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Exploring player agency in educational video games

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ABSTRACT

Player agency is the freedom and control to make decisions during gameplay. Game designers shape player agency by including alternative storylines, optional objectives, and developing a range of mechanics thereby enriching player experience with novelty and variety during gameplay. So far, there is a dearth of studies that focus on giving autonomy to players over the use of learning mechanic in educational games. This study explores the impact of providing players with the autonomy over the use of learning mechanic. Students interacted with two versions of a computer programming game prototype differing in the level of player agency in terms of freedom to employ the learning mechanics during gameplay. We employed quantitative and qualitative methods to investigate if player agency affected students' learning outcomes, game enjoyment, and intrinsic motivation to learn. The results have implications for design of educational games, suggesting that incorporating player agency, particularly in the context of choosing learning mechanics, can enhance enjoyment and intrinsic motivation without compromising the educational effectiveness of the game.

1. Introduction

Agency is the ability to have control and influence over the choices made in our everyday lives [1]. We exert agency to pursue goals, make decisions, and ultimately shape our destinies. Recognizing the significance of agency, designers have actively pursued ways to support and enhance the sense of agency experienced by individuals within various environments, such as educational and recreational settings. Learning in educational environments has undergone a pedagogical shift from being instructor-centric, which offered limited control and choices to the students, to being learner-centric [2]. Pedagogical approaches such as active learning, problem-based learning, discovery learning, and exploratory learning need the active participation of students instead of passively receiving information from the instructor [3]. Learning in these environments is self-directed, and students must self-regulate, set goals, and collaborate with their peers [3].

Similarly, games have undergone remarkable innovations in design since their inception [4]. Early games, owing to the technological limitations, offered players limited choice and freedom when playing the game [5]. Players now have the choice and freedom over many aspects of the game: players can customize their avatar, change difficulty, use novel controllers (e.g., drive a car using steering wheel), free-roam in open-world games, make choices within stories to affect the overall narrative, interact with other players, and fully immerse themselves in the game with the help of virtual reality. Additionally, many games now allow players to create custom worlds or levels within the game (e.g., FarCry [6]) and design new mechanics (e.g., DeadCells [7]). This sophistication and nuance in interaction within the games that allow players to have greater choice, control, and freedom, is broadly known as player agency [5,8].

This paper explores the ways in which educational games can support agency of the players. Students enrolled in an introductory programming course interacted with game prototypes that differed in the level of player agency during gameplay. In the agency-unrestricted game prototype, students can freely progress through the game and exercise autonomy while using the learning mechanic. In the agency-restricted game prototype, students must use the learning mechanic in a predetermined order to progress through the game. We employed quantitative and qualitative methods to investigate if player agency affected students' learning outcomes, game enjoyment, and intrinsic motivation to learn. We found evidence that students' game enjoyment and intrinsic motivation to learn was significantly higher in the game condition that supported player agency (i.e., agency-unrestricted game prototype). Both game conditions supported positive learning outcomes. We identify implications for designing and evaluating educational games.

2. Literature review

2.1. Player agency

Player agency is described differently across contexts, with three primary traditions of conceptualization: (1) Representation and community participation; (2) Narrative structure; and (3) From a game

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design perspective [5]. In the first conceptualization, player agency is described in relation to diversity [9], representation [9,10], and community participation [11]. Player agency in this tradition is the freedom, ability, and choices offered to players belonging to diverse backgrounds on how they want to represent their identity in online and social contexts [5,12]. This freedom and the ability to create and customize their avatar allow individuals to feel ownership over their character [13], which supports players' feelings of acceptance and belonging for the game and the community, thereby fostering player agency [5,10]. In the second conceptualization, player agency is the freedom to make choices that ultimately change the narrative plot of the player and the story's future events [5,14,15]. Within the third conceptualization, from a game design perspective, player agency is the product of the designers' careful organization of game elements. Game designers create rules, goals, and abilities that shape the agential skeleton for the players to inhabit in the game [16].

This paper focuses on describing player agency within the game design perspective. More specifically, we focus on game mechanics, which combines game objects within the environment in a pre-determined set of rules to produce actions that players can undertake during gameplay [17,18]. Game mechanics govern how players interact with the game [19–21]. When creating rules in the game, developers set goals and choose pre-defined actions to be made available for the players. As such, game developers *write rules* (algorithms) that "set in stone" what the players "can and cannot do" [22]. These rules create a possibility space, allowing the players to experiment with the actions available in the game [5]. This possibility space allows the players to express their agency because the rules specify the constraints—not the actual interaction [23,24]. Bogost argues that when players play a game, they "explore the possibility space its rules afford by manipulating the game's controls" [25]. For instance, the game's rules determine how the player's input (typically from an input device, such as a keyboard or a controller) changes the game state. However, the players can make choices of when (and if) they want to use specific player actions (mechanics) that are available to them.

Habel calls game mechanics "agency mechanics" because mechanics allow players to take actions in the game (e.g., jump, run, shoot) and affect the world around them [26]. However, the agency through mechanics is simultaneously constrained and afforded. Krzywinska [27] highlights how mechanics in horror games promote and restrict player agency. For instance, game designers restrict agency in mechanics by limiting the functionality of the game mechanics (e.g., low or no ammunition for shooting mechanics) to create psychological pressure in survival-horror games [26]. Open-world games, on the other hand, afford players the ability to interact with a greater variety of mechanics that they use to explore the game world and interact with non-player characters (NPCs). Moreover, non-linearity in open-world games can allow players to deviate (or ignore) the main storyline in favor of side-quests, contributing to their sense of agency and their overall player experience [28].

Previous literature in the field has predominantly focused on theoretical and conceptual aspects of player agency [5,8,15,26,29]. Only a few studies have investigated player agency empirically. Carstensdottir et al. [30] investigated how participants conceptualized player agency beyond the typical descriptions found in the literature (e.g., player agency as a meaningful choice). Players perceived agency in the game mechanics through customizable skill trees, allowing them to personalize and tailor the available mechanics [31]. Tyack and Wyeth [32] investigated the effect of prior puzzle-solving experience on subsequent video gameplay. The puzzles were designed to induce autonomy-frustration through step-by-step instructions on arranging tangrams into specific shapes or autonomy-satisfaction by allowing participants to construct the tangram shape [32] freely. The study found that participants assigned to the autonomy-frustrated puzzle-solving condition showed comparatively greater intrinsic motivation (e.g., autonomy, competence) when playing the video game (Spore). Moreover, in-game autonomy was an indicator of post-play well-being outcomes [32]. Chung and Moonson [33] investigated how giving freedom and control to players to select a backup (optional) goal affects gameplay performance and engagement with the game. The study found that participants who set backup goals were less likely to continue to play the game after achieving their goal. Anderson et al. [34] investigated how optional objectives that were either difficult or easy impacted gameplay performance and engagement of the players. The study found that games that contained optional objectives that were difficult reduced engagement with the game while the games that had objectives that were easy to complete increased engagement.

Both theoretical and empirical, indicate that player agency is central to games and affects players' overall gameplay experience, including motivation [15,16,26,29,32]. However, there remains a notable gap in empirical studies that directly investigate the effects of *player agency* on educational gameplay experience. This study aims to address this gap by conducting empirical research examining player agency's effect in an educational game. More specifically, we explore how providing freedom and control over the learning mechanic (i.e., mechanic connected with the learning activity) in the educational game affected students' intrinsic motivation, enjoyment, and learning outcomes.

2.2. Student agency

Student agency is the ability to exert control and make choices when interacting within a learning environment [35–37]. Giving students agency over their learning environment is believed to deepen their involvement while learning, and as a result, students become more invested in the learning process [38]. Empirical studies show that students report higher motivation, interest, curiosity, and learning outcomes when they control their learning environment [36,37,39]. However, it is not necessarily the case that learners, when provided with freedom and control in these learning environments, inherently excel or thrive without structural guidance from the learning environment or the instructor [40,41].

Corbalan [40] indicates three issues learners face when given agency over their learning environment. Firstly, learners may make sub-optimal choices on various aspects of the learning activity (e.g., choices which hinder their learning). Secondly, processing the additional choices imposes a higher cognitive load on learners [40]. Lastly, learners may perceive the choices afforded in the learning environment as trivial or non-consequential [40]. Educators, therefore, must strike a balance between affording agency to students while ensuring that students meet the objectives and the intended learning goals.

Educators have explored approaches to provide agency to students in the learning environment. One approach—referred to as "irrelevant instructional choices" or "choice in surface features"—is to provide students control over superficial features of the learning environment but not over the learning outcomes themselves [35,38,40]. These design choices include giving students the choice and control to personalize their names and avatars [42]. Students can also pause and play multimedia presentations, allowing them to control the pace of instruction [43], as well as select a learning activity that offers a variety of examples to gain a conceptual understanding of the subject matter (e.g., choosing different types of animals to understand the underlying concept of genetic inheritance) [40]. Collectively, these experiments have demonstrated that students who were given control over their learning environments exhibit higher motivation, task involvement, positive attitudes towards learning, and significant improvement in their post-test scores [40–43].

The other approach—"choices in structural features"—allows students to control the learning content's structural aspects, thereby affecting learning outcomes [40]. Structural aspects of learning activity encompass relevant components to reach a solution [41]. For instance, Corbalan and colleagues [41] designed an interactive learning activity wherein students engaged with concepts of biological inheritance.

Students could control structural aspects of the learning activity, such as selecting one task (e.g., determining *genotype* of offspring) among other choices (e.g., determining *phenotype* of offspring) [41]. In other words, students were offered to choose their steps instead of following a pre-determined sequence of activities when forming their solution. Similarly, other researchers have offered students the choice and control to construct their own sequence of activities and the duration of engagement with the learning activity. Sawyer et al. [36] designed an educational game (Crystal Island) wherein students play the role of medical field agent and interact with game objects (books) and non-player characters (NPCs) to learn more about microbiology (viruses, bacteria, etc.) and the spread of diseases. Students moved freely in the game world, interacting with game objects (high-agency game condition) or following a pre-determined sequence of interaction (low-agency game condition) [36]. Snow et al. [37] designed an educational game (iSTART-2) to enhance high school students' comprehension and self-explanation ability. Students could freely interact with four over-arching activities—training (learning from a pedagogical agent regarding self-explanation), practicing (i.e., playing mini-games against a computer-agent to generate self-explanations), browsing achievements (i.e., score-board) and customizing their avatars in the "high-agency" game condition while students in the "low-agency" game condition followed a pre-determined learning sequence. Nguyen et al. [38] designed an educational math game (Decimal Point) wherein students either played all mini-games in a specified sequence (low-agency game condition) or could play a subset of games in any order (high-agency game condition).

The studies described above show that providing agency to students can lead to positive [37], neutral [35,38], or adverse outcomes [36,41]. These studies also show that subtle differences in how the agency is operationalized can impact student behavior. Sawyer et al. [36] found that students who were assigned to a low agency condition (i.e., play Crystal Island in a pre-determined sequence) had higher learning outcomes on the post-test compared to the high agency game condition (i.e., playing Crystal Island according to their preference and choice). However, students in the low-agency game condition engaged in greater guesswork than those in the high-agency condition. Snow et al. [37] found that students assigned to the high-agency game (iSTART) condition had higher learning outcomes than those assigned to a low-agency game condition. However, the higher learning outcomes were only seen in students who self-selected to follow a controlled interaction pattern (as opposed to a disordered interaction pattern). Nguyen and colleagues found that the participants in both conditions improved their learning outcomes and did not differ in game enjoyment [38]. A deeper investigation revealed that students in the high-agency game condition followed a similar sequence of mini-games as the students in the low-agency game condition. The authors attributed the participants' behavior in the high-agency game condition to the *indirect control features*, such as the dashed line connecting various mini-games, subtly conveying a canonical sequence to the participants. A subsequent study where the indirect control features were removed found no difference in participants' learning outcomes and game enjoyment across the game conditions (i.e., high and low agency game conditions) with similar results [35]. However, the authors noted that students assigned to the high-agency game condition learned more efficiently than those in the low-agency game condition.

Taken together, the studies do not provide a clear indication of the impact student agency has in the learning environment. More research is needed to understand nuances in operationalizing agency in learning environments and the underlying mechanisms influencing learning outcomes.

2.3. Distinguishing player and student agency

This study focuses on player agency as opposed to student agency. Player agency, within the game design perspective, focuses on specific game elements such as objectives [33,34], narratives [8,30], and mechanics [44]. In contrast, student agency exclusively focuses on affording students freedom and control in the *learning environment*. A typical setup, common across the previously described studies [35–38] is provide learners the choice of creating their own sequence of learning activities among the available set. Consequently, students can choose a unique subset of learning activities rather than following a predetermined sequence.

In this study, we explore the impact of choice regarding *mechanics available in the game*. Students have the autonomy to using the learning mechanic during the gameplay. This includes the choice of not using the learning mechanic in order to play the game—a feature not explored in student agency. Student agency in the literature is operationalized as the ability to self-select the learning activities [36,37,40]. However, the sequence of learning activities was identical across the two game prototypes. In other words, the students did not have the choice to *directly* self-select which puzzles they wanted to interact while playing the game. Students could, however, *indirectly* construct sequence of learning activities. Consider a case where student uses the learning mechanic twice in the game. As such, the learning activity sequence for the student will be Puzzle1-Puzzle2. Similarly, a student who uses the learning mechanic three times in the game will have the sequence as Puzzle1-Puzzle2-Puzzle3. Because we focus our investigation of player agency on the learning mechanic, manipulation of student agency is unavoidable. However, we keep the manipulation of student agency to a minimum by not allowing players to *directly choose* the learning activities, as is the case with the literature that have focused on student agency [35–38].

3. Parsons game

We designed and developed a 2D platformer game (*Parsons Game*). The game featured two core mechanics: platformer and the destroy enemy mechanic. Platformer mechanics consisted of movement and jump and are commonly found in 2D platformer games (e.g., Dead Cells [7], Super Mario [45], Hollow Knight [46]). The platformer mechanic was designed for the players to navigate their character in a level while attempting to accomplish the goal in the game: collect as many coins so as to get a high score. Players can use the keyboard keys (←→ or A/D) to move the game character in the horizontal direction and perform the jump action by pressing the space bar, W, or the arrow (↑) key. As the name suggests, the destroy enemy game mechanic removes the obstacles from the player's path, making it easier to achieve the game goal. Players used the two core game mechanics to complete the three levels present in the game. To progress through the levels, the players needed to collect two items: treasure chest and the key. Collecting the treasure chest unlocked the flag, which would transport the player into the next section of the current level, and collecting the key would unlock the door to the next level.

In *Parsons Game*, the game mechanic — destroy enemy — contained a learning activity. To use this mechanic, the players could click on any enemy or environmental hazard present in the level, prompting a dialogue box, "Do you want to destroy this enemy?" On confirmation, the players were taken to a problem-based environment wherein they were presented with a Java programming puzzle. If the puzzles were solved successfully, the players would be taken back to their gameplay and see the enemies destroyed from the level (see Fig. 1).

3.1. Parsons problems

Parsons problems (also known as Parsons Puzzles, code scramble, code mangler, etc.) are puzzles that consist of pre-written code in blocks [47,48]. The puzzle blocks are code snippets learners need to rearrange to construct a solution. The problem space in Parsons problems consists of a "problem window" that contains code snippets [47]. Learners drag and drop code snippets to a "solution window" to construct a solution [49]. When the learners are satisfied with their

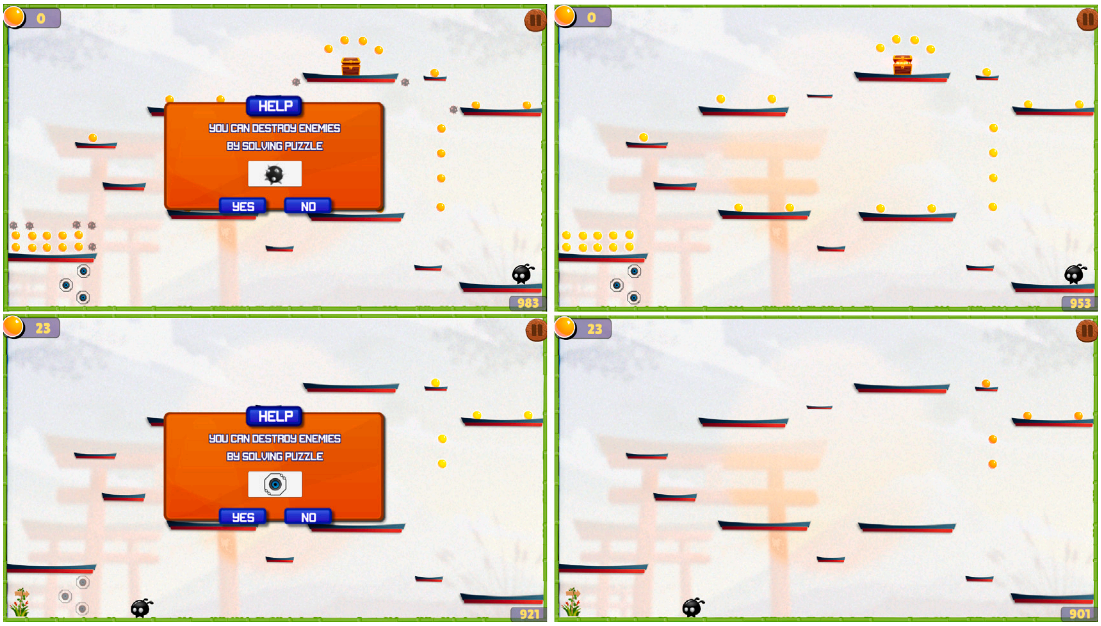

Fig. 1. The player's interaction with the "destroy enemy" game mechanic (top-left) triggers the removal of enemies from the level (top-right). By collecting the treasure chest (bottom-left), the player uncovers the waypoint, which serves as a guide for navigation to the next section. In order to advance to the next section of Level 1, the player engages with the "destroy enemy" game mechanic to eliminate any obstacles obstructing the waypoint (bottom-right).

solution, they can "submit" their code to receive feedback. Parsons problems are similar to block-based programming environments but are typically implemented with a specific programming language, such as python [50], instead of pseudo-code.

Parsons problems were initially designed to provide an engaging introduction to a programming language and to practice syntax drills [47]. However, researchers have implemented Parsons problems in a variety of contexts, such as to help students design programs [51], identify student difficulties [49], develop computational thinking skills [52], and address student misconceptions [53]. In the digital space, parsons problems have been implemented in interactive e-books [54], web applications [55], and mobile-based learning environments [50]. Parsons problems have also been investigated in a game-based learning environment [56]. However, the focus of the studies [56,57] was limited to understand usability and perceptions of students interacting with the game.

The game contained six unique puzzles and each puzzle reflected a unique misconception in the area of functions (e.g., difference between void and String as a return type). The puzzles resembled a playful exercise where the code was transformed to represent the intrinsic fantasy of the game environment [58]. For instance, the learners created a program with a class name called "Destroy Enemy". Various code statements (e.g., the print statement) connected with the description and function of the destroy enemy game mechanic so that the participants would interpret constructing puzzle solutions analogous to destroying enemies in the game. This approach to create intrinsic fantasy is also present in popular online programming games [59,60] wherein player actions (e.g., jump, attack) are represented as functions (e.g., `player.jump()`, `player.attack()`). See Fig. 2.

3.2. Player agency and gameplay description

We developed two versions of the game, each offering a distinct level of player agency. In the "agency-restricted" game condition, the progression of players was hindered by enemies and obstacles blocking access to key items such as the treasure chest and the key (see Fig. 3).

In order to advance in the game, players were required to destroy the enemies to collect these items. In contrast, the "agency-unrestricted" game condition allowed players to complete the game using only movement mechanics, as the enemies and obstacles were absent around the treasure chest and the key. The gameplay description in Fig. 3 illustrates the differences between the two conditions. In the "agency-restricted" condition, players had to employ the destroy enemy game mechanic to progress, while in the "agency-unrestricted" condition, they had the choice to use or ignore this mechanic.

Table 1
Distribution of minimum puzzles users are required to solve across the levels.

Game Condition	Tutorial	Level 1	Level 2	Level 3	Total
Agency unrestricted	1	0	0	0	1
Agency restricted	1	2	2	2	7

The agency-restricted game prototype reflects the choices educational game designers typically make while designing the game. Because the interaction with the learning mechanic improves the learning outcomes, game designers have traditionally required players to use the learning mechanic to progress in the game. As mentioned previously, the game contained six unique puzzles that addressed misconceptions regarding functions in Java programming. As such, players who complete all three levels in the agency-restricted game prototype would need to solve a *minimum* of six puzzles[1] in order to complete the game. However, the players in agency-unrestricted game condition players in the agency-restricted game condition do not necessarily need to use the learning mechanic to complete the game. In other words, the use of learning mechanic is a choice that players have when interacting with the agency-unrestricted game prototype. See Table 1 for the minimum puzzles that players needed to solve across the two game conditions.

4. Pilot study

We conducted a discount usability test known as "Rapid Iterative Testing and Evaluation (RITE)". In this method, participants' playtests are analyzed immediately after their gameplay so that changes can

[1] Each level featured two puzzles that players needed to solve. The tutorial level included one essential puzzle that players were required to solve, regardless of the game condition.

Fig. 2. Puzzle environment in the game. Players drag and drop code snippets from the problem pane to the solution pane. When players click submit, the program evaluates their solution and highlights incorrect code snippets (top-right). Players can view the solution (bottom-left) and complete the code puzzle (bottom-right).

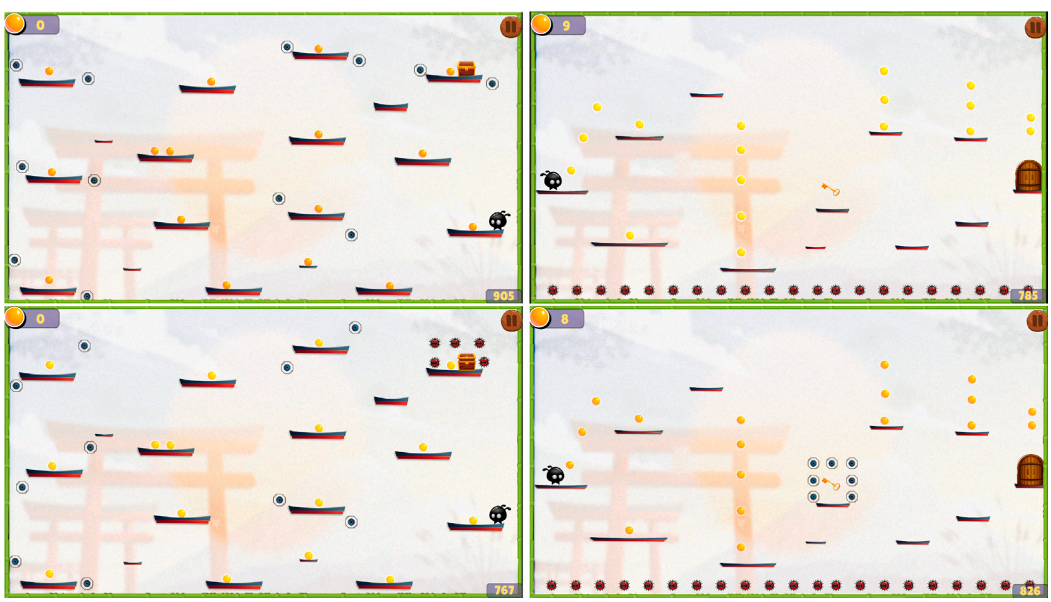

Fig. 3. Agency-unrestricted game prototype (top-left, top-right). Agency-restricted game prototype (bottom-left, bottom-right).

be made in the game as soon as the problem is identified *and* a potential solution becomes clear [61]. This way, the participants play increasingly refined versions of the game. This method of user-testing is industry standard for improving the usability of the game [61] and is increasingly used in validating game prototypes for user research [62].

We recruited participants (n = 15) from an introductory programming course conducted at a large mid-western university in the USA because we planned to evaluate the effectiveness of the educational game in the same class in the subsequent semester. As a result, the game prototypes were made more ecologically valid because we incorporated feedback from the participants who were learning an object-oriented programming language (Java).

The initial playtests signaled a need to refine the design of the levels and the platformer mechanic (movement and jump) so that the participants could complete all three levels in the game. A trend across modifications was (a) significantly reduce the number of enemies present in any given level, (b) enable easier "platforming" across levels, and (c) adjust the movement of the game character to make it more readily respond to player input. We observed an increase in participants' ability to consistently complete all game levels and a decrease in repeated player attempts to clear any given level. However, issues regarding the use of mechanics and puzzle-solving showed up infrequently in the later playtests. For example, some participants did not understand that they could destroy *all* enemies (of a given type) by activating the destroy enemy game mechanic as well as how to see the solution of the puzzle. To address these issues, we created a video tutorial. The video tutorial explained the destroy enemy game mechanic and its use on various enemies across different levels. It then showed how to solve puzzles in the puzzle user interface and the various help features that can be used to solve them successfully. Lastly, it showed the effect of successfully solving the puzzles by destroying the class of enemies selected by the player. The participants first watched the video before playing the game. After creating a video tutorial, the issues did not appear for the remaining playtests.

5. Methods

The game prototypes were designed to examine the effect of player agency on game enjoyment, intrinsic motivation and learning outcomes.

- RQ1: How does the game prototype where player agency is restricted compare to the prototype where agency is unrestricted, in terms of game enjoyment?
- RQ2: How does the game prototype where player agency is restricted compare to the prototype where agency is unrestricted, in terms of intrinsic motivation to learn?
- RQ3: Do learning outcomes differ when the player agency is restricted vs. when agency is unrestricted?

A sequential design approach was followed wherein we first collected quantitative data from the participants (n = 73). We then interviewed participants who had consented for a follow-up study (n = 13) to describe their learning experience as well as their motivations to engage with the learning activity in the game. Quantitative and qualitative data sources were used to answer the research questions: self-report measures, game analytics and semi-structured interview.

5.1. Procedure

Participants first filled an IRB-approved consent form. The consent form informed participants regarding the purpose of the study, the nature of data collected and their rights during the study. As a part of their rights, participants were informed that they could withdraw from the study at any given time without penalty.

After providing consent, participants first answered the inventories listed in the section (see Section 5.2). Participants first watched the video that explained their goal in the game and provided an overview of how to solve Java programming puzzles to successfully activate the "Destroy Enemy" game mechanic. Participants were also informed that could exit the game at any time after playing for 1000 s (~17 min).[2] After watching the video, the participants then randomly assigned to one of two game prototypes, playable on the web-browser. The participants were provided a set of disposable headphones and used the headphones when watching the video and playing the game. The Qualtrics web survey collected analytics data from the user during watching the video and playing the game. The analytics data was used to validate if the participants had actually watched the video and played the game.

After playing the game, the participants completed post-test questionnaires. This included Java Concept Inventory, Game Enjoyment, and IMI. Participants who consented for the follow-up interview were asked to reflect on their play and learning experience.

5.2. Quantitative and qualitative measures

5.2.1. Game enjoyment

Questions for game enjoyment (e.g., "I liked playing the game", "I had a good time playing the game") were adapted from Player Experience Inventory (PXI) [63]. All responses range from −3:Strongly Disagree to 3:Strongly Agree. In general, a higher score indicates a better game enjoyment. The inventory was administered once, after playing the game.

5.2.2. Intrinsic Motivation Inventory (IMI)

The Interest/Enjoyment subscale of IMI measures intrinsic motivation for any given activity [64]. We measured the intrinsic motivation of the participants to engage with the learning activity in the game. All responses range from 1 (not true at all) to 7 (very true). A higher score indicates greater intrinsic motivation for solving Java programming puzzles. The inventory was administered once, after playing the game.

5.2.3. Java Concept Inventory (JCI)

We referred to the course materials, assignments, quizzes, and examinations (midterm and end-semester) of an introductory Java programming course to develop a concept inventory. Based on the recommendations of the lab instructors — who had more than two years of experience teaching the introductory Java programming course — we decided to focus on functions because this concept served as a transition point to more difficult assignments. Functions is also a previously identified area in the literature wherein students develop misconceptions regarding their use in Java programming [65].

The inventory contains 6 questions. The first two questions focused on simple programming tasks such as identifying the correct syntax (e.g., identifying a missing semi-colon) and the correct use of in-built functions (e.g., determine the length of the string). The remaining questions focused on complex programming tasks relating to functions. This included testing students' understanding on calling a function with the appropriate arguments (e.g., `string` vs. `string[]`) and the return type (e.g., `void` return type). Participants had to select the correct answer from four multiple choice questions—a common question format employed during the examinations of introductory Java programming course at this university. The concept inventory was administered twice: before and after playing the educational video game. Each question carried one point and incorrect answers did not receive any points.

5.2.4. Game analytics

The game automatically logged gameplay data which included a number of metrics such as the total coins collected in each level, number of levels cleared, number of attempts, and number of puzzles solved. These metrics were used to investigate gameplay differences as well as providing additional data to answer the research questions.

5.2.5. Qualitative study

All interviews were conducted by the first author. Participants were interviewed once, and each interview lasted approximately 15-20 min. The interviews were audio-taped, transcribed and entered into a note-taking software for the purpose of coding, sorting and retrieving data for the analysis. The interview questions focused on understanding how the participants described their learning experience ("Did you feel like you learned anything from solving the puzzles?" and "Did any puzzle challenge or change your understanding of Java programming?") and their motivation to solve the puzzles ("What motivated you to solve the puzzles in the game?"). We followed up on the initial questions depending on the response of the participant ("What was confusing about the puzzles?" and "Talk to me about your experience destroying enemies in the game.").

We wanted the participants to feel comfortable sharing their authentic experience without the undue (or unsaid) pressure of mentioning only the positive play experience. For this, prior to the start of the interview, we informed the participants regarding the purpose of the interview and the nature of reward, emphasizing that we wanted them to share their authentic experience and that the partial course credit was not contingent on how they answer the interview question. At the end of each interview, we performed member checking [66,67]

[2] We arrived at this minimum playtime from the pilot study. We observed that the participants, on average, arrived at the second level around 1000 s. As such, we felt that requiring a minimum playtime of 1000 s would be optimal to investigate the overall motivation to play the game, given that participants would have a choice to continue playing on to the third level or quit playing the game after the minimum playtime.

wherein we paraphrased participants' comments back to them for participants to reflect or add anything further. This also served as a check on reliability and validity regarding the qualitative data analysis.

Thirteen participants consented to the follow-up study. The verbal transcripts were analyzed using a thematic analysis approach [68]. The first author was responsible for transcribing and analyzing the interview data. Open coding was used to tag parts of the transcript that were related to the research question to generate code list. This codelist was refined wherein codes were reassessed, renamed and merged with other codes during the data analysis. These codes were then combined to generate themes. For anonymity, all participants assigned agency-restricted condition are labeled as A1-A8. All participants in agency-unrestricted game condition are labelled as B1-B5.

6. Results

6.1. Manipulation check

The game prototypes were designed to offer differing levels of agency to the players. As such, we wanted to know if there were gameplay differences across the two conditions.

We compared the number of attempts (i.e., retries for a given level) players took in order to complete the game. Analyzing number of attempts is important because it highlights the choice players made on how they wanted to play the game. For instance, the destroy enemy game mechanic would eliminate enemies from the level. Since the agency-restricted game condition required players to use the destroy-enemy learning mechanic, we would expect players to have fewer retries on average compared to the players in agency-unrestricted game condition. On average, players who were assigned the agency-unrestricted game had higher number of player attempts for a given level (M = 2.04, SD = 2.86) compared to the players who were assigned to interact with agency-restricted game (M = 1.26, SD = 2.32). This difference was significant, $t(201) = 2.14, p = 0.033$.

Moreover, we would expect players who were assigned to the agency-restricted condition to solve more puzzles compared to the participants in the agency-unrestricted condition. We observe that participants assigned to agency-restricted game condition solved significantly more puzzles (M = 16.8, SD = 3.75) than the participants in the agency-unrestricted game condition (M = 9.44, SD = 4.03), $t(68) = 7.87$, $p < 0.001$. The two results suggest that the manipulation of player agency, which was operationalized as the level of autonomy over the learning mechanic affected how players' gameplay.

6.2. RQ1: How does the game prototype where player agency is restricted compare to the prototype where agency is unrestricted, in terms of game enjoyment?

The Game Enjoyment subscale was found to have good reliability (Cronbach's $\alpha = 0.88$). We conducted t-test to understand the difference between game enjoyment experienced by participants across the two game conditions. We conducted Welch's t-test that does not assume homogeneity of variance. The self-report score was the dependent variable and the game condition was the independent variable.

We found a significant difference in game enjoyment scores across the two game conditions: $t(177) = 2.28, p = 0.024, d = 0.32$. Participants who were assigned to the agency-unrestricted game condition had significantly higher game enjoyment (M = 2.09, SD = 0.80) compared to the participants who played the game agency was restricted (M = 1.81, SD = 0.98). One theme emerged when participants discussed their gameplay experience. The theme: Playful vs. Systematic highlighted how players perceived their gameplay experience.

6.2.1. Theme: Playful vs. Systematic gameplay

Participants in the agency-unrestricted game condition reported adopting a playful approach—to play the game using the movement mechanics and solving puzzles when encountering difficulty. B4: "There's like a gap [between enemies] that you could like, jump through...I think I did a couple times". However, participants were not always successful. B1 described how she experimented with the mechanics in the game, "So I attempted on some levels to not destroy the weapons [enemies], but because of my skill set coming in, I was not successful in those". B4 described a similar gameplay strategy, "I lost the enemy because I tried going through without completing the question [puzzles]". However, retrying the level was not perceived by the participants as a negative experience but rather as a challenge to overcome. In this sense, affording the autonomy over the learning mechanic allowed the participants to control the level of difficulty they wanted to face in the level which may explain the higher game enjoyment scores in the agency-unrestricted game condition.

Participants in the agency-restricted game condition described a more systematic gameplay behavior wherein they would use the learning mechanic first (A5: I would start by destroying the enemy's first. Like completing that part, and then go about collecting all of the coins). Similarly, A4 mentioned: "The beginning level, I would just get rid of the obstacles initially. And then just collect the coins". However, other used the movement mechanic first but noted the pattern in gameplay behavior. For instance, A5 mentioned how he used the movement mechanic to collect coins and then use the destroy enemy game mechanic: "So most of them [levels], it was kind of the same formula going throughout it. You went there, grabbed all the coins and stuff that you could and then defeated all the enemies by doing the code snippets and just kind of rinse and repeat. A2 mentioned experimenting with the mechanics available in the game: "I started off just kind of moving around grabbing the first coins I could, and then I went and did the puzzle". However, A2 described a similar pattern of behavior to other players towards the end of the game: "When I got to the end, like level three, I just did the puzzles right out of the gate".

The results suggest that affording player agency to the participants in the agency-unrestricted game prototype allowed to have a degree of variation in gameplay which may explain the significantly higher game enjoyment scores compared to the participants in the agency-restricted game condition.

6.3. RQ2: How does the game prototype where player agency is restricted compare to the prototype where agency is unrestricted, in terms of intrinsic motivation to learn?

Participants were asked to indicate how intrinsically motivated they felt when solving puzzles in the game. A higher score indicates greater intrinsic motivation for solving Java programming puzzles. The IMI scale was found to have good reliability (Chronbach's $\alpha = 0.91$). We conducted t-test to understand the difference between the intrinsic motivation to solve puzzles across the two game conditions. The scores on IMI scale was the dependent variable and the game condition was the independent variable. We proceeded with conducing a Welch's t-test which does not assume equality of variances. We found a significant difference in intrinsic motivation scores across the two game conditions: $t(421) = 2.52, p = 0.012, d = 0.23$. Participants who were assigned to the agency-unrestricted game condition had significantly higher intrinsic motivation scores (M = 5.34, SD = 1.47) compared to the participants who played the game agency was restricted (M = 4.97, SD = 1.74).

The qualitative interview provided more insights into the motivations participants had to engage with solving puzzles. Participants were asked to describe their motivation to solve puzzles in the game ("What motivated you to solve the puzzles in the game?"). Depending on participants' response, we followed up the initial question asking the participants to elaborate further ("Talk to me about your experience destroying enemies in the game").

Three themes emerged when participants described their motivation to solve the puzzles in the game. The two themes: puzzles helped participants complete in-game objectives (theme 1) and solving puzzles was fun and enjoyable way to learn (theme 2) was found across participants of both game condition. The third theme (puzzles were repetitive) was only found for the participants who were assigned to the agency-restricted game condition.

6.3.1. Theme 1: Solving puzzles helped participants complete in-game objectives

Participants were motivated to solve the puzzles in the game because it helped them complete in-game objectives. These included making it easier to collect coins, progressing through the levels and avoiding player death.

Participants felt that the enemies in the levels would get in their way of collecting coins. A8 mentioned the motivation to solve puzzles in the game as: "So I could collect all the gold coins easily without dying, get the key and then get to the next stage or get into the door". B4 : "Because there were a few obstacles that I want to get rid of…I wanted to get the all the all the gold star coins". A4 mentioned how the enemies annoyed him when trying to progress through the level, "I'd say so it [enemies in the game] would annoy me if I didn't solve certain ones [puzzles]. A certain part of me wanted everything to be completely cleared off the board. And so it was nice that I gave me the option of doing that". B2 further described how the difficulty present in the levels due to enemies, "[The] way this is moving [pointing to the enemies in the level]. I'm not able to get to boxes [treasure chest]".

Participants mentioned that the enemies blocked their progression to the next level. A2 described his motivation for solving puzzles as a way to progress in the game, "Just to be able to move on with the game, get to whatever I was trying to get whether it be coin or the chest or the key". B1 : "I'm not very skilled in the game playing. But like, if I tried over and over again, to get a certain coin, a certain area, and I couldn't get it". As a result, B1 was motivated to solve puzzles so that she could complete the goal in the game, "after, like, three failed attempts at completing the level, and getting to the door, I was like, Okay, I have to destroy the weapon." Similarly, B2 : "I cannot skip them [solving puzzles]. And because I have a risk to, like, fall over [dying]".

6.3.2. Theme 2: Solving puzzles was a fun and enjoyable way to learn

Participants described that they liked solving puzzles in the game. A5 described, "Completing the puzzles. That was really fun. I guess, after I'm done completing the puzzle, I just want to do more puzzles". A6 similarly described, "It's kind of fun. I don't know, I like whenever I play games, especially with something like this. So I've taken the time to do it". B5 described "It [solving puzzles] was helpful. Like a study kind of a study guide…A fun way to study it out through a game". B3: "I've always thought Java was like, a bit more complex than like Python or something. So personally, for me, my motivation was just I know I need to get better".

6.3.3. Theme 3: Puzzles were repetitive

Participants in the agency-restricted game condition mentioned that the process of solving puzzles became repetitive. This repetitiveness was perceived in two ways: having to solve puzzles repeatedly to progress through the levels and the lack of novelty of puzzles. A6 mentioned, "I did notice that some of the levels, at least some like the coding parts, when we were destroying the enemies got a little repetitive". A4 emphasized the lack of novelty in puzzles which made the puzzles repetitive, "It was just kind of repetitive in the sense where the puzzles were all in a very similar structure". However, repetition was not universally perceived as bad. A7 mentioned, "I liked the coding part of it, too, because one side of it was like, it was kind of repetitive. But I think it was good that it was repetitive. Because, like, at first I didn't get it [the puzzles correct]. Like I went through three tries, I didn't get it. But then like, through repetition, I got it towards the end".

6.4. RQ3: Do learning outcomes differ when the player agency is restricted vs. when agency is unrestricted?

Java concept inventory was administered twice to the participants (pre-test and post-test). We conducted two-way repeated measures of ANOVA with Java concept inventory scores as the dependent variable. We found a significant effect of time $F(1,68) = 7.334$, $p = 0.009, \eta_p^2 = 0.17$. There was no significant effect of Condition ($F(1,68) = 2.06, p = 0.15$) or Condition:Time ($F(1,68) = 1.71, p = 0.19$). This suggests that there was no significant difference in Java Concept Inventory scores across condition. Additionally, the change in Java Concept Inventory scores did not differ across conditions over time.

We conducted pairwise comparison to understand the difference in learning over time. We found a significant difference between the pretest (M = 3.09, SD = 1.20) and the posttest (M = 3.41,SD = 1.46), $p = 0.008$. Post-hoc tests were bonferroni corrected.

Each puzzle in the game was related to a question on the Java Concept Inventory. Solving six puzzles in the game, in theory, would "complete" the learning activity. We observe that participants across the two game condition solved more than six puzzles when playing the game (see Section 6.1). As such, the results from the game analytics data supports the findings of the learning gains documented measured by the Java Concept Inventory.

We interviewed participants who consented to the follow-up study after the conclusion of the game. We asked participants to describe their learning experience in the game. More specifically, we asked two questions ("Did you feel like you learned anything from solving the puzzles?" and "Did any puzzle challenge or change your understanding of Java programming?"). We followed up on the initial questions depending on the response of the participant ("What was confusing about the puzzles?").

Three themes emerged when asked to elaborate on the puzzle solving experience: participants described learning about functions (theme 1), learning programming concepts beyond functions (theme 2) and revision of Java programming concepts (theme 3).

6.4.1. Theme 1: Learning functions

The participants described how constructing solutions for a particular problem helped them understand different aspects of functions such as syntax, return type, and arguments.

A5 described a prior difficulty she had when constructing functions: "I always had trouble in calling functions, in the main method". She mentioned how the puzzle environment helped her understand how to construct functions and pass arguments to the function from the main method: "But since you [the game] only gave us the main method and just one other function, it was helpful to identify how actually to go through with it [constructing the function], and there was only one variable [function's argument] as well. So yeah, that was helpful in understanding how like multi-functions work in a class". Similarly, B1 mentioned how the puzzle afforded her "a small environment" where she could understand various object-oriented concepts through an example: "But it [solving puzzles] just it really helped me hone in on a smaller level and as someone who learns by lots of examples but focusing on like niche areas, that really just tapped into me a lot better".

Participants improved their syntactical and logical understanding of the functions when the puzzle environment provided feedback on the mistakes. A2 mentioned, "I made like one or two mistakes with order [incorrect ordering of code snippets] and the dot length function [string.length()]". B2 noted how she could use functions to obtain information for a problem: "I really like [learned] functions and return string and how to print out the in different ways". A7, similarly described his confusion regarding function parameters while constructing functions, "I just didn't really know what either of them [string[] vs. string] meant. Then I'm really new to Java. I noticed they're different, but I wasn't sure the meanings". When making mistakes, the puzzle environment provided feedback which led the students to reflect on their mistakes and to correct their misconceptions. A8 noted, "I kept putting static string and the array boxes [string[] vs. string]. But then once I made that mistake once, I was like, oh, okay. This is wrong. So then I corrected myself".

6.4.2. Theme 2: Learning beyond functions

The process of solving the puzzles also helped the participants to understand how to construct a Java class. Participants frequently compared how they learn from class assignments and exercises to learning from the puzzles in the game. Students were recruited from an introductory Java programming course where the class assignments typically contain starter code. This starter code serves as a scaffolding and helps students to focus on specific Java programming concepts. However, when the students interacted with programming puzzles, they also needed to drag and drop code snippets to create their own class. B1 said:

> In 255 [Introduction to Java Programming class], like the starter code, it's kind of given to us. And so like, occasionally, we'll have to write a class. But that's not really something that frequently happens... But I think what I do miss is the opportunity to learn the **structuring** [emphasis added] on a smaller scale.

Participants also referred to the process of constructing a Java class as "structuring" or "ordering". B2 mentioned: "I think it was destroy enemy [class name]. And then we need to public static [referring to the main function code snippet in Java] and then like, return it [return statement], but I just put it in [wrong] order. A3 indicated that constructing Java functions was a novel experience and helped her understand how to correctly end the function definition, "The curly brackets. Which I didn't, I had never like stopped and actually looked at those before... So that I kind of learned a little bit about because I learned, okay, you have to do this for this [pointing at the curly bracket and the function description] first".

6.4.3. Theme 3: Revision of java programming concepts

Participants also described how the puzzle environment provided a refresher on the concepts they had recently learned in the classroom. A4 mentioned how solving puzzles reinforced the concepts he had previously learned in the classroom, "It [solving puzzles] really cemented the idea of which ones are returning a value [return statement] and which ones are for receiving one into a function [function's arguments]". B3 mentioned: "It was mostly just like refreshing what I'd already known... I guess syntax things that I was a bit foggy on". A2 described how solving puzzles improved his confidence, "It gave me more confidence and my ability to read the Java code and like, execute it properly". A5 mentioned, "It [puzzles] helped me solidify the concepts". B2 mentioned: "It was kind of a good refresher on specifically the structure that should be".

7. Discussion

In this study, we manipulated the agency afforded to the participants who interacted with an educational game. We investigated how interaction with the game affected their game enjoyment, intrinsic motivation to learn, and learning outcomes.

We observed a significant increase in students' learning outcomes after interacting with the educational game, suggesting that the differing levels of player agency did not negatively affect the learning outcomes. Despite the autonomy over the use of learning mechanic in the "agency-unrestricted" game condition demonstrated an inclination to consistently use the learning mechanic during gameplay. The results of the qualitative study indicated a playful experimentation of game mechanics when playing the game. Participants, during their experimentation came to value the the destroy enemy game mechanic to help them progress in the game. On the other hand, participants assigned to the agency-restricted game condition were limited in their ability to experiment with mechanics by design and as a result had a systematic gameplay behavior as described qualitative study as well as quantitative data documenting a preference to first using the learning mechanic followed by the movement mechanic to complete the levels in the game. While participants in both game conditions reported that interacting with the learning environment through puzzle-solving was enjoyable (theme 2) and helped them achieve in-game objectives (theme 1), only the participants who interacted with the game prototype where the agency was restricted reported that solving puzzles became repetitive. This repetitiveness was perceived as having to solve puzzles frequently to progress through the levels and the lack of novelty of puzzles. We hypothesize that the participants' ability to experiment with the destroy enemy game mechanic in the agency-unrestricted game condition coupled with the repetitiveness perceived by participants in the agency-restricted game conditions explains the significantly higher game enjoyment and intrinsic motivation to engage with puzzle solving activity for the participants in the agency-unrestricted game condition.

These results suggest that affording greater player agency (i.e., choice and autonomy over the mechanics) in educational game can lead to higher game enjoyment as well as increased intrinsic motivation to use the learning mechanic. However, more research is required to understand how player agency can "scale-up" in serious games. For instance, if learning mechanic is optional in the educational games, learners may miss crucial information that are essential for problem solving activities. While this paper compared scenarios where the learning mechanic was either completely optional or mandatory for solving *all* puzzles, player agency consists of a range of possibilities [5]. In other words, providing player agency does not necessitate making the learning mechanic entirely optional. One approach could involve limiting player agency when presenting new concepts (e.g., conditional statements) so as to ensure that learners interact with newly introduced concepts. Educational game designers can consider affording greater player agency for subsequent puzzles that are intended for practice, such as presenting similar puzzles intended to reinforce concepts through repetition. Players can have the autonomy of using the learning mechanic to solve some of the practice questions, instead of requiring them to use the learning mechanic to complete all the puzzles. The results from our study indicate that participants who interacted with the game prototype where the agency was unrestricted had higher game enjoyment and intrinsic motivation to learn.

7.1. Implications for the broader community

The results have implications for designing learning mechanics, player agency, and the learning environment.

7.1.1. Promoting player agency via mechanics

Previous studies have investigated affording player agency via optional objectives. Chung and Moonson [33] investigated how giving freedom and control to players to select a backup (optional) goal affects gameplay performance and engagement with the game. The study found that participants who set backup goals were less likely to continue to play the game after achieving their goal. Anderson et al. [34] investigated how optional objectives that were either difficult or easy impacted gameplay performance and engagement of the players. The study found that games that contained optional objectives that were difficult reduced engagement with the game while the games that had objectives that were easy to complete increased engagement. Taken together, there is a lack of consensus regarding promoting player agency with the use of optional objectives.

The results of our study highlights that player agency, when afforded through game mechanics, increased game enjoyment and intrinsic motivation, without compromising on the performance (i.e., learning outcomes). Participants came to value the learning mechanic to collect coins, avoid player death and reduce difficulty. We believe that optional game mechanics (i.e., secondary game mechanic [19]), as opposed to objectives may be a more robust way to support player agency because mechanics help players achieve a variety of in-game goals. As such, the results provide a promising way to integrate optional learning activities in the game through the use of additional mechanics.

7.1.2. Unlocking motivational pathways via player agency

Educational game designers face the challenge of balancing the elements of “play” and “learn” when designing the game [69]. Traditionally, designers have exerted direct control to ensure that players engage with the learning activities as a prerequisite for game progression. While this method effectively guarantees engagement, it may limit the motivational pathways available to learners, consequently making the gameplay repetitive and boring. The results from our study suggest that players are naturally inclined to use the learning mechanics, even when not mandatory, because these mechanics help achieve various game objectives such as collecting coins, reducing difficulty, and preventing character death. These findings are promising as they demonstrate that designers can employ a broader range of in-game motivational pathways to enhance engagement with educational content.

Future research may also explore a notable gap in the literature—the examination of interaction between player and student agency. One potential venue for investigation is to include student agency in the game prototype described in this paper. The game prototype — which currently does not allow students to self-select the puzzles — can be modified so that students can self-select puzzles from a library of puzzles. Such an interaction will allow students to construct their own learning trajectory and may yield valuable insights into the influence of student and player agency on learning outcomes and the overall player experience.

7.1.3. Parsons problems support learning outcomes in educational games

Our study documents the efficacy of utilizing Parsons problems in educational video games. Previous studies had limited their focus on evaluating subjective measures (i.e., students perceptions) and their usability in educational games [56,57]. Our study featured a quantitative and qualitative investigation of students’ learning outcomes after their interaction with the Parsons puzzles in the educational video game. We observed a significant increase in students’ learning outcomes after their interaction with solving puzzles in the game. The qualitative study provided further evidence of learning in the game. Namely, the participants described how the learning environment helped them understand various aspects of functions (e.g., specifying appropriate arguments and return statements). The qualitative study also highlighted additional learning opportunities that were not part of the Java Concept Inventory (JCI). Participants described learning how to construct a class for a given problem and understanding the program flow execution (e.g., incorrectly placed code snippets).

It is important to situate these results in the broader educational context for the participants. The programming assignments in the introductory computer programming course contains pre-written code, including the code for function and classes. Students complete the lab assignments by writing specific code lines inside these pre-written functions. The students only started creating their own classes and functions at a later stage in the course. Given this, it is reasonable for them to make mistakes while building programs on their own in the learning environment of the game. Overall, the quantitative and qualitative results indicate that participants improved their conceptual understanding of Java programming by playing the educational game.

8. Limitations

Participants in this study were recruited from an undergraduate course, and their ages ranged from 18-24. Previous research indicates that it is crucial to evaluate the engagement and performance of learners from diverse backgrounds to improve game design [70]. As such, evaluating players’ motivation and learning outcomes with a more diverse student population (e.g., older participants) can help us better understand the degree to which the results of this study are generalizable.

The scope of the educational game was limited to identifying and correcting misconceptions about string functions in the Java programming language. While the results indicate that learning outcomes were no different between players in the agency-unrestricted game condition and those in the agency-restricted game condition, more research is required to understand how player agency can be utilized in the broader context of educational games that feature multiple learning outcomes.

We designed a 2D platformer game for research purposes that featured game mechanics operationalized with specific constraints (and freedoms) of player agency. For instance, the game included an action mechanic (i.e., movement mechanics) combined with a puzzle-solving mechanic (i.e., destroy enemy mechanic). Previous research indicates that players, depending on their demographics, have preferences for game elements such as puzzle-solving activities and action-oriented mechanics [71,72]. Therefore, more research is needed to determine if player agency and its benefits generalize to other educational games that feature different mechanics and learning activities.

9. Conclusion

In this paper, we explored how educational games can be designed to support and facilitate player agency. We designed two prototypes that differed in the level of agency afforded to the player. In the agency-unrestricted game prototype, the students can freely progress through the game and exercise autonomy while using the learning mechanic. In the agency-restricted game prototype, the students must use the learning mechanic in a predetermined order to progress through the game. The results from the quantitative and qualitative methods show that students who were assigned to the game prototype where agency was supported (i.e., agency-unrestricted game prototype) had significantly higher game enjoyment and intrinsic motivation to learn. Both game conditions significantly increased learning outcomes. These findings advance our understanding of how to create meaningful and effective learning experience using game-based learning approaches. Further research is needed to explore additional dimensions of player agency and its effect on gameplay and learning outcomes.

CRediT authorship contribution statement

Amogh Joshi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Christos Mousas:** Supervision. **Samin Shahriar Tokey:** Software, Supervision. **Dominic Kao:** Conceptualization, Methodology, Supervision, 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

Data will be made available on request.

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