*(6), 772–794, 2014.
Carvalho, J., Duarte, L., & Carriço, L. (2012). Puzzle games: Player strategies across different interaction modalities. In *Proceedings of the 4th International Conference on Fun and Games* (pp. 64–72).
Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. SAGE.
Christou, G. (2014). The interplay between immersion and appeal in video games. *Computers in Human Behavior, 32*, 92–100.
Chuang, T.-Y., & Chen, W.-F. (2007a). Effect of computer-based video games on children: An experimental study. *2007 First IEEE International Workshop on Digital Game and Intelligent Toy Enhanced Learning*, 114–118 (DIGITEL'07) (2007).
Chuang, T.-Y., & Chen, W.-F. (2007b). Effect of digital games on children's cognitive achievement. *Journal of Multimedia, 2*, 5, 2007.
Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research, 86* (1), 79–122. https://doi.org/10.3102/0034654315582065. Mar. 2016.
Cox, A., Cairns, P., Shah, P., & Carroll, M. (2012). Not doing but thinking: The role of challenge in the gaming experience. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 79–88). New York, NY, USA, May 2012.
Csapó, B., & Funke, J. (2017). *The nature of problem solving*. OECD.
Csikszentmihalhi, M. (2020). *Finding flow: The psychology of engagement with everyday life*. Hachette UK.
Dasgupta, D., Ferebee, D. M., & Michalewicz, Z. (2013). Applying puzzle-based learning to cyber-security education. In *Proceedings of the 2013 on InfoSecCD '13* (pp. 20–26). Information Security Curriculum Development Conference. New York, NY, USA, Oct. 2013.
Deterding, S. (2016). Contextual autonomy support in video game play: A grounded theory. In *Proceedings of the 2016 CHI conference on human factors in computing systems* (pp. 3931–3943). New York, NY, USA, May 2016.
Dostál, J. (2015). Theory of problem solving. *Procedia-Social and Behavioral Sciences, 174*, 2798–2805, 2015.
Fonteyn, M. E., Kuipers, B., & Grobe, S. J. (1993). A description of think aloud method and protocol analysis. *Qualitative Health Research, 3*(4), 430–441. https://doi.org/10.1177/104973239300300403. Nov. 1993.
Fullerton, T. (2019). *Game design workshop: A playcentric approach to creating innovative games*. AK Peters/CRC Press.
Gainer, J. S. (2010). Critical media literacy in middle school: Exploring the politics of representation. *Journal of Adolescent & Adult Literacy, 53*(5), 364–373, 2010.
Gee, J. P. (2005). Learning by design: Good video games as learning machines. *E-Learning and Digital Media, 2*(1), 5–16.
Gee, J. P. (2007). *Good video games+ good learning: Collected essays on video games, learning, and literacy*. Peter Lang.
Giannakos, M., Papamitsiou, Z., Markopoulos, P., Read, J., & Hourcade, J. P. (2020). Mapping child–computer interaction research through co-word analysis. *International Journal of Child-Computer Interaction, 23*, Article 100165, 2020.
Hamlen, K. R. (2018). General problem-solving styles and problem-solving approaches in video games. *Journal of Educational Computing Research, 56*(4), 467–484, 2018.
Henrie, C. R., Halverson, L. R., & Graham, C. R. (2015). Measuring student engagement in technology-mediated learning: A review. *Computers & Education, 90*, 36–53, 2015.
Hoggan, E., & Brewster, S. A. (2010). Crosstrainer: Testing the use of multimodal interfaces in situ. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 333–342). New York, NY, USA, Apr. 2010.
Iacovides, I., Cox, A. L., Avakian, A., & Knoll, T. (2014). Player strategies: Achieving breakthroughs and progressing in single-player and cooperative games. In *Proceedings of the first ACM SIGCHI annual symposium on Computer-human interaction in play* (pp. 131–140), 2014.
Iacovides, I., Cox, A. L., & Knoll, T. (2014). Learning the game: Breakdowns, breakthroughs and player strategies. In *CHI'14 extended abstracts on human factors in computing systems* (pp. 2215–2220).
Iacovides, I., Cox, A. L., McAndrew, P., Aczel, J., & Scanlon, E. (2015). Game-play breakdowns and breakthroughs: Exploring the relationship between action, understanding, and involvement. *Human-Computer Interaction, 30*(3–4), 202–231.
Ito, M., Gutiérrez, K., Livingstone, S., Penuel, B., Rhodes, J., Salen, K., et al. (2013). *Connected learning: An agenda for research and design*. Digital Media and Learning Research Hub.
Joseph, D. (2011). *State intervention, videogames & the public sphere: A critical political economic analysis*. Toronto: Ryerson University Press.
Juul, J. (2008). *The magic circle and the puzzle piece*, 2008.
Keen, R. (2011). The development of problem solving in young children: A critical cognitive skill. *Annual Review of Psychology, 62*, 1–21, 2011.
Koster, R. (2013). *Theory of fun for game design*. O'Reilly Media, Inc.
Lee, S., & Ke, F. (2019). The format of problem representation for in-game learning supports. *Journal of Computer Assisted Learning, 35*(3), 390–406, 2019.
Lee-Cultura, S., Sharma, K., & Giannakos, M. (2021). Children's play and problem-solving in motion-based learning technologies using a multi-modal mixed methods approach. *International Journal of Child-Computer Interaction.* , Article 100355. https://doi.org/10.1016/j.ijcci.2021.100355. Jul. 2021.
Linehan, C., Bellord, G., Kirman, B., Morford, Z. H., & Roche, B. (2014). Learning curves: Analysing pace and challenge in four successful puzzle games. In *Proceedings of the first ACM SIGCHI annual symposium on Computer-human interaction in play* (pp. 181–190), 2014.
Maloney, A. E., Mellecker, R., Buday, R., Gao, Z., Hinkley, T., Esparza, L., et al. (2015). Fun, flow, and fitness: Opinions for making more effective active videogames. *Games for Health Journal, 4*(1), 53–57, 2015.
Martin, C. (2012). Video games, identity, and the constellation of information. *Bulletin of Science, Technology & Society, 32*(5), 384–392. https://doi.org/10.1177/0270467612463797. Oct. 2012.
Mayer, R. E. (2011). *Problem solving and reasoning*. Learning and cognition in education, 2011.
Mekler, E. D., Iacovides, I., & Bopp, J. A. (2018). A game that makes you question…" exploring the role of reflection for the player experience. In *Proceedings of the 2018 annual symposium on computer-human interaction in play* (pp. 315–327), 2018.
Michailidis, L., Balaguer-Ballester, E., & He, X. (2018). Flow and immersion in video games: The aftermath of a conceptual challenge. *Frontiers in Psychology, 9*, 1682, 2018.
Shokeen, E., Pellicone, A., Weintrop, D., Jass Ketelhut, D., Williams-Pierce, C., Plane, J. D., & Cukier, M. (2020). Designing Failure and Feedback within Puzzles. In *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play* (pp. 370–374). New York, NY, USA, Nov. 2020.
Nordin, A.I., Cairns, P. and Hudson, M. The effect of surroundings on gaming experience. Vol. 8.
NPD Market Report: https://www.npd.com/. Accessed: 2022-01-05.
Pelletier, C., & Oliver, M. (2006). Learning to play in digital games. *Learning, Media and Technology, 31*(4), 329–342. https://doi.org/10.1080/17439880601021942. Dec. 2006.
Play in the NECL. https://playnecl.com/play-in-the-necl/, (2021) Accessed: 2022-01-05.
Prensky, M. (2001). Fun, play and games: What makes games engaging. *Digital game-based learning, 5*(1), 5–31, 2001.
Prensky, M. (2005). In digital games for education, complexity matters. *Educational Technology, 45*(4), 22–28, 2005.
Rahman, M. (2019). 21st century skill'problem solving': Defining the concept. *Rahman, MM (2019). 21st Century Skill "Problem Solving". Defining the Concept. Asian Journal of Interdisciplinary Research, 2*(1), 64–74, 2019.
Ryan, W. and Siegel, M.A. Evaluating interactive entertainment using breakdown: Understanding embodied learning in video games. Vol. 9.
Schell, J. (2008). *The art of game design: A book of lenses*. CRC press.
Shaffer, D. W., & Gee, J. P. (2006). *How computer games help children learn*. Springer.
Shin, H., Kim, B., & Gweon, G. (2020). Guessing or solving? Exploring the use of motion features from educational game logs. In *Extended abstracts of the 2020 CHI conference on human factors in computing systems* (Vols. 1–8). New York, NY, USA, Apr. 2020.
Shute, V. J., Ventura, M., & Bauer, M. (2009). *Melding the power of serious games and embedded assessment to monitor and foster learning: Flow and grow*. Routledge: Serious games.
Shute, V. J., Wang, L., Greiff, S., Zhao, W., & Moore, G. (2016). Measuring problem solving skills via stealth assessment in an engaging video game. *Computers in Human Behavior, 63*, 106–117, 2016.
Squire, K. (2006). Video games as designed experience. *Educational Researcher, 35*(8), 19–29.
Swartout, W., & van Lent, M. (2003). Making a game of system design. *Communications of the ACM, 46*(7), 32–39, 2003.
Tsvyatkova, D., & Storni, C. (2019). A review of selected methods, techniques and tools in Child–Computer Interaction (CCI) developed/adapted to support children's involvement in technology development. *International Journal of Child-Computer Interaction, 22*, Article 100148. https://doi.org/10.1016/j.ijcci.2019.100148. Dec. 2019.
Turner, S. L., & Lapan, R. T. (2005). Evaluation of an intervention to increase non-traditional career interests and career-related self-efficacy among middle-school adolescents. *Journal of Vocational Behavior, 66*(3), 516–531, 2005.
Vanbecelaere, S., Cornillie, F., Depaepe, F., Guerrero, R. G., Mavrikis, M., Vasalou, M., et al. (2020). Technology-mediated personalised learning for younger learners: Concepts, design, methods and practice. In *Proceedings of the 2020 ACM interaction*

design and children conference (pp. 126–134). New York, NY, USA: Extended Abstracts. Jun. 2020.

Verenikina, I., & Herrington, J. (2009). Computer game design and the imaginative play of young children. In *Proceedings of the 8th international conference on interaction design and children* (pp. 254–257). New York, NY, USA, Jun. 2009.

Visani Scozzi, M., Iacovides, I., & Linehan, C. (2017). A mixed method approach for evaluating and improving the design of learning in puzzle games. *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*, 217–228, 2017.

Voulgari, I., Zammit, M., Stouraitis, E., Liapis, A., & Yannakakis, G. (2021). *Learn to machine learn: Designing a game based approach for teaching machine learning to primary and secondary education students*. New York, NY, USA: Interaction Design and Children. Jun. 2021.

Weintrop, D., & Wilensky, U. (2014). *Program-to-play videogames: Developing computational literacy through gameplay, 10*, 264–271.

Williams-Pierce, C. (2019). Designing for mathematical play: failure and feedback. *Information and Learning Sciences, 120*, 589–610.

Wise, S. L., & Kong, X. (2005). Response time effort: A new measure of examinee motivation in computer-based tests. *Applied Measurement in Education, 18*(2), 163–183, 2005.

Youth eSports League: https://pcxnow.com/youth-esports-league?gclid=Cj0KCQiAoNWOBhCwARIsAAiHnEjHq6UyBp16D01Pf1mHBshDB-dJNkPnajc_H_CYthualqs87i5usB4aAiTqEALw_wcB. Accessed: 2022-01-05.