Automation Confusion: A Grounded Theory of Non-Gamers' Confusion in Partially Automated Action Games

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ABSTRACT

Partial automation makes digital games simpler by performing game actions for players. It may simplify gameplay for non-gamers who have difficulty controlling and understanding games. However, the automation may make players confused about what they control and what the automation controls. To describe and explain non-gamers' experiences of automation confusion, we analyzed gameplay, think-aloud, and interview data from ten non-gamer participants who played two partially automated games. Our results demonstrate how incorrect mental models, behaviours resulting from those models, and players' attitudes towards the games led to different levels and types of confusion.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; • **Applied computing → Computer games**.

KEYWORDS

digital games, one-switch, automation, shared control

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1 INTRODUCTION

Playing digital games can be overly challenging for non-gamers, who sometimes have difficulty using controllers and keeping up with fast-paced games [6, 20, 27, 28, 30, 75]. For example, non-gamer parents may want to play games with their children, but may not want to invest the time needed to become competent at complex games. Similarly, friends may not enjoy playing together if there are vast differences in their skill levels. Partial automation is a form of player assistance that divides control of the game between the player and an automation system. In contrast to full automation, which performs all actions for the player, partial automation has the player and automation control the game at the same time. This can simplify how the game is controlled and reduce the number of decisions players need to make [12, 24, 94, 98]. In *Kingdom Come: Deliverance* [85], for example, players can command their horse to steer itself along the road, simplifying control and reducing the number of navigational decisions players need to make. Partially automated games may assist non-gamers by performing actions on their behalf and reducing the number of game mechanics they need to learn. Partial automation has also been shown to improve the accessibility of digital games to players with motor disabilities [12].

While partial automation may simplify games, it can also make players confused about how the game is controlled; we term this phenomenon *automation confusion*. Partial automation adds to what players need to understand; they need to understand the game's rules, which actions they can control, and which actions the automation can control. A user evaluation of two partially automated games found that the automation confused some players [12]. They became frustrated when they disliked their avatar's automated actions and tried to take control of the automation. It is not yet known how common or problematic automation confusion is, what types of confusion can occur, or how players become confused by the automation.

If automation designed to simplify a game can inadvertently make players confused about how the game works, then designers need to understand players' confusion. Many games have used automation as a form of player assistance [10, 12, 13, 22, 24, 35, 37, 55, 71, 72, 85, 98] and its use by designers unaware of automation confusion may have unforeseen consequences. To better understand how partially automated games can make players confused and to provide designers with knowledge about how to reduce automation confusion, we conducted an in-depth study in which ten non-gamer adults played two partially automated games and reported their understanding of the automation during play. We found that participants' mental model errors led them to misattribute the causes of avatar actions. When participants were unable to make their avatars do what they wanted, they looked for alternative ways to control their avatars. Most participants believed that they could

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control some actions that they could not, while some others stopped believing that they could control the games at all.

This paper contributes empirical evidence that automation confusion can occur and provides a theory of the types of confusion that arise when control of games is partially automated. We analyzed participants' gameplay, think-aloud, and interview data to develop a grounded theory of non-gamers' automation confusion in two partially automated action games. This new understanding will help game designers reduce confusion and improve players' experiences of partially automated games—increasing the chance that non-gamers and players of widely different skill levels will be able to successfully play together.

2 RELATED WORK

Our work is built on four areas of prior research: non-gamers' experiences of digital games, partial automation in games, users' mental models of automated systems, and users' awareness of automation.

2.1 Non-gamers & Gaming

Gaming has become a popular pastime, social activity, and cultural touchstone. Over 60% of Canadians aged 18 to 64 play digital games [63], but there are still many people who choose not to play. These *non-gamers* have given many reasons why they do not play, citing a lack of interest in games, not finding them fun, and seeing them as a "*waste of time*" [6, 20]. However, non-gamers may find themselves excluded from social activities involving games [20]. In 2020, approximately 43% of Canadian adult gamers and 70% of teen gamers used digital games as a way to stay socially connected to friends and family while physically isolated [63]. For non-gamer parents, digital games present opportunities to share time with their gamer children. However, games are designed to challenge players and for some these challenges can exclude [19, 28, 73]. Non-gamers likely want to play with their gamer friends and family for social reasons, even if they are not attracted to games for their own enjoyment.

Non-gamers have not spent the necessary time to learn gaming conventions and so are unfamiliar with the *language of games* [20]. Games are systems of rules [88], made of smaller games [50], and the fun of play is in learning the game's underlying mathematical patterns [49, 92]. Non-gamers may not know, for example, that hearts represent their avatar's health points or that red containers explode. They may misinterpret what happens onscreen and come to learn the wrong lessons [75], making games even more difficult to understand.

Non-gamers also find game controllers difficult to use [6, 20, 27] and find complex input sequences especially difficult [28, 30]. The complexity of games and their controllers has increased dramatically over the last five decades [19]. For example, *Frogger* [46] can be played with a single joystick, whereas more recent games involve multiple sticks, triggers, buttons, and accelerometers. Non-gamers can find these newer devices daunting; in an evaluation of *Wii Sports Bowling* [21] for older adults, participants had difficulty releasing the 'b' button to throw the ball and one participant said that "*It would have been easier without pressing the button.*" [28]

2.2 Partial Automation in Games

Partial automation simplifies games by performing actions for the player, such that *both player and automation control the game at the same time.* This reduces the number of controls that players have to learn and the speed at which they have to make game decisions. The assistance provided by partial automation is especially potent in *action* games—real-time games in which the player makes an avatar perform actions to overcome challenges. For example, the first two *Bayonetta* games [71, 72] provide partially automated "Automatic" modes that automate target selection and avatar movement. The player is tasked with selecting which attack to do and the automation selects which enemy to attack.

There are two forms of partial automation: *input automation* and *one-switch* [12]. Input automation assists players by taking over some of the game's inputs. For example, Hwang et al. balanced a shooting game for differences in players' manual abilities by aiming directly towards the most likely target when the player shoots [37]. Cechanowicz et al. helped players align their steering with the road in a racing game [10]. Hougaard et al. helped players more reliably control an infinite runner game using a brain computer interface by making the avatar jump on its own [35]. Conversely, one-switch games assist players by reducing their control to a single button [24, 98]. For example, *Zac - O Esquilo* is a one-switch adaptation of *Frogger* [46] in which an algorithm chooses which direction the avatar moves when the player presses the button [55].

Partial automation is related to, but distinct from, several other forms of player assistance. *Player balancing* helps weaker players compete with stronger players [2], so some player balancing solutions use partial automation [10, 37] while others do not [29]. *Dynamic difficulty adjustment* changes game mechanics in response to individual players' abilities [36], buffing players or spawning fewer enemies but not automating control. And finally, *full automation* automates control of all player tasks, so that both player and automation control the game at different times. For example, the "Auto-Battle" feature in *Fire Emblem: Three Houses* [87] fully automates battles, selecting actions that adhere to the player's chosen strategy.

2.3 Conceptualizing Automation

When interacting with a system, users form in their minds models of how the system operates, called mental models [44, 59, 60, 69, 91]. Users' interactions follow seven stages of action, from specifying a goal to determining whether it was achieved, and each step along the way depends on the quality of the user's mental model. Good mental models enable users to recognize and understand what the system is doing, crossing the *gulf of evaluation*, and also to predict how their use of the system might achieve their goals, crossing the *gulf of execution.* Bad mental models make users confused about what the system is doing and how it might respond to their actions. Prior investigations into the human factors of highly automated flight decks found that pilots' most commonly asked questions about the automation were: "*What is it doing?*", "*Why is it doing that?*", and "*What will it do next?*" [78, 93] These sorts of questions are answered by users' mental models [41, 59, 60, 81].

Rather than providing unified and complete explanations of all aspects of a system's operations, the mental models users form through use are fragmentary and incomplete [81]. They are collections of theories analogous to specific parts of the system and they can leverage metaphors to explain how and why the system does what it does [15]. *Functional* mental models tell users how to use the system, while *structural* mental models tell users how the system works [51]. While investigating users' mental models of calculators, Norman found that users would press the 'CLEAR' button excessively due to erroneous beliefs about how the calculator stored values in memory [60]. These erroneous beliefs led them to develop harmless superstitions about the effects of their 'CLEAR' presses.

Although automation can improve users' interactions, it can also make users' tasks more difficult and complicated [1, 61, 84, 93]. The automation may perform tasks that the human does not know how to do using knowledge that the human has not learned. Therefore, users may be unable to understand the automation's actions and have difficulty cooperating with it. Users employ different combinations of analytic, analogical, and affective reasoning to determine when to trust the automation, which may lead users to rely on it inappropriately [53]. Users may misuse the automation, applying it to tasks that it cannot do, or disuse the automation, not applying it to tasks that it can do [67]. A mismatch between the user's understanding of the automation and its actual operations means that when things go wrong, users may be surprised and not know how to respond [16, 17, 77, 78, 80].

For example, drivers were expected to change their braking behaviour with the introduction of anti-lock braking systems (ABS), which pumps the brakes for the driver to prevent wheel lockup. However, survey data from 1998 indicates that 18% of ABS users thought that they had to pump the brakes to activate ABS [8]. In 2017, the Boeing 737 Max entered service, equipped with a new Maneuvering Characteristics Augmentation System (MCAS) [66]. Pilots were not trained on how to use, or even told about, the MCAS, which would force the plane's nose down when a single sensor detected that the plane's pitch was too high [66, 82]. When faulty sensors caused the MCAS to activate erroneously during Lion Air flight 610, the pilots were surprised and unable to disengage the automation [82]. The stakes are not so high for games using partial automation, but automation accidents in the wild (e.g., Three Mile Island [70, 90], Therac-25 [54, 80], Sudden Unintended Acceleration [42, 48]) demonstrate how automation can cause users to hurt themselves and others in their confusion.

Partial automation can simplify games, but it may confuse players who do not know how to cooperate with the automation. Human-machine cooperation decomposes users' knowledge of a joint task into their *know-how* and their *know-how-to-cooperate* [26, 56, 65]. Know-how comprises users' knowledge of how to operate a system, which necessitates good mental models. Know-how-to-cooperate comprises users' knowledge of their collaborators, including their capabilities, intentions, and how to coordinate with them. To support players' mental model development, with respect to their know-how-to-cooperate, partially automated games need to support players' awareness of the automation.

2.4 Awareness

Insufficient awareness of automation can diminish users' task performance, as users may need to think harder to understand what the automation is doing [25]. To help users make sense of the automation, special interfaces have been developed. Wintersberger et al. designed augmented reality aids, displayed on the windows of an autonomous vehicle, indicating the presence and proximity of other vehicles [95]. Other interfaces framed the automation as a collaborator that would inform users of its actions. Koo et al. created voice alerts to inform autonomous vehicle passengers that the "*Car is braking*" [47] and Häuslschmid et al. designed a chauffeur avatar that appeared to react to objects and drive the vehicle [38]. In doing more complex tasks, such as air traffic control, users' awareness of automation can be supported using a *common work space* that displays the user's situation along with the automation's current actions and intentions [56, 65].

Designers of automated systems can also learn from human-to-human collaboration through groupware. In groupware, information about collaborators' activities is communicated via *awareness cues* [33]. As with sharing control with automation, cooperative work in groupware can be tightly coupled, meaning that users need to interact frequently to achieve their goals [76]. Awareness cues support tightly coupled interactions by conveying useful information about collaborators' interactions in a shared workspace, called the *elements of workspace awareness* [32]. For example, *Action* cues indicate what action a user is doing while *Authorship* cues indicate who is doing an action. The feedback that awareness cues provide may help users to attribute changes in the workspace to their collaborators and make sense of what they are doing.

In multiplayer games, awareness cues are used to help players coordinate with other players. Bortolaso et al. used awareness cues to facilitate communication between tablet players and VR players in an asymmetric home decoration game [5]. Stach et al. found that information-rich avatar embodiments helped players to more effectively strategize in an arcade-style space shooter [83]. Toups Dugas et al. proposed a framework of cooperative communication mechanics that facilitate non-verbal communication between team members [89] and Wuertz et al. proposed a framework for the design of awareness cues in games [97]. Awareness conferring game mechanics have been shown to be useful for enabling human-to-human cooperation in digital games, but it is unknown whether they can facilitate cooperation between a human player and automation.

2.5 Summary

We know that users' mental models may be fragmentary and incomplete [81] and that automation changes users' tasks [1, 68, 84], which can make using the system more difficult [61, 93]. Users may only understand the parts of the system that they interact with and therefore have difficulty making sense of automated actions, unless their awareness is supported. While interacting with the system, users may be unaware of what the automation is doing [25] and become surprised when it does things that they did not expect [77, 78, 80]. It is not yet known whether partial automation can make players confused about how games are controlled. To address this question, we developed two partially automated games and conducted a systematic investigation of automation confusion.

Figure 1: Screenshots from *Ninja Showdown*'s tutorial. In the image on the top left, Emi turns her head to look at the player, indicating that she is awaiting player input. In the bottom left, she displays an Intention cue indicating that she intends to use a Bomb if the player does not tell her to use the Sword. In the image on the bottom right, Emi has initiated the Bomb attack and displays an Action cue, indicating that she decided to use the Bomb.

3 PARTIALLY AUTOMATED GAMES USED IN THE STUDY

Partial automation reduces the number of controls and mechanics that players need to master. It may help non-gamers, who have difficulty controlling and understanding games, to play with their gamer friends and family. To better understand non-gamers' experiences of partially automated games, and to characterize the confusion that can arise while playing them, we created two partially automated games. These games represent different genres within action games (i.e., fighting & platformer) and use different forms of automation (i.e., input automation & one-switch), as described in Section 2.2.

Both games were designed with guidance from literature in partial automation, human-machine cooperation, and awareness. To help players make sense of their avatar's automated actions, we created awareness cues informing players of its current actions and intentions (Table 2). To help induce functional mental models in players, we created tutorials that teach players which actions they can control and how to control them (Figures 1 & 2). Both games are controlled using only one button, the spacebar, although they afford different styles of play. The first is a fighting game called *Ninja Showdown* in which the player controls one of their avatar's attacks, while its other attacks are automated (i.e., input automation). The second is a recreation of an existing platformer called *Spelunky*, in which the player can make their avatar do different actions using the same button, while the avatar's movement is automated (i.e., one-switch). In this section, we describe the games used in this study and explain how we designed their automation.

3.1 *Ninja Showdown*

Ninja Showdown is a simple fighting game inspired by *Rock, Paper, Scissors*. The player controls a ninja avatar, named Emi, and is tasked with defeating a ninja opponent, named Takeshi. A game of *Ninja Showdown* lasts three rounds and each ninja can do one attack each round. A ninja can do a **Sword** attack, a **Bomb** attack, or a **Dart** attack. Each attack beats another: **Swords beat Bombs, Bombs beat Darts, and Darts beat Swords**. When a round begins, the announcer counts down from three and when the countdown reaches zero both ninjas do their chosen attack. On the count of two, the player's opponent chooses his weapon and displays it for the player to see. Once a ninja chooses an attack, their choice cannot be changed. If a ninja chooses the weapon that beats their opponent's, then that ninja gets a point and their opponent loses a point. If both ninjas do the same attack, then the attacks cancel each other out and no points are gained or lost. A full playthrough comprises 10 games, for a total of 30 rounds. *Ninja Showdown* was designed to be simple to facilitate analysis of automation confusion, without the confound of confusion arising from complex game mechanics.

Figure 2: Screenshots from *Spelunky*’s tutorial. In each image, an explanation for how to make the avatar perform an action, as well as the action’s corresponding Option cue, are displayed. Refusal cues were purely auditory and so are not visualized.

Players can command Emi to do the Sword attack by pressing the spacebar. Otherwise, **the automation makes Emi do either the Bomb or the Dart attack**. A tutorial tells players that Emi will choose an attack on her own if the player does not command her to use the Sword. In this way, *Ninja Showdown* implements input automation, as it delegates control of a subset of the game’s inputs to the automation. To help players recognize and anticipate automated actions, *Intention* cues, indicating which move Emi intends to do, and *Action* cues, indicating which move Emi has chosen to do, are presented to the player (Figure 1 & Table 2). Emi’s intentions are represented by a thought bubble beside her and Emi’s chosen actions are represented by a speech bubble above her head. These cues were designed to inform players of what the automation will do in future and enable them to correctly attribute automated actions to the automation.

3.2 *Spelunky*

Spelunky is a recreation of the popular game of the same name [57], using its original open source assets[1]. The player controls an explorer avatar that runs, jumps, climbs, and smashes its way through labyrinthine caves in search of loot and a way to escape. If the player’s path is blocked by a thick wall, the avatar can deploy a **rope** to climb over it. If the player’s path is blocked by a thin wall, then the avatar can throw a **bomb** to clear a path through it. *Spelunky* levels contain dangerous snakes, spiders, bats, and cavemen that the player can fight using a **whip** attack. If an enemy touches the player’s avatar, then the avatar loses one of its two health points, represented by hearts floating above its head. Players are allotted between 30 and 120 seconds to complete each level.

Players can command their avatar to use the whip, the rope, and the bomb by pressing the spacebar. The automation decides which action occurs, if any, when the spacebar is pressed. In this way, *Spelunky* implements one-switch automation by reducing players’ interactions to a single button used to control multiple actions. This reduces the number of decisions players need to make; players decide *when* to do an action, and let the automation decide *what* action to do. To help players understand and anticipate their *Spelunky* avatar’s actions, *Option* cues display the avatar’s selected action and *Refusal* cues inform the player that their spacebar press did not result in an action (Figure 2 & Table 2). Whenever the avatar is in range to hit an enemy, needs a rope to climb up, or can clear a path with a bomb, a thought bubble containing the needed item is shown next to the avatar. The player then has the option of making the avatar use that item by pressing the spacebar. Should the player press the spacebar when the automation has not selected an action, voice recordings of an actor saying “*Nah*” or “*Huh*” are played. **The avatar’s walking, running, jumping, and climbing are controlled exclusively by the automation**, so players do not need to learn how to control these actions.

[1]Original source files available at https://github.com/oyvind-stromsvik/spelunky

Table 1: Participants' demographic data including the game genres they had played before (Genres), the number of hours they spent playing games each week (Current Gaming H/W), the number of hours they spent playing games each week at their peak (Peak Gaming H/W), whether they mentioned wanting to play games with friends or siblings (Friend), and whether they mentioned wanting to play games with their children (Parent). Participants' mean age was 38.8 and their mode gender was woman.

ID	Age	Gender	Genres	Current Gaming H/W	Peak Gaming H/W	Friend	Parent
P1	25	Man	Platformer	0	0	✓	
P2	31	Woman	None	0	0		✓
P3	47	Woman	None	0	0		✓
P4	53	Man	Puzzle, Sports	0	2		✓
P5	23	Woman	Fighting, Platformer, Simulation	0	3	✓	
P6	28	Woman	Adventure, FPS, RPG, Strategy	0	3	✓	
P7	26	Woman	Puzzle	0	2	✓	
P8	57	Woman	Puzzle, Rhythm	0	1		✓
P9	47	Woman	Puzzle	0	0		✓
P10	51	Woman	Puzzle	1	2		✓

Table 2: Each game's awareness cues and their meanings.

Game	Awareness Cue	Meaning
Ninja Showdown	Action	*What* automated action the avatar is currently performing
	Intention	*What* automated action the avatar will perform
Spelunky	Refusal	No action was performed *when* the player pressed the button
	Option	*What* action the avatar will perform *when* the player presses the button

3.3 Summary

The games were designed to be simple to play and easy to understand. The tutorials were designed to tell players explicitly which actions they can control and how they can control these actions. The awareness cues were designed to inform players of what the automation is doing and what it will do. Both games provide players all of the information they need to learn how the games work, how they are controlled, and how to cooperate with the automation. Both games successfully reduced the number of inputs players needed to control, which consequently reduced the number of decisions they needed to make.

This does not always come without a cost. The automation in *Ninja Showdown* reduces the complexity of players' control, while slightly increasing the complexity of players' decision-making. When the player can choose any of the weapons, *Ninja Showdown* is no more complicated than *Rock, Paper, Scissors*. But, when some of the game's inputs are automated, some of this choice is delegated to the automation. Players need to determine whether it is possible to win the round, which is always possible in the manual version. In contrast, Spelunky simplifies both how players control the game and the decisions players make.

4 METHOD

To better understand whether partial automation can make non-gamers confused, we recruited ten non-gamer participants to play the partially automated *Ninja Showdown* and *Spelunky* games. During play, participants were prompted to think aloud and discuss anything in the games that they found confusing. Gameplay logs and screen capture video with eye tracking were recorded to provide post-hoc insight into which buttons participants pressed and which objects on screen they looked at. After playing both games, participants were interviewed about their experiences, their opinions of the games' avatars, and which avatar actions they believed that they could or could not control. This combination of gameplay, think-aloud, and interview data was analyzed using grounded theory methodology [31] to answer our research questions:

RQ1:
Can partial automation make non-gamers confused about how a game is controlled?

RQ2:
What types of confusion can non-gamers experience when playing partially automated games?

This study was approved by Queen's University's General Research Ethics Board.

4.1 Recruitment

Non-gamer participants were chosen because they may benefit from the simplification afforded by partially automated games. We wanted to understand how these games are experienced by players who may have difficulty playing games without the automation. A recruitment poster was posted on local social media pages and circulated within several departments of our host institution. Participants were required to have played fewer than 100 hours of video games in their lives, be aged eighteen or older, be able to use a keyboard, and speak English. Since colloquial use of the term "*video game*" is ambiguous, we did not recruit respondents who identified as gamers or whose responses indicated that they had ever played action games regularly. Participants took part in lab-based study sessions, lasting approximately an hour and a half, and were given a $20 honorarium.

4.2 Procedure

Before each study session, participants provided their informed consent to participate. They were seated at a desk with a 31.5" Benq EW3270U monitor, a full keyboard, and a Tobii Eye Tracker 5. Participants completed a short demographic questionnaire asking about their age, gender, and familiarity with popular gaming genres. They were then interviewed about the people in their lives that play video games and their attitudes towards playing with these people. Following the first interview, the researcher explained how participants should think aloud while playing the games and informed them that the researcher would periodically ask them questions. The instructions read to participants are provided in the supplemental materials.

Before playing either of the digital games, participants first engaged in a simple drilling exercise with cards to familiarize them with the *Ninja Showdown* scoring rules. Informal testing during the *Ninja Showdown*'s development indicated that players had difficulty remembering which weapons beat each other, so this activity was intended to teach participants how to win before teaching them how to play with the automation.

Before playing each game, the researcher read to participants a short primer explaining the game's goals, which actions they could make the avatar do by pressing the spacebar, and that their avatar was "*pretty smart*" and could do other actions on its own. During the explanations, the games' visual elements, such as avatars and enemies, were identified in screenshots to help participants recognize them during play. Both games began with a short tutorial section. In the *Ninja Showdown* tutorial, automated avatar actions and the meaning of the awareness cues are explained during scripted gameplay sequences with explanatory text (Figure 1). In the *Spelunky* tutorial, large signs in the game's first two levels instruct players to press the spacebar to make the avatar attack, use ropes, and throw bombs (Figure 2). Participants played *Ninja Showdown* first and *Spelunky* second, each for approximately 15 minutes.

While playing the games, participants were encouraged to think-aloud and were prompted to speak using questions such as "*What are you thinking?*", "*Why did you do that?*", and "*How do you know that?*" Screen capture video, including an overlay displaying where on the screen participants were looking, and audio of participants speaking were recorded using OBS[2]. Both games recorded frame-by-frame gameplay data, including all of the keyboard keys participants pressed and held as well as the visual elements they looked at. After playing both games, participants were interviewed for approximately 30 minutes about their experiences, their understanding of how the games were controlled, and their opinions of the avatars. Participants were asked whether they ever believed that they could make their avatars perform specific actions in the games, including actions that players could not control. The interviewer also asked whether participants ever wanted to or tried to make their avatar perform actions that they could not make them do and encouraged participants to explain their thinking during these incidents. Participants' think-aloud data and explanations of their thinking during the final interview were used to elicit their mental models and determine how output from the games made them confused about how they were controlled.

[2]https://obsproject.com/

5 RESULTS

In total, ten participants enrolled in our study. All participants answered "*No*" to the screening questions: "*Do you play video games?*", "*Do you identify as a gamer?*", and "*Have you played more than 100 hours of video games in your life?*". All participants, except P10, reported spending zero hours each week playing video games. P2-4 and P8-10 were parents who wanted to play with their gamer children, but had difficulty controlling and understanding games. P1 and P5-7 mentioned feeling excluded from gaming activities because they were not as skilled as their gamer friends or siblings. Participants' demographic and gaming data (Table 1) suggest that they were people for whom gaming is not, and has never been, a significant part of their personal or social lives.

All ten participants were able to play both games; nine of the participants experienced at least one episode of confusion about how at least one of the games was controlled. Participants' gameplay, think-aloud, and interview data were analyzed using classical grounded theory methodology [31] from a constructivist perspective [11], as is typical of recent usage [7, 14]. The resulting theory is organized around the core category of *automation confusion*, which we organized into four properties: *types*, *attitudes*, *behaviours*, and *sources* (Table 3). Our analytical process is visualized in Figure 3 and described in the text below.

Data Collection: During each session, we documented participants' behaviours and utterances that we believed held theoretical significance. During interviews, we asked participants to explain these behaviours or utterances.

Data Analysis: After each session, the data were analyzed in isolation, yielding new codes (i.e., labels) and memos (i.e., free-form notes). There were often commonalities between participants' data, but the purpose of this initial analysis was to elucidate and explain their differences.

Theory Generation: During theory generation, the new data, codes, and memos were compared to our developing theory and used to detect poor fit in its concepts. When we were unsure whether the same concept explained two or more different observations, or when the same observation was explained by multiple concepts, we created short stories called confusion episodes (such as in Figures 4-6). By creating narratives from multiple slices of data, we ensured that our stories, and thereby our theory, made sense.

Theory Refinement: Comparing the codes, memos, and confusion episodes generated from different participants' data helped us to refine our concepts and led to the development of progressively abstract conceptual categories whose relations were apparent in the confusion episodes.

Saturation: When new data prompted the construction of new codes and concepts, we sought more data for further development. When new data prompted theoretical refinement, but not generation (i.e., P8), we concluded that we had reached saturation. Significant theoretical generation occurred following P2, P5, and P7's sessions. Our developing theory was tested for fit (i.e., fit to the data) and grab (i.e., explanatory power) with P9 and P10, both of whom found the theory comprehensible and relevant to their own experiences of playing the games.

Table 3: Definitions for all of automation confusion's concepts.

Theory of Automation Confusion		
Types of Mental Model Errors		
Category	**Concept**	**Definition**
False Causation	Over-Attribution	Player believes that they control actions that they do not
	Under-Attribution	Player believes that they do not control actions that they do
Explanation Errors	Extra-Rule	Player has a rule that does not explain any aspect of the game's output
	Overly-Simple-Rule	Player has a rule too simple to explain some aspect of the game's output
	No-Rule	Player has no rule to explain some aspect of the game's output
Attitudes Towards the Games		
Category	**Concept**	**Definition**
Analytical	Uncritical	Player plays without trying to improve their understanding
	Critical	Player plays to improve their understanding
Emotional	Frustrated	Player feels frustrated by avatar's actions
	Uninvolved	Player feels uninvolved in play
Behaviours Resulting from Confusion		
Category	**Concept**	**Definition**
Learning	Exploration	Player presses buttons to discover their effects
	Confirmation	Player presses buttons to confirm that an expected effect occurs
	Contemplation	Player observes the game's output without pressing buttons
Superstitious	Shadowing	Player presses buttons along with automated actions
	Mashing	Player presses buttons with no intended effect
	Manner Modification	Player modifies the way they press buttons to change their effects
Sources of Confusion		
Category	**Concept**	**Definition**
Feedback	Misinterpreted Feedback	Feedback whose meaning players misunderstand
	Missed Feedback	Feedback that players do not notice
	Missing Feedback	Feedback that does not exist but might otherwise prevent confusion
Wrong Expectations	Inherited Expectations	Expectation that the game works like something else
	Incorrect Mappings	Expectation that buttons control actions because of arbitrary associations
	Wishful Thinking	Expectation of control borne of a desire for control

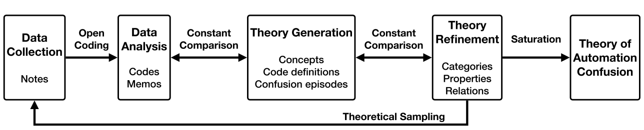

Figure 3: The analytical process we followed during theoretical development.

5.1 Automation Confusion

Automation confusion is a theory we developed of how players become confused by partially automated games. When both the human player and the automation control actions in the game, players may become confused about which actions they can control. Our theory posits that players construct mental models of a game's rules by providing input to the game, interpreting the game's outputs, and then comparing their interpretations with their expectations. However, automated actions may lead to outputs that cause the player to learn incorrect rules or doubt correct rules; they may misinterpret what happens in the game and therefore learn an incorrect mental model of the game. Players may infer causal relations that do not exist and only appear coincidentally. As we will show, many aspects of a game's output can make players confused about how the game works. But perhaps most detrimental to their understanding is players' desire for control over the game; players want to make their avatars perform specific actions and can become frustrated when they cannot make them do those actions. As concrete examples, we now illustrate through storyboards how the games confused P2, P7, and P3. To disambiguate the Bomb in *Ninja Showdown* and the bomb in *Spelunky*, *Ninja Showdown* actions are capitalized and *Spelunky* actions are not.

P2: P2 incorrectly believed that the 'b' key made Emi use the Bomb (Figure 4). To test her hypothesis, P2 pressed the 'b' key to verify that it did what she expected. When Emi coincidentally pulled out the Bomb, P2 misinterpreted Emi's automated action as confirming that she made Emi use the Bomb.

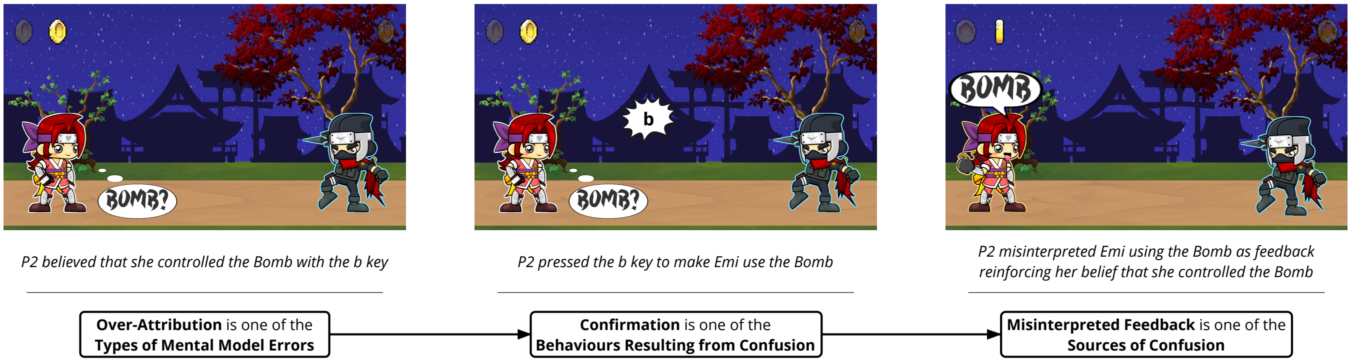

Figure 4: Storyboard depicting P2 pressing the 'b' key to make Emi use the Bomb.

Figure 5: Storyboard depicting P7 mashing the spacebar because she felt uninvolved in play.

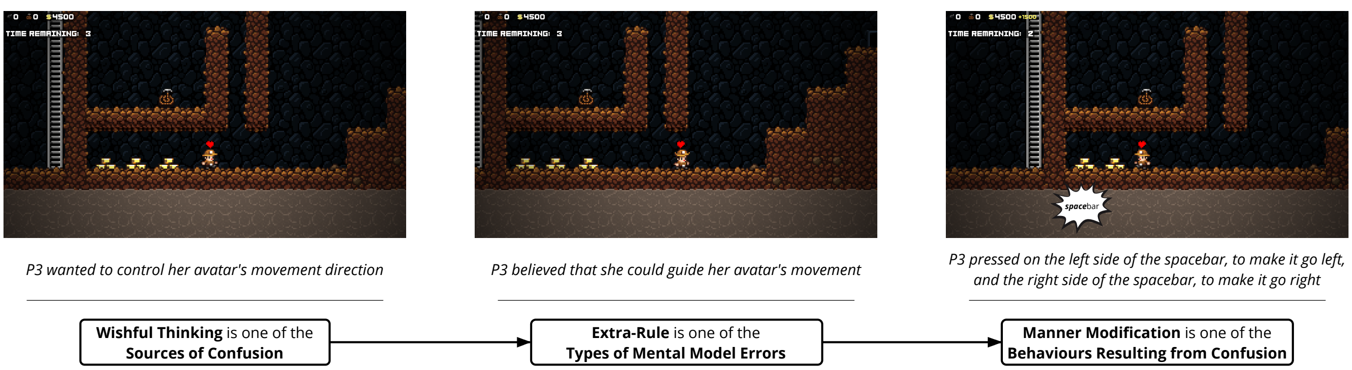

Figure 6: Storyboard depicting P3 pressing on the left and right sides of the spacebar to guide her avatar.

P7: P7 felt uninvolved in play because the avatars would do actions on their own (Figure 5). Being unable to control all of her avatars' actions frustrated P7 so much that she stopped trying to learn how the games worked and stopped paying attention to what happened in them. In *Ninja Showdown*, P7 pressed the spacebar incessantly, believing it would always cause her to win, and she often did not notice when she lost.

P3: P3 was often frustrated because her *Spelunky* avatar would move in directions that she did not want it to go (Figure 6). She wanted to influence its movement direction and took to pressing on different sides of the spacebar to signal her desires to the avatar. While playing, P3 explained that "*In my mind,* ***I'm feeling if I*** [**press on the left**] ***it will go left and if I*** [**press on the right**] ***it will go right.***" P3 pressed on different sides of the spacebar to guide her avatar's movement and sometimes it did what she wanted.

We found that participants exhibited a variety of **mental model errors** that influenced their **attitudes towards the games** and their **behaviours while playing them**. Participants' behaviours

Table 4: Definitions for the types of mental model errors experienced by participants.

Types of Mental Model Errors		
Category	**Concept**	**Definition**
False Causation	Over-Attribution	Player believes that they control actions that they do not
	Under-Attribution	Player believes that they do not control actions that they do
Explanation Errors	Extra-Rule	Player has a rule that does not explain any aspect of the game's output
	Overly-Simple-Rule	Player has a rule too simple to explain some aspect of the game's output
	No-Rule	Player has no rule to explain some aspect of the game's output

determined the games' outputs, which sometimes helped them to make sense of what was going on and sometimes created **sources of confusion**. In P2's example, her incorrect mental model caused her to press the 'b' key, which indicated that she could control an action that she could not. In P7's example, her feelings about the games caused her to press the spacebar with no specific intention and miss feedback that might have told her what her pressing did. In P3's example, her desire to control her avatar's movement led her to believe that she could by pressing on different sides of the spacebar. In this section, we explain our theory's four properties and describe how they relate to each other in ways that can affect players' confusion.

5.2 Types of Mental Model Errors

All participants, save for P4, constructed mental models that contained errors. While playing the games, participants were prompted to explain the games' rules as they understood them. When participants mentioned pressing buttons other than the spacebar, they were asked what they believed the buttons made their avatar do. As shown in Table 4, we categorize participants' mental model errors as errors of *false causation* and *explanation errors*. Errors of false causation occurred when participants misunderstood what caused the avatar to perform actions and *explanation errors* occurred when participants learned rules that incorrectly explained what happened in the games.

5.2.1 False Causation: Over-attribution & Under-attribution. False causation errors occurred when participants misattributed the causes of avatar actions. Participants sometimes misattributed automated actions to themselves (i.e., over-attribution) or misattributed their actions to the automation (i.e., under-attribution). For example, P1, P3, P5, P7, and P9 all believed at some point that they could make their *Spelunky* avatars jump, an action that only the automation could control.

Over-attribution: Over-attribution errors occurred when participants believed that they could control actions that they could not. P3 incorrectly believed that the spacebar made Emi use the Bomb, and not the Sword, in *Ninja Showdown*. When asked why she pressed the spacebar, causing her to tie instead of win the round, P3 sighed and said "***I wanted Bomb for the Dart... but the things was not there.***" P3 believed that she could control actions that she could not and became surprised when her avatar did not do them.

Under-attribution: Under-attribution errors occurred when participants did not believe that they could control actions that they could. P3 expected her avatar to use the Bomb attack when she pressed the spacebar, but was surprised when the avatar used the Sword instead. The avatar appeared to be ignoring P3's commands, which caused her to question whether she could control either character in the game. When asked which character she could control, P3 said "***I don't think I am able to control any of them****, because there is no option for me to tell them what to use...* [my avatar] *must have the Sword to destroy the Bomb. So,* ***where I can give him the Sword?***" P3 was unable to make her avatar do the actions she wanted and so stopped believing that she could control any action.

5.2.2 Explanation Errors: No-Rule, Overly-Simple-Rule, & Extra-Rule. Explanation errors occurred when participants believed in rules that incorrectly explained the game's output. The causal connections between players' inputs and the game's outputs can be thought of as 'explanation rules' that explain what is going on in the game. For example, P2, P7, and P10 all thought that they needed to press the spacebar, twice sometimes (i.e., P7 & P10), to make bombs explode in *Spelunky*; this was not an avatar action and neither the automation nor participants could control it. Participants sometimes invented rules that did not hold up, came up with rules that were too simple to account for the variety of outcomes they observed, or failed to discover rules explaining part of the game's output.

Extra-Rule: Extra-rule errors occurred when participants believed in rules that did not explain any aspect of the game's output (e.g., *Takeshi does what Emi predicts*). P2, P3, P5, P7, and P10 spent some of their time playing *Ninja Showdown* believing that their avatar's Intention cues, which indicated which attack their avatar intended to do, actually predicted which attack their opponent would do. These participants would not look at their opponent at all, decide what to do based on their avatar's Intention cue alone, and then become surprised when they lost the point they thought they had won. P2 made her avatar use the Sword when she thought that her opponent would use the Bomb, even though he was already holding the Dart. When she lost the round, P2 laughed and said "*This is crazy!* ***I think I do not understand the rules to play it.***" Participants who believed in rules that did not exist had difficulty making sense of the feedback they received.

Overly-Simple-Rule: Overly-simple-rule errors occurred when participants came up with rules that did not account for all of the different outcomes they observed (e.g., *spacebar makes*

Table 5: Definitions for the attitudes towards the games experienced by participants.

Attitudes Towards the Games		
Category	**Concept**	**Definition**
Analytical	Uncritical	Player plays without trying to improve their understanding
	Critical	Player plays to improve their understanding
Emotional	Frustrated	Player feels frustrated by avatar's actions
	Uninvolved	Player feels uninvolved in play

the avatar do something). While playing *Spelunky*, P1 understood that pressing the spacebar would make his avatar attack, use a rope, or throw a bomb, but he did not know which specific action his avatar would do. P1 also believed that pressing the spacebar would make his avatar jump, and he often wanted it to jump. He pressed the spacebar so prodigiously that he seldom had time to see his avatar's Option cue before it performed the action. When asked whether he knew what his avatar would do when he pressed the spacebar, P1 said "***I know what he's doing.***" P1 was content with the actions his avatar was doing and so did not try to discern which action it would do in particular.

No-Rule: No-rule errors occurred when participants did not have a rule to explain some aspect of the game's output (e.g., not knowing that the avatar can use ropes and bombs in *Spelunky*). P2 knew only that she could make the *Spelunky* avatar attack and was surprised when it did anything else. Any time her avatar threw a bomb, P2 became worried because she thought that it would hurt her avatar. In the game's third level, P2 pressed the spacebar to attack a nearby enemy while her avatar was preparing to throw a bomb. When she saw the bomb, P2 said "*No. No. No. No. No. No. No. No.* ***I'm not in control of this avatar... I pressed the spacebar to kill the snake.***" She could not make sense of the Option cues, informing her of which action her avatar would do, and did not understand why her avatar would sometimes ignore her commands to attack.

Participants were content with believing that they could control actions they could not. P1 and P5 wanted the *Spelunky* avatar to jump and liked that it did—coincidentally—when they pressed the spacebar. However, some participants became frustrated when they could not make their avatars do what they wanted or when the games played out differently than they expected. Participants' erroneous beliefs about how the games worked affected both their attitudes towards the games and their behaviours while playing them. Realizing that they misunderstood the rules of play prompted some participants to more critically analyze the game's output and press buttons in service of improving their understanding.

5.3 Attitudes Towards the Games

Participants' attitudes towards the games affected how they played with partial automation. Participants became frustrated when they did not like what their avatar was doing and could not make it do what they wanted. Frustration caused some participants to pay more attention and make sense of what happened. In some cases, participants became so frustrated that they felt uninvolved in play and stopped trying to understand what was going on. In this section, we describe the *analytical* and *emotional* attitudes that participants' confusion engendered (Table 5).

5.3.1 Analytical Attitudes: Critical & Uncritical. Participants adopted different analytical attitudes towards making sense of the games' outputs. When they were content with their understanding, participants played the games with an *uncritical* attitude, meaning that they were not trying to improve their understanding. However, when they could not explain their observations, some participants adopted a more *critical* attitude, meaning that they carefully observed the games' outputs to improve their mental models.

Uncritical: Participants were uncritical of the games when they were not trying to improve their understanding. P7 disliked *Ninja Showdown* so she did not care to improve her understanding of the game. P7 lost many rounds, but nevertheless concluded that all she needed to do to win every round was to press the spacebar. She explained that "*It's too boring. Like,* ***if I kept just pressing the spacebar I'll win in all the games, right?"*** *I don't even need to see what she's predicting.* ***You don't even need to hear, just press.***" P7 was uncritical in her analysis of the game and did not notice or care when she lost.

Critical: Participants were critical in their analysis of the games when they played with the intention of improving their understanding. While her opponent was holding the Sword, P5 saw her *Ninja Showdown* avatar's 'Bomb?' Intention cue and pressed the spacebar to use the Sword in response. Noticing her mistake, P5 said "*Oh, wait no. I chose the wrong option... 'Cause* ***I thought that guy had the Bomb, so I had to choose the Sword.***" Over the next several rounds, P5 explained what her observations told her about how the game worked. She described how "*Takeshi brought out the Dart,* [my avatar is] *supposed to bring the Bomb, but instead she brought the Dart...* ***That was the point where I was like 'is she saying for herself or the guy?'***" She carefully and critically analyzed her avatar's actions and explained that "*Later in the round it kinda, like, made sense that they were her thoughts about herself not Takeshi.*"

5.3.2 Emotional Attitudes: Frustrated & Uninvolved. Participants adopted different emotional attitudes towards playing the games. When they were unable to make their avatars do what they wanted, some participants became *frustrated.* Often, participants' frustration made them more interested in discovering how the games worked and caused them to search for alternative ways to control their avatars. However, when participants determined that they could

Table 6: Definitions for the behaviours resulting from confusion exhibited by participants.

Behaviours Resulting from Confusion		
Category	**Concept**	**Definition**
Learning	Exploration	Player presses buttons to discover their effects
	Confirmation	Player presses buttons to confirm that an expected effect occurs
	Contemplation	Player observes the game's output without pressing buttons
Superstitious	Shadowing	Player presses buttons along with automated actions
	Mashing	Player presses buttons with no intended effect
	Manner Modification	Player modifies the way they press buttons to change their effects

not control their avatar in a way that they liked, they felt *uninvolved* and gave up on trying to control it. Frustrated and uninvolved were not the only ways participants felt while playing; P1 and P5 had fun believing they could make the *Spelunky* avatar jump and P6 felt accomplished when she correctly timed her attacks to hit the snakes. Feeling frustrated and uninvolved contributed significantly to P1-3 and P6-9's confusion and were therefore included as concepts in our theory.

Frustrated: Participants were frustrated by the games when they could not make their avatars do the actions they wanted them to do. P6 did not know what to do when her opponent chose the Sword and became frustrated that she was unable to "*rescue Emi*" when her avatar intended to choose a Bomb. She wanted some action she could do to help her avatar and suggested that she should be made able to '*reject*' her avatar's selection with the '*r*' key. But eventually P6 stopped being frustrated and realized that she could reject her avatar's suggestions by choosing the Sword. She explained that "***When I stopped thinking about how to use the other weapons** and what to press to have the other weapons, **I tried to analyze how it works.***" Frustration caused by the avatar not doing what participants wanted caused some participants to more critically analyze the game's outputs.

Uninvolved: Participants felt uninvolved in play when they could not make their avatars do what they wanted. P7 felt uninvolved in playing *Spelunky* because her avatar made all the decisions for her. She said "*He's the one who's knowing how to get out of this maze. Like, **I feel really like I'm not doing anything. I'm just doing what he wants.***" Just as in *Ninja Showdown*, P7 concluded that the optimal way to play *Spelunky* was to press the spacebar as often as possible. Since her avatar was "*Just using what he wants*", P7 did not need to improve her understanding of the game.

In sum, participants' emotional attitudes towards the games affected their analytical attitudes and consequently their behaviours. Frustrated participants pressed buttons and reflected on their observations to verify that their mental models were correct. Overly frustrated participants (i.e., P2, P3, & P7) stopped taking actions and stopped trying to make sense of their observations.

5.4 Behaviours Resulting from Confusion

Participants cited many reason for pressing or not pressing buttons. Their erroneous mental models and attitudes towards the games caused them to exhibit both *learning* and *superstitious* behaviours (Table 6). Sometimes participants would press buttons, or selectively not press buttons, to learn what would happen. Other times, participants superstitiously pressed buttons that had no effect, pressed buttons with no express intention, or changed the way they pressed buttons to make the avatars do different actions.

5.4.1 Learning Behaviours: Exploration, Confirmation, & Contemplation. Participants exhibited learning behaviours when they selectively pressed buttons to learn their effects. Participants used three types of behaviours to improve their understanding of the games. They employed *exploration* when they pressed buttons to observe their effects, *confirmation* when they pressed buttons to confirm their effects, and *contemplation* when they did not press buttons to observe what would happen.

Exploration: Participants exhibited exploration when they pressed buttons to discover their effects. Participants often wanted to control actions that they could not and would explore the keyboard for ways to make their avatars do them. P1 knew that the spacebar made his *Ninja Showdown* avatar use the Sword, but wanted to make his avatar use the Bomb and Dart attacks and tried pressing keys other than the spacebar to make it do them. When asked why he was pressing the arrow keys, P1 explained that "***I'm going to get to see what it does**, because it's only Swords*" Eventually, through a series of coincidences, P1 discovered that he could make his avatar use the Bomb with the left arrow key and the Dart with the right arrow key, even though he actually could not. Participants who went looking for the keys that made their avatars do what they wanted (i.e., P1-3, P8, & P9) often believed that they could control these actions.

Confirmation: Participants exhibited confirmation when they pressed buttons to confirm that they did what participants expected. P9 was frustrated that "[*Ninja Showdown*] *doesn't give you a chance to defend yourself*" and tried pressing the 'control' key to make her avatar choose the winning weapon. Coincidentally, the avatar did what P9 wanted, which led her to suspect that she was the cause of the avatar's action. At the beginning of the next round, P9 said "***I'm testing a theory***" and tried pressing the 'control' key again to confirm her suspicion. When asked why she believed that 'control' may make her avatar choose the winning weapon, P9 said "***'Cause it just worked when I did it.***" When they doubted their understanding of how to control the avatars, P1-3 and P7-10 tried pressing buttons to confirm their effects.

Table 7: Definitions for the sources of confusion experienced by participants.

Sources of Confusion		
Category	**Concept**	**Definition**
Feedback	Misinterpreted Feedback	Feedback whose meaning players misunderstand
	Missed Feedback	Feedback that players do not notice
	Missing Feedback	Feedback that does not exist but might otherwise prevent confusion
Wrong Expectations	Inherited Expectations	Expectation that the game works like something else
	Incorrect Mappings	Expectation that buttons control actions because of arbitrary associations
	Wishful Thinking	Expectation of control borne of a desire for control

Contemplation: Participants exhibited contemplation when they chose not to press buttons to observe what would happen. When asked whether she thought that she could make her *Spelunky* avatar jump, P8 said "*I don't think so. I'm not sure. But, I think that if I were to play it again,* ***I'd just watch what he does more and pay more attention to what I actually have control over.*** [I was watching] *for whether my pressing the bar had an action; for whether he would do things on his own without. So, just for the, you know,* ***whether my pressing things was needed and whether it had an effect.***" While pressing buttons to explore and confirm their effects led some participants to develop superstitions, not pressing buttons and contemplating what happened helped participants to dispel them.

5.4.2 Superstitious Behaviours: Shadowing, Mashing, & Manner Modification. Participants exhibited superstitious behaviours when they pressed buttons that did not have the intended effects. *Shadowing* occurred when participants pressed buttons along with automated avatar actions. *Mashing* occurred when participants pressed buttons with no specific intention or to avoid an undesired outcome. *Manner modification* occurred when participants changed the way they pressed buttons to change their effects.

Shadowing: Participants exhibited shadowing when they pressed buttons to make their avatars do actions they were already doing. Most participants (i.e., P1, P3, P5-10) at some point believed that they could make their *Spelunky* avatar jump or pick up items by pressing the spacebar. P5 immediately started tapping the spacebar along with her avatar's jumping in the first level of *Spelunky*. When asked if she thought that she could make the avatar jump, P5 said "*Sometimes I did but sometimes I didn't...* ***I felt that it was my instinct that I was making him do, but sometimes I didn't press the key and he was doing it by himself.***" Jumping was an action that only the automation could control but, since her avatar was already jumping, P5 thought that she was contributing.

Mashing: Participants exhibited mashing when they pressed buttons with no intended outcome or to avoid an undesired outcome. P9 was unsure of what she could make her *Spelunky* avatar do but pressed the spacebar anyway. When asked whether the avatar did what she expected, P9 said "*I don't know, because* ***I don't know what I'm expecting him to do***." We then asked her why she pressed the spacebar at all and she said "*Force of habit. I feel like I have to...* ***'Cause if I don't, I die.*** *See?*" P9 had no expectation for what her avatar would do when she pressed the spacebar; she believed only that if she did not press it she would lose.

Manner Modification: Participants exhibited manner modification when they modified the way in which they pressed buttons to modify their effects. If a desired outcome did not occur, participants sometimes suspected that they pressed the button at the wrong time or in the wrong way. P3 pressed on different sides of the spacebar to influence her avatar's movement. Although P3 recognized that "*spacebar is a spacebar*" and that pressing on different sides would not produce different effects, she never entirely gave up hope that she could guide her avatar. When asked if pressing on different sides of the spacebar ever made her avatar do what she wanted, P3 said "*Yeah, yeah. It does.* ***I feel like it does... I wanted to go like this and sometimes it's happen and sometimes it's not.*** *Is that something, like,* ***there is a connection?***"

The participants who developed the most accurate mental models of the games were those who struck a balance between pressing buttons and not pressing buttons. As explained by P8, "*As* [my avatar] *was doing his stuff* ***I was trying to pay attention to what he was doing, but I was also trying to interact****... It only meant that* ***sometimes I was just, you know, hitting it, as opposed to really paying attention****: 'is it actually doing anything?'*" Participants wanted to make their avatars do what they wanted them to do and so would press buttons to feel more involved in their avatar's activities. They would misinterpret the games' outputs in favorable and convenient ways that aligned with their expectations and desires.

5.5 Sources of Confusion

Participants developed erroneous mental models due to both the feedback they received and their expectations for how the games worked. Each participant approached the games with their own set of expectations and so imagined that the games would work in different ways. Participants' incorrect expectations about how the games worked caused them to misinterpret the games' outputs. In this section, we describe how *feedback* and participants' *wrong expectations* caused them to become confused about how the games were controlled (Table 7).

5.5.1 Feedback: Misinterpreted Feedback, Missed Feedback, & Missing Feedback. Feedback is intended to inform users of the results of their actions. This was a common source of confusion for participants; they *misinterpreted feedback* in ways that agreed with their incorrect mental models of the games. Sometimes participants *missed feedback* because they were looking for it in the wrong places. Other times, participants' button presses produced no effects and the games were *missing feedback* that might have helped them to understand what happened.

Misinterpreted Feedback: Participants misinterpreted feedback when they misunderstood the meaning of the games' outputs. Automated avatar actions sometimes produced outputs that participants misinterpreted as validating their erroneous mental models. P3 suspected that the 'control' key might make her *Ninja Showdown* avatar use the Sword, pressed it, became surprised that no Sword appeared, and said "*I'm thinking Bomb, **where is the Sword?***" In the next round, still confused about why she did not see the Sword, P3 looked at her opponent, noticed that it was using the Sword, and said "*Yeah, **Sword is now there.***" P3 misinterpreted her opponent's attack as feedback indicating that she was actually in control of her opponent and successfully commanded him to use the Sword.

Missed Feedback: Participants missed feedback when they attended to the wrong parts of the games' outputs. P2 knew that she could make her avatar attack in *Spelunky*, but did not know about the other actions she could control. She pressed the spacebar to make her avatar throw a rope and a bomb during the tutorial, but when asked why she pressed the spacebar, P2 said "***The space is for attack.***" P2 could not make sense of the Option cues, informing her of which action her avatar would do, and so missed this feedback.

Missing Feedback: The games were missing feedback when they produced no feedback informing participants of the effects of their actions, or the lack thereof. Much of P3's confusion about *Ninja Showdown* seems to have been caused by missing feedback in the tutorial. P3 pressed the spacebar while her avatar was already using the Bomb, which indicated to her that she could make her avatar use the Bomb. There was a critical lack of feedback from the game that might have informed P3 that her spacebar press had no effect.

5.5.2 Wrong Expectations: Inherited Expectations, Incorrect Mappings, & Wishful Thinking. Participants had the wrong expectations when they expected the games to work in ways that they did not. We found that some participants inherited expectations from other systems they understood, as they expected the games to work in similar ways. Some participants came up with *incorrect mappings* inspired by arbitrary associations between the actions they wanted to control and the buttons they believed should control these actions. Perhaps the greatest source of confusion for participants was their desire to make their avatar do what they wanted it to do and their *wishful thinking* when interpreting the games' outputs in ways that satisfied this desire.

Inherited Expectations: Participants inherited expectations when they expected the games to work like other technologies they already understood. Both P1 and P5 immediately shadowed the *Spelunky* avatar's jumping out of "*instinct*" (P5) and may have inherited an expectation that they could make their avatar jump from platformers they played as children. For other participants, who were unfamiliar with platformers, their expectations for how the games worked seem to have been drawn from their expectations of other technologies. P8 was shocked to discover that her *Ninja Showdown* avatar was not as 'smart' as she expected and would sometimes choose the losing weapon. When P8 tried to intervene and make her avatar choose a different weapon, she pressed the 'enter' key because "***Enter does everything.***" Each participant approached the games with their own set of expectations informed by the interactive systems they already knew.

Incorrect Mappings: Participants came up with incorrect mappings when they hypothesized that buttons controlled actions because of an arbitrary association between them. P2 wanted her *Spelunky* avatar to jump over and avoid snakes, so she repeatedly tapped the spacebar and asked "***I want to jump... Is there any way to jump?***" Shortly after, P2 said "***I tried to press 'j'*** and when asked why she chose the 'j' key she said "*The game didn't tell me that but I just wish... **I just think 'j' would be for jump.***" Just as she had in *Ninja Showdown*, when she hypothesized that she could make her avatar use the Bomb and the Dart with the 'b' and 'd' keys, P2 invented an incorrect mapping between the first letter in the name of the action she wanted her avatar to do and the key for that letter on the keyboard.

Wishful Thinking: Participants were given to wishful thinking when they believed that they could control actions that they could not because they wanted to control these actions. While describing what about the avatar's behaviour was frustrating, P8 said "*Unless I have opportunities I don't know about... If she's not* [trustworthy] *then I'm like 'uh, am I missing something in the game? **Is there another key that I have access to that I don't know about?***'" Being unable to make their avatars perform specific actions made participants frustrated and prompted them to think wishfully about how the games were controlled. P8 went on to explain how her desire to make the her avatar use the Bomb led her to believe that she could. She said "***I thought I could, but I couldn't, when she needed to, but wasn't.** 'Cause I figured, if the goal is to win and she can't be trusted to do the right thing, **there's gotta be somebody who can do it and I'm the only other person here.***" P8's desire to make her avatar do specific actions led her to expect that she could.

5.6 Summary

All ten participants were able to successfully play the games. However, we found that partial automation made participants confused about how to control the games, answering RQ1. Participants' frustration with being unable to fully control their avatars led them to spend a significant amount of their playtime trying to control actions that they could not. They came up with convoluted ways of playing that, because they did not actually produce the effects participants expected, would only appear to work for so long. Participants had to continually revise their mental models of the games and consequently reinterpret the same outputs. Our grounded theory of automation confusion describes the types of confusion participants experienced, answering RQ2. It explains how participants' expectations made them confused by the games, how their confusion made them frustrated, how their frustration made them behave differently, and how their behaviours led them to misunderstand the games in new ways.

Our results also suggest that partial automation enabled non-gamer participants to play games that they may have had great difficulty playing otherwise. After P9 had played both games with automation and completed the interview, we asked her to play *Spelunky* without automation, using different buttons to jump, move around, sprint, and use items. P9, and every participant who preceded her, said that they would have preferred to play without automation, so we wanted to check whether they could and ask which version they preferred. P9 was unable to get her avatar to jump across the first series of platforms and said "*I can't even jump properly.* ***I guess it's not better if I have any controls.***" P9 wanted to use a bomb to circumvent a gap, but did not have any bombs, and had to be told that bombs were finite. Although we cannot make strong claims (see Section 6.3), we interpret P9's difficulty playing *Spelunky* without automation as evidence that partial automation simplified how this game was controlled and reduced the number of decisions participants needed to make. The automation performed actions that P9 found difficult (i.e., jumping) and performed cognitive tasks (i.e., resource management) that she was unaware of. We planned to ask P10 to play without automation as well but, surprisingly, she did not want to play without the automation.

6 DISCUSSION

All participants, except P4, experienced at least some confusion about the automation and our theory of automation confusion describes the types and causes of confusion participants experienced. We believe that our results may generalize to other non-gamers, action games, and partial automation for the reasons listed below.

Non-gamers: Our results may generalize to other non-gamers because we recruited non-gamer participants who wanted to play games with their gamer friends and family (Table 1). Most of our participants were women, a group that has been historically marginalized by gamer culture [34, 39, 64], and so may be representative of non-gamers generally.

Action Games: Participants played two action games and games within the same genre often involve similar mechanics [49, 50]. Playing these games involved making complex and real-time decisions with uncertain information and limited time; these are exactly the conditions in which non-gamers might benefit from partial automation. Due to the games' mechanical similarities with other action games and the rapid decision-making involved in playing them, we believe our results may generalize to other real-time games in the action genre.

Partial Automation: The games used in our study exemplify the two forms of partial automation used in games. *Ninja Showdown* provides input automation, controlling some inputs on the player's behalf, while *Spelunky* provides one-switch automation, mapping multiple actions to the same button. Our theory of automation confusion synthesizes the confusion caused by both types. This makes it difficult to directly compare the confusion caused by each game or each type of partial automation, but provides designers a robust and unified tool for understanding the confusion that might arise in other partially automated games.

Understanding automation confusion may enable designers to better realize partial automation's potential to make digital games simpler. In this section, we relate our findings to prior work, discuss our findings' implications, and propose guidelines for the design of partially automated games.

6.1 Recommendations for Design

We designed both games with guidance from the literature, including tutorials and awareness cues to help players understand the automation, but our results suggest that more guidance is needed. Our analysis identified several issues in the design of the games (e.g., unclear feedback & insufficient training) and the automation (e.g., ceding control & cooperation) that we believe can be addressed. In this section, we provide recommendations for the design of partial automation for non-gamers based on our observations.

6.1.1 Increase Control. Partial automation should afford players as much control over their avatars as possible. The partially automated games used in our study were designed to help non-gamers' play successfully by reducing their control. However, this confused participants if they wished to make their avatars perform actions which were not under their control. Instead of removing control altogether, partial automation could allow both the player and the automation to control all of an avatar's actions at the same time, falling back on the automation for support when the player fails to act. This approach may scaffold non-gamers' learning by allowing them to choose which mechanics they control. This form of support is analogous to training wheels [9] or a stencil [43], where the support is provided only when necessary, and could be removed altogether if the player becomes proficient in the game.

6.1.2 Beware Misinterpretation of Feedback. Designers of partially automated games should rigorously test the comprehensibility of their games' feedback with target players. *Ninja Showdown* and *Spelunky* provided awareness cues designed to improve participants' understanding, but participants often misinterpreted the meaning of these cues. Confused participants continually revised their mental models of the games and so ascribed different meanings to the same outputs over the course of play. Had the meanings of these cues been reinforced some other way, for example having Emi say "*I think I'll use a Dart this time*" (instead of just showing a Dart icon), then participants might have more faithfully interpreted what the cues were designed to convey.

6.1.3 Provide Training. Partially automated games should provide training for non-gamers to front-load their learning and thereby minimize the learning they do during play. Instructing players on how to play has fallen out of vogue for game design, in favor of gameplay tutorials that teach players through play. However, we believe that training participants on what they could control might have prevented some of their confusion. Automated games could show players what to do in a variety of gameplay situations and also quiz players about what is happening in the game to verify their understanding. Training was specifically requested by both P3 and P8, who suggested that video game courses be made to teach them how to play the games their children play.

6.1.4 Tell Players How to Cooperate. Partially automated games should teach players how to cooperate with their avatars by telling them what to do when they dislike their avatar's behaviour. In *Ninja Showdown*, most participants understood what to do when their success was determined entirely by them. They often knew, for example, that they should always make Emi use the Sword when Takeshi used the Bomb, because Swords beat Bombs. However, some participants were less sure what to do when their success was dependent on the automation. When Takeshi used the Sword, pressing the spacebar would force a tie, while not pressing the spacebar would result in either a win or a loss. Most participants wanted to win. P6 wanted additional actions she could do to "*save Emi*" and P9 was frustrated that there was no way to "*defend yourself*". Participants had significant difficult learning how to cooperate with the automation and may have benefited from being told what to do when they needed the automation to act.

6.2 Parallels to Automation Confusion in Other Contexts

Many of our findings run parallel to, and may be partly explained by, findings in other contexts that suggest humans employ magical thinking [23, 86] in their interactions with computers. In this section, we discuss parallel findings from other contexts as well as some of the more general implications of automation confusion.

Illusion of Control: Langer found that human subjects were prone to an illusion of control, believing that their choices controlled events even when, rationally, they did not [52]. For example, people sometimes throw dice harder for high numbers and softer for low numbers. These behaviours are similar to the superstitious behaviours exhibited by participants, such as when P3 pressed on different sides of the spacebar to guide her avatar. Humans have a tendency to accept evidence that confirms their beliefs [45] (i.e., confirmation bias) and also to infer causal relations from co-occurrences [4, 96] (i.e., *post/cum hoc ergo propter hoc*), so partial automation may promote such illusions.

Jakob's Law: Jakob's law is a principle in web design that states: "*Users prefer your site to work the same way as all the other sites they already know*" [58]. This idea that users expect systems to work like more familiar systems may help explain why participants who had played platformers expected to be able to make their *Spelunky* avatar jump. Participants expected the games to work like the interactive systems they already knew and therefore become confused in ways specific to their prior experiences. This phenomenon, in which prior learning impedes further learning, is well known in HCI as negative transfer [3].

Curious Rituals: Nova et al. compiled a list of 'curious rituals' [62] users perform when interacting with digital devices, such as tilting the controller when playing racing games. While we did not observe these specific rituals, some of our participants took to mashing, a strategy commonly employed by novice fighting game players [18, 74]. These participants' mental models inadequately explained the consequences of their button presses; they sometimes knew only that pressing buttons made good things happen.

Mode Confusion: The mode of an automated system determines how it responds to users' input [40]. Mode confusion occurs when users provide inappropriate input because they are unaware of the automation's current mode [77–80]. Although the games used in our study had no modes, players' button presses did produce different outcomes depending on the games' states. P2, for example, pressed the spacebar to make her *Spelunky* avatar attack and was surprised when it instead threw a bomb. She was unaware that the automation had selected the bomb, because she thought it always selected the whip.

Paradox of Automation: Feeling frustrated and uninvolved are common to the experiences of pilots in highly automated aircraft. Wiener describes a situation in which pilots were unable to perform a necessary maneuver because the flight automation would not switch modes at the appropriate time [61, 93]. The pilots explained that they would turn the automation off, and revert to manual control, when it got in their way. The paradox of automation is that "*When the workload gets heavy you turn off the thing that was designed to reduce the workload.*" [61] All participants, except for P10, said that they would have preferred to play both games without partial automation, although they likely would have been unable to play *Spelunky* successfully.

Cheating the System: Our results show that automation can make learning how interactive systems work a risky prospect and can lead users to search for alternative ways to control the system. For example, pilots in highly automated flight decks tried to 'cheat' the automation by entering fabricated data into their instruments to trigger a change of mode [61, 93]. Similarly, users of an automated operating room humidifier did not understand the meaning of the device's alarms and would simply power cycle the device whenever an alarm occurred [16]. Further investigation is needed to understand how automation confusion, in a wider variety of domains, might affect users' mental model development.

6.3 Limitations

While our study's results may generalize to other non-gamers learning to play partially automated action games, they are based on the data of a small number of participants, so suggestions regarding their generalizability are speculative. Further investigations with more participants and a greater variety of partially automated games are needed to determine whether similar forms of confusion arise in different players and play contexts.

We did not ask participants to play the manual versions of the games because we expected them to have great difficulty (see Section 2.1). The difficulty posed by manual control may have caused participants to expect subsequent automation conditions to also be difficult, priming them to expect a negative experience. Furthermore, the inclusion of manual play would have greatly increased session lengths. Manual play data would, however, have allowed us to determine whether partial automation enabled participants, other than P9, to play and to isolate confusion caused by the automation from confusion caused by the games themselves.

The automation used in our study greatly reduced participants' control and, although players may still become confused in similar ways, it remains unknown how prevalent or problematic automation confusion can be when players have more control over the game. Furthermore, our study's exclusion of gamers makes it difficult to determine whether participants' confusion was caused by the automation or their lack of familiarity with game idioms. Further studies could consider whether automation confusion manifests differently, or at all, in players who have more control and are more conversant with gaming conventions.

7 CONCLUSION

Partial automation can simplify games for non-gamers, but players can become confused about what parts of the game they control. To provide information about the prevalence and types of automation confusion, we analysed gameplay and interview data from ten non-gamers who played two partially automated games. Partial automation made the games work differently than participants expected, which made interpreting the games' outputs difficult. Participants experienced automation confusion when automated avatar actions caused them to develop incorrect mental models of how the games were controlled. Our systematic investigation yielded a theory of automation confusion that provides designers with new knowledge to inform the creation of more comprehensible partially automated games and to improve the play experience for a wider range of players.

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