Puzzles Unpuzzled: Towards a Unified Taxonomy for Analog and Digital Escape Room Games

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Fig. 1. This work closes the gap between analog (left and middle images) and digital escape room games (right images) by providing a uniform taxonomy that operates on the level of atomic challenges. The picture is completed by a high-level framework aimed at the overall design process of escape rooms.

Escape rooms exist in various forms, including real-life facilities, board games, and digital implementations. The underlying idea is always the same: players have to solve many diverse puzzles to (virtually) escape from a locked room. Within the last decade, we witnessed a rapidly increasing popularity of such games, which also amplified the amount of related research. However, the respective academic landscape is mostly fragmented in its current state, lacking a common model and vocabulary that would withstand these games' variety. This manuscript aims to establish such a foundation for the analysis and construction of escape rooms. In a first step, we derive a high-level design framework from prior literature. Then, as our main contribution, we establish an atomic puzzle taxonomy that closes the gap between the analog and digital domains. The taxonomy is developed in multiple steps: we compose a basic structure based on previous literature and systematically refine it by analyzing 39 analog and digital escape room games, including recent virtual reality representatives. The final taxonomy consists of mental, physical, and emotional challenges, thereby providing a robust and approachable basis for future works across all application domains that deal with escape rooms or puzzles in general.

CCS Concepts: • **Human-centered computing** → **Virtual reality**; • **Software and its engineering** → **Interactive games**; Virtual worlds software.

Additional Key Words and Phrases: Escape rooms; puzzles; board games; exit games; virtual reality games

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1 INTRODUCTION

Escape rooms are games where one or multiple players solve puzzles to exit from a locked room. Due to the growing popularity, we are witnessing more and more variations of this concept: real-life facilities, board games, mobile/desktop versions, and, most recently, virtual reality (VR) implementations (cf. Figure 1). The unique selling point of escape rooms is the diversity of puzzles [37, 56]. Players are required to bring in a variety of problem-solving skills to overcome mental and physical challenges. It is precisely this variety—combined with a coherent room theme—that differentiates escape room games from common, standalone puzzles.

The concept of escape room games does not only benefit the commercial sector. Researchers have especially acknowledged and utilized the potential of such games for educational purposes [23, 52]. Besides the educational domain, the research on escape rooms covers a broad spectrum of topics ranging from theoretical puzzle concepts [56] to distributed multi-user VR setups [50]. Nevertheless, what is still missing due to this vast scope—and what this manuscript provides—is a common vocabulary, a common ground for escape rooms, be them analog or digital. Such a basis will facilitate the transfer and application of scientific findings, increase the comparability of results, and prevent from reinventing the wheel (= a puzzle) for different gaming modalities.

To find and contribute such a vocabulary, this work proceeds in the following way: Firstly, we extract a high-level **escape room design framework** from prior literature. The framework points out important design considerations that arise in the creation process, such as choosing the target audience and setting up a room theme. Secondly, we provide a deep dive into the most important component of escape rooms, namely the puzzles. Once again, we start from prior works and known classifications, which leads us to the basic version of an **atomic puzzle taxonomy**. We then consider a wide range of available escape room games to refine, improve, and validate the taxonomy. In particular, we begin with an examination of analog versions (real-life facilities and board games) and thereafter move on to digital alternatives (mobile, desktop, and VR). To summarize, the manuscript improves on the status quo by the two following contributions:

- overview of state of the art in escape room design, condensed in a high-level framework
- analysis and classification of analog and digital puzzles, formalized in an atomic puzzle taxonomy

These insights are meant to assist researchers and practitioners involved in the exploration and/or creation of escape rooms and puzzles in general. For example, we see benefits for future works in the field of educational or team-building escape rooms. In such cases, our taxonomy can be utilized as a set of atomic building blocks for novel puzzles, whereas the high-level framework can be applied to streamline and speed up the overall design and decision-making process.

2 ESCAPE ROOM GAME DESIGN

Escape room games, sometimes also called “exit games,” “breakout games,” “unlock games,” or similar, exist in various forms and have become increasingly popular within the last decade. With the word “room” being part of the term escape room, most people immediately associate real-life escape facilities when hearing that notion. Starting in Japan in 2007, live escape rooms soon became a global trend and spread all over the world [41]. People visit such facilities and try to find a way outside by physically moving through the room(s) and interacting with the physical

objects inside [41]. Most escape rooms can be played by one or multiple players, and some rooms additionally include a game master or actors inside the room.

Apart from stationary escape rooms, there are also different forms that can be played at home: on the one hand, board games, locked boxes, and books represent analog forms of escape room games; on the other hand, there exist digital games for diverse platforms. The analog games are often based on cards (which display rooms, items, and text), or they offer a compilation of different materials such as maps, turntables, and booklets. Some hybrid games combine analog with digital game elements, e.g., by adding a digital device or companion app, usually used to offer hints, surprising events, or multimedia content. One example is the story-based analog game "Escape Tales - The Awakening" that mostly relies on cards and a playbook but also features a web application that guides players through the story [9].

Digital escape room games often present rooms and puzzles in 2D or 3D graphics and rely on simple point and click or touch mechanics, though there are also solely text-based games working with text commands [16, 41]. Some mobile games additionally use unique features of smartphones and tablets such as the gyroscope to include motion control (e.g., shaking or tilting) [18, 37]. A special form of digital escape games is augmented reality (AR) and virtual reality (VR) games. AR games use digital devices such as monitors, special glasses, and projectors to enhance the real world with virtual elements, while VR usually relies on immersive head-mounted displays (HMDs) [30, 53, 54]. AR escape rooms can often be found in educational or research contexts [30, 54]. However, AR escape rooms also exist outside of laboratory settings, particularly in the form of augmented museum exhibitions [3, 4]. VR escape rooms are a topic of ongoing research as well (e.g., [31, 42, 44]), but there are also various commercial VR escape rooms (e.g, [1, 48]). It can be differentiated between games for consumers who own an HMD and games offered by stationary escape room facilities that provide the needed equipment. VR escape rooms can provide natural interactions and a high immersion similarly to real-life escape rooms [33], yet they do not require physical objects and therefore little physical preparation before a player enters the room [30]. Zhang et al. [58] suggest that natural movement and interactions make a VR game more appealing and engaging for the player, which is in line with more general VR game locomotion research [32, 40]. Therefore, a VR escape room experience closely resembles a real-life escape room with the addition that the game world can be expanded with virtual objects, interactions, and effects that would not be possible in real-life escape rooms.

2.1 Escape Room Design Framework

In general, although the diverse forms of escape room games differ regarding their mechanics and input modalities, they still share a similar conceptual structure with a focus on a series of connected puzzles. Hence, in the first step to approach escape room games, we will compile a high-level escape room design framework, which applies to all types of escape games. Based on the literature review, we want to answer the question: which aspects have to be considered in the escape room design process?

Some related works highlight important constituents of escape rooms [41, 56] or explicitly focus on the design of escape room games [11, 12, 25]. Nicholson [41] conducted a survey including 175 live escape facilities and presents data about players' demographics, room themes, features, and design patterns. His paper provides a broad first look at the phenomenon of escape rooms and points out integral design aspects of escape rooms such as team size and composition, themes and narratives, puzzle organization, and puzzle types. Wiemker et al. [56] also provide a discussion of the current state of live escape rooms. They particularly discuss puzzle types, puzzle paths, hint systems, themes, and required player skills. Although neither Nicholson [41] nor Wiemker

et al. [56] formulate concrete design guidelines or implications, they provide insights on relevant escape room characteristics, which we will take up in our framework.

In his book, Clare [11] gives advice on how successful live escape rooms can be designed and operated. He emphasizes the importance of a compelling theme, game flow, and playtesting. Other parts of the book refer to the business models and the operating of live escape room facilities, which is only relevant for this specific kind of escape room and, thus, not considered in our design framework.

Other work describing escape room designs refers to the experience pyramid model by Tarssanen and Kylänen [51]. Examples for the use of this model in the development process can be found in [25, 29]. The experience pyramid model is a tool meant to describe the aspects constituting a meaningful experience and consists of six elements in three groups: The *Core of Product* consists of the elements *Individuality, Authenticity, and Story*, the *Target Group* comprises the element *Contrast*, and *Experiencing* includes the elements *Multisensory Perception and Interaction* [51]. Heikkinen and Shumeyko [25] emphasize the stimulation of all senses, target group analysis, and the consideration of engaging marketing strategies as important benefits of using the model from the beginning of the design process.

Clarke et al. [12] present a theoretical design framework for educational escape rooms ("escapED") and define six consecutive steps of the process: participants, learning objectives, theme, puzzles, equipment, and evaluation. The authors point out that the puzzle design (step 4) relies on the previous steps as puzzles should be adjusted to fit the participants, the learning objectives, and the room's theme and narrative. While this framework is tailored to an educational context and, thus, includes aspects that are not relevant for escape rooms in general (such as the learning objective), we take up the other aspects in our more general framework on escape room design.

By consolidating the information from related work as discussed above, we identify six main design aspects of escape room games: (1) target group and team composition, (2) theme and narrative, (3) modalities and platform, (4) puzzle organization, (5) puzzle design, and (6) hint system and failure handling. The first three aspects describe general design considerations that provide the framing for the creation of the room concept and concrete puzzles. The other three aspects, in contrast, refer to more specific facets of the puzzle design and composition. Basic decisions regarding a certain theme, target group, or technology can have implications on appropriate puzzles and implementations. Hence, we recommend considering the general aspects early during the design process. However, we emphasize that designers do not have to work through the list of considerations in a linear process. In line with popular more general game design frameworks (e.g., the elemental tetrad by Schell [47] or the MDA framework by Hunicke et al. [26]), our framework is rather meant to highlight important design considerations and to give guidance on each topic to support the successful creation of escape room games. As depicted in Figure 2, the six design aspects influence each other and have to mesh well to create a compelling escape room experience. Each aspect is shortly described in the following.

2.1.1 Target Group and Team Composition. As with most design processes, one important aspect of escape room design is the definition of the *target group* [12, 25, 41]. The characteristics, interests, and abilities of the target group should be considered to create a tailored experience, including an appealing theme, a suited level of difficulty, and a mix of different challenges. Particularly when designing for players with specific demands, such as older adults or individuals with disabilities, a need assessment is crucial and the incorporation of the target group in an iterative design process is recommended [14, 39]. Besides, current surveys on live escape room facilities around the world suggest that there might also be regional or cultural differences regarding players' preferences for certain themes or puzzle types [36, 37, 41].

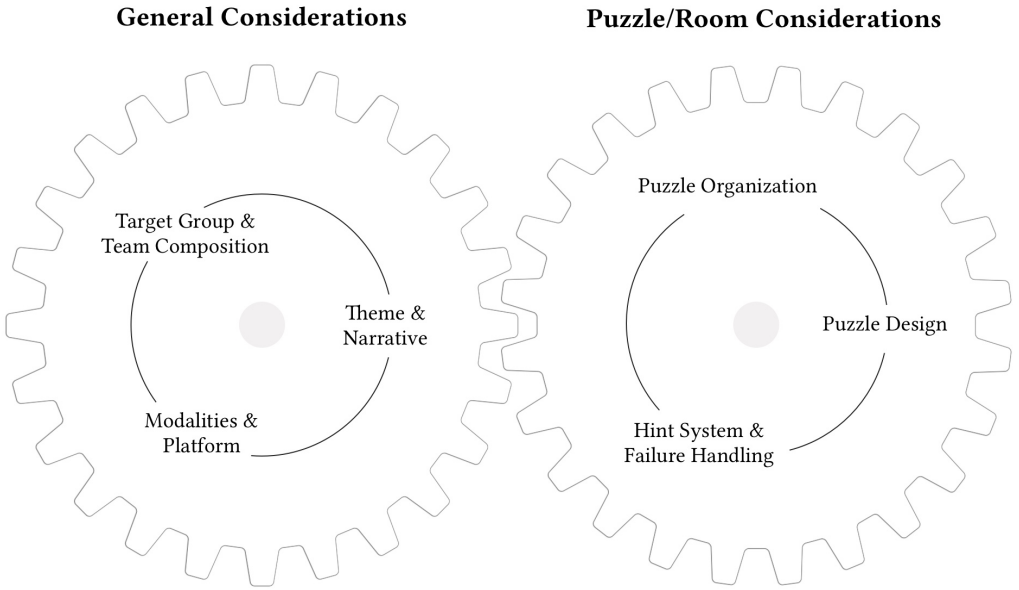

Fig. 2. Our escape room design framework highlights important design considerations with a focus on six different game design aspects in two categories. On the one hand, there are general considerations (left), including the definition of the target group and team composition, the choice of a theme and narrative, and technological decisions regarding modalities and platform. On the other hand, designers have to deal with more specific facets of the room concept (right) by considering the puzzle organization, the design of single puzzles, and the implementation of a hint system.

In addition to defining the main target group, designers also have to determine the number of players they want to address [12, 41]. For escape room facilities and board games, which are mostly promoted as multiplayer games, the required or recommended team size is usually defined as a range between a minimum and a maximum number of players. However, games may also target a single user, as more common for digital escape games.

While usually all team members have the same role and collaborate to solve all puzzles, some researchers examined multiplayer escape rooms where players use different devices and, thus, have different roles and perspectives [33, 54]. A study by Li et al. [33] indicates that asymmetric roles and perspectives can be an enjoyable and challenging game mechanic for an escape room game. Warmelink et al. [54] investigated team behavior in a collaborative escape room game with asymmetric roles and report that their mixed reality escape room generates similar team behavior as real-life escape rooms [43, 54]. In addition, they also describe that a mixed reality approach can create a stronger need for collaboration by establishing asymmetric roles and skills for the different players [54].

2.1.2 Theme and Narrative. Another characteristic of escape room games often highlighted in related work is the inclusion of a *theme* and a *narrative* [11, 12, 41, 56]. The theme describes the general setting of the game and mainly influences the aesthetic audio-visual design of the room (e.g., "secret laboratory" or "haunted house") [41]. Some themes notably support or restrict the use of certain objects and props, e.g., electrical equipment is misplaced in a medieval setting. Popular themes in current escape room facilities are "crime scene", "Sherlock", and "spy" (see the survey by Elumir [37] for an extensive list).

A narrative provides further story information on how players ended up in the current room/situation and explains the main goal and motivation. The narrative can be presented in form of a background story before entering the room. It can also be integrated via narrative elements that can be found in the room, e.g., after puzzle completion, so that the story unfolds during play [41]. While a narrative is not necessary for a successful escape room game, it can enhance players' immersion and motivation, particularly for target groups who seek a suspenseful narrative experience instead of just focusing on solving puzzles [41]. Clare [11] emphasizes the importance of the theme and narrative of escape rooms and argues that a strong narrative may even make up for design mistakes [11]. Similarly, Wiemker et al. [56] point out that the theme has to be reflected through all aspects of the game to create a believable experience.

2.1.3 Modalities and Platform. As stated at the beginning of this section, escape room games exist in various forms. Most literature focuses on one of these forms (e.g., live escape room facilities [41, 56]) and, thus, does not highlight the choice of technology in the design process. We add the decision on *modalities and game platform* as an important design consideration in our design framework to emphasize the diverse design possibilities. One main difference is whether the games will be played at home or a stationary live escape room facility. If a stationary room is used, the design space in terms of props is different from games delivered to the players. Another differentiation can be made between analog and digital games. In the latter case, the choice of game platform and interfaces (e.g., tablet PC or VR headset) influences the design process. Digital escape rooms generate a larger variety of input modalities—i.e., how players can interact with the game and the puzzles—that have to be considered. Player movement and the interaction with the game can either be discrete or continuous: discrete manipulation and movement provides fixed states and endpoints that can be reached such as a rotation that only takes steps of 45 degrees but nothing inbetween. Continuous manipulation, on the other hand, describes manipulation that has no clearly distinguishable states.

2.1.4 Puzzle Organization. Designers need to think about the general *puzzle organization* and composition of the game, meaning the way how all the puzzles and tasks are connected and in which order they can be solved [41, 56]. Wiemker et al. [56] differentiate three core approaches of puzzle paths: linear, open, and multi-linear. Linear means that puzzles have to be solved one after another, with only one possible, predefined sequence. In contrast, in the case of an open puzzle path, all puzzles are available and solvable from the beginning in any sequence. Multi-linear structures combine linear and open paths, with multiple linear paths being available at the same time. In a similar way, Nicholson [41] mentions sequential, open, and path-based structures as the basic forms of puzzle organization. At the same time, the author points out that escape room facilities often have much more complex puzzle structures, as they combine open and sequential paths into complex hybrid structures.

The puzzle organization is intertwined with other design choices, such as the integration of a narrative or the number of players. If a narrative progresses with the puzzles, linear or multi-linear puzzle paths work better than open paths, yet the number of players may promote multi-linear or open puzzle paths as these enable a group of players to work on multiple puzzles simultaneously [11].

2.1.5 Puzzle Design. Current surveys on escape rooms show that the types of puzzles and the skills required by players to solve all puzzles are manifold [37, 41, 56]. Results indicate that interesting puzzles and challenges are the strongest motivators for players to enter an escape room or start an escape room game [36, 37]. At the same time, there is little guidance in the current literature on how to create great escape room puzzles and which elementary challenges can be incorporated. Wiemker et al. [56] point out that a good puzzle has the following four characteristics: it is integrated into the room's storyline, it can be solved by using the information within the room, it adds to the

room's atmosphere, and the clues to the puzzle are logical. While these aspects seem reasonable to check when evaluating puzzles, they are still abstract and do not tell anything about the structure or mechanics of a puzzle. Just as the puzzle design is at the heart of any escape room game, it is also the focus of this paper. Hence, the puzzle design is considered in detail in the following main section (see section 3) and not discussed here.

2.1.6 Hint System and Failure Handling. Another important aspect of escape room games is to make sure that players do not get completely stuck. In general, design recommendations for puzzle games suggest starting with simple puzzles to introduce the main mechanics and then, over time, make the puzzles more complex to support players' learning process [34, 53]. However, escape room games are different in that regard: they usually include a lot of different types of puzzles and do not offer easy introductions to a certain puzzle mechanic. Hence, designers should also consider how they could integrate a hint system into their game. In live escape rooms, a game master usually monitors players' progress and can provide appropriate hints and assistance [41, 56]. Other games may differ in whether players can request hints at all, in the way to ask for and receive hints, and in the number and the individual adaptation of the hints received [56].

Related to the *hint system* is the *failure handling*. It describes how the game reacts to incorrect attempts at solving a puzzle. Failures may either be disregarded, activate a reset of the puzzle, or result in a punishment for the player. In typical live escape rooms, players do not get directly punished for mistakes. However, they usually have a time limit, and failing in solving a puzzle will finally lead to being defeated when time runs out. In contrast, in digital games, it is more common to implement punishment, as players are able to repeat the game. In any case, different types of punishment can result in very different experiences for players, even if the puzzles are similar. Sometimes, *failure handling* and *hint systems* are linked, and failure leads to receiving a hint.

3 ATOMIC PUZZLE TAXONOMY

Now that readers have an overview of escape room design in general, we turn our attention to its most important components—the puzzles. Having a great theme and impressive hardware is worthless if players are not properly challenged. Diverse and engaging puzzles form the basis of each escape room. Hence, this section focuses on proper classification of such puzzles and introduces the respective vocabulary.

3.1 Research Goals

The overarching goal of our atomic puzzle classification is to provide designers a tool for more efficient and systematic creation of escape room puzzles. Having such a condensed collection of various elements and mechanics facilitates the design process in multiple ways: As a ***lookup table***, the classification can be a source of inspiration. As an ***inspection tool***, the classification can be used for a retrospective analysis of the created room, helping to discover certain overused or underrepresented mechanics. In our work, we selected a *taxonomy* [38] as a formal method to classify puzzles. Taxonomies usually include different attributes and features, which leads to a more exhaustive and intuitive overview. Accordingly, we had the following subgoals in mind when establishing our taxonomy:

Universal Applicability. The taxonomy should be applicable to all types of puzzles, be it digital or analog. Similarly, the taxonomy should work in both research and commercial escape room contexts. For this reason, our exploration includes as many digital and analog escape room variants as possible. We argue that covering such a broad spectrum of puzzles increases the value for designers, as it allows for repurposing ideas and concepts from different domains. In contrast, previous works and classifications usually focus on only one domain, such as real-life facilities [41].

Unambiguity. Looking further down the road, we will see that most of the existing puzzle classifications introduce a high level of abstraction. Such abstractions can lead to ambiguity, i.e., a single puzzle might fall into multiple categories. This ambiguity, in turn, is a source of fuzziness, possibly impacting the clarity and helpfulness of such classifications. To prevent ambiguity issues, we construct our taxonomy on an atomic level. The granularity should guarantee that simple puzzles fall into exactly one category. Similarly, complex puzzles consisting of multiple challenges should be uniquely decomposable into atomic components.

3.2 Methodology

We applied an iterative approach to include insights from different contexts in consecutive steps. Similar to other escape room research (cf. escapED framework [12]), our design process started by reviewing current research on the topic. For that purpose, we searched for "escape rooms", "escape games" and "exit games" on different platforms, including ACM Digital Library, IEEE Explore, AIS eLibrary, Springer Link, and Google Scholar. Furthermore, cross-references were scanned for other relevant research. In total, we identified 39 papers discussing the design, application, or evaluation of escape room games. We worked through these papers and took notes on all puzzles and puzzle types that were described.

However, since the taxonomy should not be limited to research contexts, we also included different forms of commercial escape rooms into our analysis. We explored analog offers, i.e., real-life facilities and board games, as well as digital representatives in the form of desktop, mobile, and VR escape room games. Since the development of the taxonomy took place during the COVID-19 pandemic, we could not visit real-life escape room facilities in person. Instead, we had to rely on our own previous experiences and also conducted informal interviews with five university participants, who stated to have experience with escape room facilities. We asked them to name the room(s) they had visited and to describe all the puzzles they could recall. To analyze the board games and digital games, two of the authors played through all the games and independently took notes on all puzzles they encountered. For all games, the researchers then tried to classify all described puzzles using the current version of the taxonomy and discussed their findings. A detailed overview of our procedure is provided in Figure 3.

To summarize, the core principles of our investigation are similar to prior works in this area: we utilize a combination of literature review and insights from current escape room games. However, in contrast to our predecessors, we are not limiting our search to one dedicated domain, e.g., real-life facilities or card games. By including various modalities and representatives from digital and analog

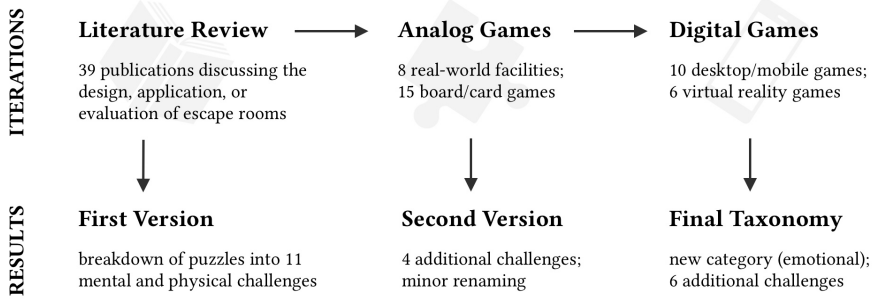

Fig. 3. The development process of our taxonomy. Firstly, we created a basic version based on prior literature. We then extended and refined the taxonomy by examining commercial analog and digital games listed in Appendix A.1.

areas, we aim at creating a taxonomy that is not limited to only one application scenario. We believe that such diversity is beneficial for designers, as it fosters cross-domain transfer and a combination of puzzle ideas and mechanics.

On the downside, our methodology cannot guarantee the completeness of puzzle types, as we only include elements that are already present in the escape room landscape. In other words, our approach is not meant for the discovery or construction of entirely novel atomic challenges. To overcome this limitation in follow-up research, we suggest an atomic decomposition of the underlying design space in order to identify missing representatives and categories.

3.3 Initial Taxonomy Based on Prior Works

Before constructing our taxonomy, we briefly outline existing definitions and classifications related to escape rooms and puzzles in general. Subsequently, we motivate the need for our cross-domain approach and explain how our method differs from and extends the prior literature in this area.

The word *puzzle* is used regularly in research concerning escape rooms, yet most works do not include a definition of this term. In one of the fundamental papers on escape rooms by Wiemker et al. [56], puzzles are described as a game loop consisting of a challenge, a solution, and a reward. Some papers even go as far as to say that "*within an escape room, all activities are called puzzles*" [52]. Alternative definitions differ in the details, for example, describing puzzles as *challenges* that can be completed by understanding the logical core rules of the game [59]. Other research defines puzzle games as "*those in which the fun is derived primarily from learning and applying specific skills to progress*" [34].

Similarly, related works rarely provide a classification of puzzles. In some cases, authors employ a general distinction between mechanical and logical puzzles [52, 56]. In other cases, researchers name only the type of a puzzle with no further explanation. This occurs especially when the name describes a well-known category of puzzles, such as a *jigsaw puzzle* [50] or a *crossword puzzle* [14].

During our literature review, we determined two existing approaches to classify puzzle types. A large body of escape room research uses the work of Nicholson [41] as a basis. In their survey, 175 escape room facility owners provide information about their facility, visitors, and escape rooms' features. The survey includes a list of puzzle types featured in the escape rooms of the participants. Several researchers use this list as a classification of puzzle types [25, 35]. A second approach to classify puzzles can be found in the escape room paper of Wiemker et al. [56]. The authors provide a basic subdivision into physical, mental, and mixed puzzles. Some researchers use this distinction to provide a basic classification of a puzzle they use. In this case, the exact type of puzzle is usually just stated using a name but not a reference or definition [24, 57]. Apart from these two approaches by Nicholson and Wiemker et al., a number of other related works [2, 28, 49] tends to bypass a formal classification or categorization and instead describes the puzzles in detail.

In addition to the puzzle types listed in the high-level approaches [41, 56], we collected the following puzzle types from mostly application-oriented literature (e.g., papers on design of a particular escape room):

- jigsaw puzzles [24, 27, 46, 50]
- tiling puzzles [60] / arrangement puzzles [6, 57]
- lock puzzles [23]
- search for hidden objects [6, 44]
- action puzzles [6]
- word puzzles (e.g. crossword [14], or riddle [17, 49])
- quizzes or questions [3, 6, 24]
- mathematical puzzles [17, 57]

- spot the difference [3] / pattern recognition [57]
- knowledge or skills (usually in educational games) [2, 35, 49]
- 3D combination puzzles (such as Rubik's cube) [55]

What all of the outlined types and classifications have in common is their focus on one application domain. For instance, the work by Nicholson [41] targets real-life facilities. This narrow scope of exploration might result in missing out on certain puzzle concepts offered by alternative escape rooms, such as VR games. Furthermore, we argue that an overly strong focus limits the applicability of existing classifications, as designers from other areas, e.g., card games, are less likely to come across these domain-specific findings. Instead, we decided to include as many digital and analog variations as possible to find overlooked puzzle types and to compile a domain-agnostic list of puzzle building blocks. Ideally, our taxonomy can be used as a compact source of inspiration for all kinds of (escape room) puzzle designers and foster the interdisciplinary exchange of puzzle concepts.

Apart from this aspect of universality, we contribute to existing research by increasing the level of granularity in the escape room design space. We argue that too abstract/generalized categories can be quite intangible and, thus, less suited for the creation process of escape rooms. We demonstrate this issue on the example of the *jigsaw puzzle*: Some interpretations include searching or fighting for tiles [27] and thereby emphasize the physical aspect. Others contain recognition of parts and logical combinations, which shifts the focus towards the mental aspect of the puzzle [46, 50]. In both cases, authors utilize the term jigsaw puzzle because the solution is achieved by assembling a physical object from pieces. Nevertheless, this generalization leaves out important information about the building blocks of the puzzle. Therefore, we argue that a precise classification should not only provide the main puzzle type but instead include all components of the puzzle. In other words, we suggest a classification of atomic puzzle elements rather than overarching puzzle types, combined with clear descriptions for each category.

In a first step, we decided to incorporate the subdivision of puzzles in **physical** and **mental** challenges, as proposed by Wiemker et al. [56]. This structure helps to understand how the players are (mainly) challenged, which appears highly practical for such an escape room taxonomy. We decided against approaches based on Nicholson's list [41] as a starting point due to two main reasons: Firstly, the categories listed are only those reported by the participants of the survey and may not be exhaustive, especially for describing other escape rooms than real-life facilities [35]. Secondly, since the categories are reported as stated by the participants, they may not be distinct and well-defined. Some categories may be ambiguous or overlap. For example, there are three categories that include searching (in the room, in pictures, and word search), and one that describes "noticing something in the room" [41, p. 19].

In a second step, we broke down the puzzles found in literature into atomic, distinct challenges, as depicted in Figure 4. In the following, we summarize the resulting first version of our taxonomy:

`Observation/Searching` [6, 41]. A challenge where players have to notice or find something visually. The category includes observing a number of objects and therefore contains *counting* challenges, as well. Since it is a mental challenge, it only describes the mental but not the physical effort. Hence, in escape rooms, respective puzzles often include an additional physical challenge, such as `Movement/Arrangement`.

`Knowledge` [3, 6, 35, 41]. The category describes mental challenges that can be solved using certain knowledge or expertise. Many literature examples describe puzzles that expect players to have that specific knowledge already and do not provide it in the room. Such challenges are especially common in educational escape rooms requesting knowledge from the learning domain. However, in real-life facilities, it is more common to provide the needed knowledge somewhere in

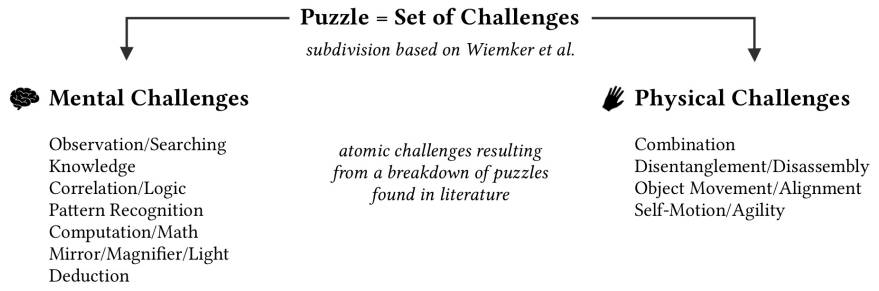

Fig. 4. The initial version of our taxonomy was created based on a literature review. We incorporated the subdivision in mental and physical challenges, as previously suggested by Wiemker et al. [56]. The particular atomic challenges resulted from a breakdown of puzzles found in the literature.

the room. Since these facilities often attract players with widely different backgrounds, they should avoid making assumptions about players' previous knowledge [56].

`Correlation/Logic` [56]. The category specifies mental challenges where players have to notice a connection between one or more room elements to solve the puzzle. This link between objects may be visual, spatial, or contextual. The solution can be the connection itself or a logical continuation. For instance, one might have to read a newspaper and learn the date of a historical event, which is then used as a numerical lock code.

`Pattern Recognition` [56, 57]. Challenges where players have to spot a similarity or identify something that is somehow perceivable. This pattern can be visual, auditory, tactile, or can even target taste or smell. The solution may be to identify it or the pattern may hold a clue or direction.

`Computation/Math` [17, 57]. This category covers all mathematical, numerical, and algorithmic challenges.

`Mirror/Magnifier/Light` [24, 41, 50]. Visual challenges where players have to alter the way they look at something. This may include looking at something in more detail, looking at something from a different angle or perspective, using a tool (e.g., mirror/magnifier), or changing the room lighting.

`Deduction` [24, 41]. Challenges that target social empathy and reasoning. For instance, players might have to estimate the trustworthiness or try to anticipate a person's behavior. This challenge can incorporate the usage/analysis of objects, texts, or even interaction with non-player characters.

`Combination` [41, 50]. This category specifies challenges where players have to assemble an object using its pieces physically. The pieces may need to be combined considering the shape and the look of the pieces. A classic example is the combination of jigsaw parts.

`Disentanglement/Disassembly` [41]. Challenges where players have to untangle, unlink, or disassemble something physically. The challenge may target either strength or fine motor skills.

`Object Movement/Alignment` [6, 41, 60]. Challenges that focus on placing physical objects in a specific place or a specific location in relation to each other. Such challenges can require strength, fine motor skills or can be combined with other challenges to generate more complex puzzles.

`Self-Motion/Agility` [6, 41]. Challenges where the players have to perform a certain body movement or physically reach a destination. For example, players might have to maneuver through a laser maze.

3.4 First Iteration: Commercially Available Analog Games

After reviewing the related academic literature, we focused on commercially available analog escape room games and subsequently adapted our taxonomy. In the following, we summarize our

general observations and mention noteworthy puzzles that feature challenges not included in our taxonomy up to this point.

The first form of escape rooms that we examined were real-life escape facilities. Due to the COVID-19 pandemic, we could not visit the rooms in person but conducted informal retrospective interviews with visitors of different facilities. Overall, we collected insights from eight different rooms (cf. Appendix A.1.1).

Most reported puzzles fit well into the existing taxonomy. This was no surprise, as our first version already took into account the puzzles reported in Nicholson's survey [41]—a list having been made by escape room owners. The majority of reported puzzles was based on mental challenges, including a lot of **Oberservation/Searching** and **Pattern Recognition** challenges, often combined with **Correlation** challenges (e.g., finding a key with a colored tag and understanding that the color hints to the lock it is unlocking). The use of an ultraviolet lamp (**Light**) and the **Combination** of a torn piece of paper (e.g., letter) was also mentioned several times.

However, we observed a gap regarding the physical components for puzzles which require players to connect two or more objects that do not necessarily belong together, e.g., connecting two electrical cables to close a circuit or connecting several pins on a map with a wool thread to find the intersection point of two paths. The related challenge **Combination** refers to the assembly of pieces that all belong together and create one complete object when combined, such as a torn letter. Hence, we add to the taxonomy:

[added] **Connection**. This category describes challenges that require players to link certain objects that do not represent pieces of a greater whole (i.e., they are not parts of the same disassembled object), e.g., connect two electrical cables to close a circuit.

No further modifications were necessary at this point, so we moved on to analyze escape rooms implemented as board and card games, as well as locked boxes. We browsed the huge board game database of BoardGameGeek [1] for escape room games and selected 15 games based on their popularity (rank) and availability. In the case of game series (such as "Exit: The Game" [8]), we picked a couple of exemplary scenarios. Moreover, we also included two less popular board games published by real-life escape room facilities as a means to overcome the COVID-19 lockdowns. A complete list of the analyzed "domestic" games can be found in Appendix A.1.2.

Especially in card games, such as "Deckscape" [10] and "Escape Tales" [9], many puzzles revolve around visual patterns and picture puzzles. Within the initial taxonomy, these would all be categorized as **Pattern Recognition** and **Observation/Searching** challenges. Consequently, puzzles that require players to search for or count specific objects would not be distinguished from puzzles where players have to notice differences between seemingly similar pictures. An example for the latter challenge can be found in the game "Escape Tales: The Awakening" [9]: Players have to compare two scenes and find the objects that differ between the real scene and the mirrored scene, and the numbers linked to the dissimilar objects have to be added to get the numeric solution. To account for this kind of puzzles, we implemented the following modification of our taxonomy to obtain a more distinct classification:

[added] **Comparison/Distinction**. These challenges require players to spot the difference(s) between similar images or scenes.

Furthermore, many paper-based games emphasize the usage of pens. A prominent example is the "connect-the-dots" puzzle, where players have to draw lines between dots to obtain the final image. Such challenges can be classified as **Connection** challenges as defined above and require no modification of the taxonomy.

[1] https://www.boardgamegeek.com/

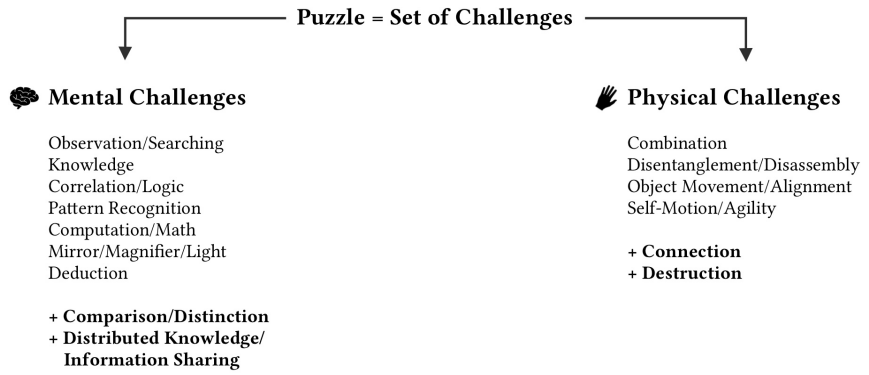

Fig. 5. The modified version of our taxonomy after the consideration of analog escape room games, i.e., real-life facilities and board/card games.

We observed several challenges that involved some sort of destruction or ripping objects apart. In contrast to **`Disassembly`**, which is usually reversible, destruction is a one-time action. To underpin this irreversibility, we expanded our taxonomy:

[added] **`Destruction`**. Challenges that require players to rip something apart or intentionally break an object.

Finally, the card-based game "The Island of Doctor Goorse" from the "Unlock!" series revealed a new challenge not yet represented in our taxonomy. The game requires players to divide into two groups, which have access to different places, objects, and information as they are located on different sides of a temple. After some progression, they are allowed to talk to each other (through a hole in the wall), but they are not allowed to show or hand over their cards. Hence, they have to share their information and communicate to find out how they can help each other. Such a setting creates high interdependence between players and fosters communication and social interaction [15, 50]. At this point, we considered whether there was the need to include an additional puzzle type (i.e., "social" or "communicative") to account for challenges that are based on multiplayer interaction. However, after analyzing the underlying mechanics and challenges of different social/communicative puzzles we encountered in different board games, we concluded that they all basically revolve around the mental challenge of presenting or sharing certain pieces of information. We add a respective mental challenge to our taxonomy:

[added] **`Distributed Knowledge/Information Sharing`**. Challenges that require players to exchange information that is asymmetrically distributed among them. Such challenges are particularly suited for multiplayer escape rooms in which players take different roles/perspectives or are (temporarily) spatially separated.

The resulting first iteration of the taxonomy can be found in Figure 5. In sum, we did no change the underlying structure, i.e., the subdivision into mental and physical challenges. However, we added several challenges to obtain a more distinct classification.

3.5 Second Iteration: Digital Escape Rooms

Until now, we (and most of the prior works) considered analog, real-world puzzles. However, the digital gaming domain should not be overlooked, as it offers some unique challenges for players. In a second iteration, we explored a number of desktop and mobile escape room games (cf. Appendix A.1.3). We also included recent VR escape rooms, which will be discussed towards the end of this section.

Fig. 6. **Pattern Recognition** is often combined with other challenges, such as **Memorization/Reproduction**. In the depicted point-and-click game [16], players have to memorize a certain pattern found at a fireplace and then reproduce it to open a box.

First of all, one might argue that the global subdivision in mental and physical challenges is a bit misleading in the context of digital input/output. Hence, we considered the option to rename physical into *mechanical* challenges to have a more precise vocabulary. On the other hand, such challenges still involve motor skills and have a physical in-game representation. Hence, we decided to keep the initial name, which also avoids an unnecessary deviation from the categorization of Wiemker et al. [56].

Furthermore, our examination revealed that **Pattern Recognition** often appears in combination with other mental components. The challenge is either combined with **Searching** and/or players have to memorize and reproduce a pattern. An example is provided in Figure 6: in this point-and-click escape room [16], players have to find and memorize a pattern in one area of the room and then reproduce it in another area. Hence, we further expanded the taxonomy:

[added] **Memorization/Reproduction**. These challenges require players to memorize some information, e.g., a pattern or a text passage, in order to reproduce it at another place or in a later stage of the game.

The game series "The Room" [18–21] introduces an interesting twist on **Mirror/Magnifier/Light** challenges: In these games, players are equipped with a mystic eyepiece (cf. Figure 7), which, on the one hand, represents certain mechanics from the **Mirror/Magnifier/Light** category by revealing otherwise hidden signs on surfaces comparable to an ultraviolet lamp. However, in the later games, this eyepiece additionally allows superhuman interactions, such as looking and reaching through walls, or teleporting into small spaces, thereby changing the player's size. This goes beyond a mere change of perspective. Another example in this context is the object manipulation involved in many puzzles of the game "Superliminal" [45]: the game uses the ambiguity of depth and allows players to change the size of objects in the physical space by changing their perspective on them, making optical illusions become true. Hence, we extended our taxonomy to include such nonrealistic behaviors:

[added] **Supernatural Abilities**. Challenges that require players to apply certain superhuman skills of their character or perform a self-transformation. We argue that such challenges are rather mental and not physical, as they require players to think and decide when to reasonably use the ability rather than to act and manipulate.

Other than that, each digital puzzle that we faced had a straightforward mapping to a distinct set of challenges in our taxonomy. Clearly, the ways to solve such digital puzzles differ from analog variants. In most games, we used a mouse or touch input as a mediator to accomplish physical tasks instead of directly manipulating an object. For instance, we had to click on a tile to rotate it or drag and drop the end of a rope to establish a connection. However, the underlying challenges are the same as in non-digital puzzles, which explains why the taxonomy did not require significant alterations.

Fig. 7. The game series "The Room" [18–21] introduced a magical eyepiece that provides **Supernatural Abilities** to the players, such as shrinking their sizes to enter certain areas or revealing hidden patterns.

As the last step in our taxonomy development process, we explored the available VR escape rooms. In particular, we included games playable on the Oculus Quest (including Oculus Link capabilities) and classified as "escape room", "escape puzzle", or "escape game" in the respective stores. A list of all tested VR titles can be found in Appendix A.1.4.

Again we observed that certain games, such as "The Room VR" [22], integrated superhuman abilities into their puzzles. The Room VR uses a similar concept of a mystic eyepiece as its non-VR predecessors. Another example of a virtual escape room transcending beyond what is possible in reality can be found in work by Krekhov et al. [31]. They present escape room games with non-humanoid animal avatars that feature 'superhuman' abilities and characteristics.

The game "I Expect You To Die" [48], where players take the role of an elite spy, inspired a minor adaptation of our taxonomy. The **Destruction** challenge is present in almost every mission of the game. The possibilities include breaking, ripping apart, and shattering fragile objects, stabbing or cutting with a sharp object, shooting, burning, and blowing something up by detonating a bomb or grenade. Hence, we rendered our taxonomy more precisely by including the degree of inflicted damage:

[modified] **Destruction** → **Damaging/Destruction**.

A second observation made in "I Expect You To Die" was related to **Self-Motion/Agility**. In one scene, players have to evade the defensive system of the car they are trapped in. However, the challenge in this puzzle is more the timing and not the actual motion. Hence, we extended our taxonomy as follows:

[added] **Timing**. Challenges that require players to execute a certain action within a very limited time frame and/or synchronized with certain events. For instance, players might have to press a button when they hear an audio cue or evade a light beam by moving at the right time. These challenges can also be implemented as a team challenge so that multiple players have to synchronize their actions.

Finally, the game "Last Labyrinth" [1] pointed us to another facet of games we had not yet considered. In this game, the player is strapped to a wheelchair, unable to move, and has to use a laser pointer and head movements to communicate with a girl—a non-player character—who can then perform actions. For every mistake, the player is punished gruesomely, as both the player and the girl are killed. Belonging to the horror genre, this game combines challenging puzzles with a constant thread of dying, causing harm to the young girl, and the unpleasant experience of immobility. Though being an important aspect of the experience, the challenge induced by the scary environment cannot be mapped to physical or mental challenges. In general digital games research, recent publications indicate that games can feature a third type of challenge: emotional challenges [7, 13]. Emotional challenges include dealing with intense negative emotions, difficult decisions (due to ambiguity or a moral dilemma), and negative consequences of previous

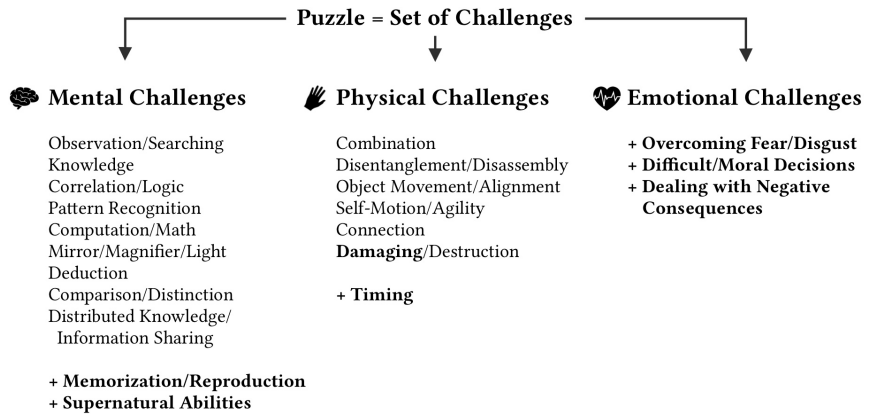

Fig. 8. Final version of our taxonomy after the inclusion of digital escape room games. We introduced the emotional challenge category, which requires players to overcome fear, question moral standards, or deal with negative consequences from their decisions.

actions [7]. Such challenges cannot be overcome by dexterity or skill. Instead, players have to deal with unpleasant feelings and resolve ambiguities [13].

Although the exemplary escape room games we examined do not clearly feature emotional challenges (except "Last Labyrinth"), we have to point out that we did not include any real-life escape rooms with a horror theme. Such games are more likely to include emotional challenges, as they aim at invoking anxiety and uncertainty. For instance, Pendit et al. [44] created an escape room simulation called "the last breakout" to induce fear of the dark environment. Compared to real-life escape rooms, immersive digital escape rooms seem particularly suitable to face players with dangerous and fear-inducing events because such games can convincingly simulate a situation that would be too dangerous in real-life (e.g., a player can be forced to cross a deep abyss by balancing on a thin plank).

We decided to include these considerations in our taxonomy to enhance its range. As depicted in Figure 8, we added **emotional** challenges as the third branch of challenge types. As atomic emotional challenges, we integrated the following (inspired by the work of Bopp et al. [7]):

[added] **`Overcoming Fear/Disgust`**. Challenges where players have to deal with and overcome intense negative emotions, in particular fear or disgust, to move forward. The negative feelings can either be induced by a specific frightening stimulus (e.g., a spider or a deep abyss) or by a high level of uncertainty (e.g., when having to put a hand in a box or hole without knowing what is inside).

[added] **`Difficult/Moral Decisions`**. Challenges where players have to make decisions while all possible choices are linked to unwanted consequences without a clear best option. A classic example is the decision whom to save if several persons are threatened, but the player can only save one.

[added] **`Dealing with Negative Consequences`**. Challenges that make players carry the burden of negative consequences that arise from their previous in-game actions and decisions, such as seeing a companion suffer.

3.6 Exemplary Application of the Taxonomy

We demonstrate the applicability of the final taxonomy on three examples: "I Expect You To Die" [48], "The Room VR" [22], and "Last Labyrinth" [1]. VR games are arguably the least explored representatives in terms of puzzle design. Hence, we suggest that they provide a suitable basis to test the robustness of our taxonomy. Furthermore, due to the rapidly growing popularity of

VR escape rooms, the involved developers and researchers might find such hands-on examples helpful for their future work. In Appendix A.2, we compiled a list of all occurring challenges for each of the three games, sorted by the respective scene and chapter, where applicable. This list is the result of an analysis conducted by two researchers (one being involved in the development of the taxonomy, the other not) who played the games and independently categorized all puzzles. Eventually, both researchers were able to classify each puzzle of these three games within our taxonomy (cf. Figure 8) and agreed in all cases.

This exemplary application process is not limited to testing the robustness of the taxonomy. By breaking down the VR escape rooms into atomic challenges, we obtain an opportunity to determine underrepresented and overused mechanics. Based on our playthrough experience, the three games provide a good balance between mental and physical challenges. In particular, most prominent representatives of mental challenges are **`Observation/Searching`** and **`Pattern Recognition`**. In the case of "Last Labyrinth", one might argue that **`Pattern Recognition`** is rather overrepresented compared to other challenge types. In contrast, the mental challenges **`Calculation/Math`** and **`Knowledge`** are hardly present in all three games. For the physical part, **`Object Movement/Alignment`** challenges are utilized most often, which might be due to the realistic and immersive object manipulation provided by VR setups. Physical challenges that require agility or swiftness were found only in "I Expect You To Die", which might indicate a missed opportunity for the other games. Lastly, regarding emotional challenges, "Last Labyrinth" was the only game that relied on such mechanics and caused fear or disgust throughout the game session. We argue that emotional challenges are underrepresented in available escape room games and recommend a closer look at this category as part of future work.

4 CONCLUDING DISCUSSION

Throughout our analysis of existing games, we went through 39 analog and digital representatives. And while there are certainly some puzzle types that we have not faced in our development process, the number of included games allows us to assume a certain level of robustness and applicability. Moreover, we argue that the overall structure, i.e., the subdivision in mental, physical, and emotional challenges, and the chosen level of abstraction allow for easy integration of novel challenges in the future. In this section, we briefly report how this manuscript's results can be applied and discuss our gathered insights regarding the gap between digital and analog puzzles.

4.1 Beneficiaries and Applicability

One prominent question regarding such taxonomies is whether their usage indeed provides explicit (real-world) advantages–apart from a purely descriptive tool. Hence, in our case, the question to be asked is: "why is it important to classify existing puzzles?" We provide two major use-cases as an answer: Firstly, practitioners are able to assess the overall state, i.e., the diversity, of a particular escape room. By applying our taxonomization to the room's puzzles, one obtains a comprehensive breakdown of implemented challenges. Consequently, practitioners can make necessary adjustments for a better balance, e.g., adding some agility-based challenges or removing certain pattern recognition tasks due to their overrepresentation. Secondly, this breakdown can be used to comprehend the fundamental orientation of a room, which is advantageous when planning for a certain target audience. For instance, some players like to show off their mechanical dexterity, and others might be attracted by a room with an explicit emotional challenge (e.g., horror escape rooms).

The taxonomy has another raison d'être, namely being a source of inspiration for puzzle synthesis. This is particularly handy given the current demand for digital multiplayer escape rooms as means to overcome the social distancing in times of COVID-19. Furthermore, especially in the scientific

and education domains, escape rooms are often created by non-experts regarding puzzle design. Hence, such works will benefit from the operationalization provided by our taxonomy, no matter if the digital or the analog domain is targeted.

4.2 Digital vs. Analog Puzzles

When we started working on the taxonomy, one of the key discussion points was whether we could include both the digital and analog domains without sacrificing too many domain-specific attributes. In retrospect, the utilization of player challenges as atomic building blocks for puzzles was a proper choice to close the gap between the two domains. Initially, we expected a significant difference for the digital part of our analysis, especially as we also considered VR escape room games. However, most digital puzzles are copies of their analog counterpart, with the only difference being the I/O modality. For instance, instead of physically rotating a tile until the correct alignment is achieved, the digital versions require players to, e.g., click on a tile to trigger a discretely stepped rotation.

A study by Ang et al. [2], in which they created an online escape room using the puzzles of a physical escape game and compared them in playtests, also indicates that most physical puzzles can easily be implemented digitally and that missing physicality can easily be replaced by adding visual cues. However, in our opinion, by simply porting analog puzzles, developers are missing out on unique opportunities offered by the digital domain. Virtual worlds allow mechanics, skills, and experiences that are not available in the real world—digital puzzles do not have to follow the laws of physics. The few games utilizing "unrealistic" concepts, such as the **`Supernatural Abilities`** in "The Room VR" [22], are quite successful, which is an indication of the huge potential of such supernatural experiences. Hence, we postulate that researchers and developers should consider a *digital-first* approach where applicable instead of just copying analog variants.

Furthermore, we noticed a digitalization/hybrid trend for analog puzzles, which is particularly observable in the area of escape room board games. One of the main reasons for this development is grounded in hint systems. Many analog games come with some digital assistant realized as a companion app for smartphones or as standalone hardware. The inclusion of digital components does not stop with the hint system. Recent games can require the players to call a certain number, visit a homepage, or scan a QR-code in order to solve a puzzle. In other words, the boundaries between digital and analog puzzles tend to vanish, and having a uniform vocabulary to describe these challenges is once more of importance.

An even more promising trend in hybrid puzzle design is the inclusion of augmented and mixed reality (AR/MR) technologies. Unfortunately, we did not encounter any commercial representatives in that domain and, thus, did not include AR/MR escape rooms in our playtests. However, we suggest relying on prior research [3, 4, 30, 54] as a pointer to characteristic opportunities that such rooms can offer. For instance, Warmelink et al. [54] emphasize the benefits of asymmetric roles and skills for team-building purposes. Regarding atomic challenges, the AR/MR rooms described in prior research are already covered by our final taxonomy. Typical AR/MR puzzles include information-related mental challenges, such as **`Distributed Knowledge/Information Sharing`**, in combination with **`Supernatural Abilities`**, e.g., for revealing additional clues. Another prominent way to apply AR/MR technologies is to digitally recreate a certain historical object or scenario for **`Knowledge`** challenges [3].

5 LIMITATIONS AND FUTURE WORK

Our work breaks new ground by unifying digital and analog (escape room) puzzles in a single taxonomy. By nature, such contributions are imperfect regarding their completeness, and they are meant to lay down a foundation for future research. To provide a starting point for further

improvements of the taxonomy, we outline our considerations regarding the weaknesses and missing parts of our work.

One thing to be noticed is that—contrary to most works in our community—we did not include any evaluations. In general, taxonomies do not require studies, as they are theoretical concepts based on observation and analysis of prior works. However, we believe that empirical follow-ups are more than appropriate, as our taxonomy is meant to be applicable. We see two major directions for future studies: Firstly, one should evaluate whether participants can use our taxonomy to break down and understand escape rooms. Such insights would provide a better assessment of soundness, unambiguity, chosen vocabulary, and completeness of the taxonomy regarding the included challenges. Secondly, we propose a study aimed at escape room creators to obtain feedback on our high-level framework (cf. Section 2.1) for future improvements.

Going further down the road of evaluations, we argue that the category of emotional challenges is particularly interesting for future investigations. Until now, this category was not explicitly targeted in puzzle and escape room literature and only scarcely represented in the games we analyzed. However, we see the potential of emotional challenges to add another layer to the puzzle experience, particularly in digital escape games, which allow for the simulation of dangerous and/or frightening situations without actually endangering the player.

Similar to our introduction of emotional challenges, we can also imagine the creation of completely novel categories in future inventive game designs. One interesting starting point might be the work by Caillois [5] revolving around vertigo and a willful loss of control. This type of play, also being referenced as *ilinx*, is based on the manipulation of a player's visceral sensations and might lead to new challenges in escape room games.

Another limitation of the current taxonomy is the missing analysis concerning the interplay of challenges. The taxonomy allows us to break down puzzles into a set of atomic building blocks—the opposite process, however, is not as straightforward. Until now, we cannot provide sophisticated predictors for the combinability of different elements. Hence, as an important follow-up step, we suggest an extensive analysis of the interaction between atomic challenges. For instance, a reasonable outcome would be a list of mutually excluding challenges or those particularly suited for multiplayer scenarios.

To summarize, the current contribution is meant and suited as a tool for analyzing existing digital and analog escape rooms. The next major step is to operationalize the whole creation process of such games. Therefore, we suggest a refinement of our high-level framework by including puzzle designers and escape room owners in future iterations, paired with an in-depth guide aimed at the interplay and combinability of atomic challenges. Finally, due to its atomic nature, we emphasize our taxonomy's potential applicability for puzzles in general, i.e., beyond escape rooms as application domain.

REFERENCES

[1] Amata K.K. 2019. *Last Labyrinth.* Game [Windows]. Amata K.K., Tokyo, Japan. Last played December 2020.

[2] Jayden Wei Jie Ang, Yin Ni Annie Ng, and Rou Shen Liew. 2020. Physical and Digital Educational Escape Room for Teaching Chemical Bonding. *Journal of Chemical Education* 97, 9 (2020), 2849–2856.

[3] Angeliki Antoniou, Marios Ilias Dejonai, and George Lepouras. 2019. 'Museum Escape': A Game to Increase Museum Visibility. In *International Conference on Games and Learning Alliance*. Springer, 342–350.

[4] Jon Back, Svante Back, Emma Bexell, Stefan Stanisic, and Daniel Rosqvist. 2019. the Quest: An Escape Room Inspired Interactive Museum Exhibition. In *Extended Abstracts of the Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts*. 81–86.

[5] Hans-Joachim Backe. 2008. Caillois Revisited. In *Playing by the Rules of the Game*, Ghosh-Schellhorn, Martina and Marti, Roland (Ed.). Lit Verlag, 53–63.

[6] Boyan Bontchev, Albena Antonova, and Yavor Dankov. 2020. Educational Video Game Design Using Personalized Learning Scenarios. In *International Conference on Computational Science and Its Applications*. Springer, 829–845.

[7] Julia Ayumi Bopp, Klaus Opwis, and Elisa D. Mekler. 2018. "An Odd Kind of Pleasure": Differentiating Emotional Challenge in Digital Games. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3173615

[8] Inka Brand and Markus Brand. 2016. *Exit: The Game*. Game [Board Game]. KOSMOS, Stuttgart, Germany. Last played October 2020.

[9] Jakub Caban, Matt Dembek, and Bartosz Idzikowski. 2018. *Escape Tales: The Awakening*. Game [Board Game]. KOSMOS, Stuttgart, Germany. Last played October 2020.

[10] Martino Chiacchiera and Silvano Sorrentino. 2017. *Deckscape: Pocket Escape Room Games*. Game [Board Game]. AbacusSpiele, Dreieich, Germany. Last played November 2020.

[11] Adam Clare. 2016. *Escape The Game: How to make puzzles and escape rooms*. Smashwords Edition.

[12] Samantha Clarke, Daryl J Peel, Sylvester Arnab, Luca Morini, Helen Keegan, and Oliver Wood. 2017. escapED: a framework for creating educational escape rooms and Interactive Games For Higher/Further Education. *International Journal of Serious Games* 4, 3 (2017), 73–86.

[13] Alena Denisova, Christian Guckelsberger, and David Zendle. 2017. Challenge in Digital Games: Towards Developing a Measurement Tool. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 2511–2519. https://doi.org/10.1145/3027063.3053209

[14] Amir Doroudian, Simone Hausknecht, and David Kaufman. 2018. Creating an online escape room game for older adults: Needs assessment, design process, and usability testing. In *International Conference on Human Aspects of IT for the Aged Population*. Springer, 516–525.

[15] Katharina Emmerich. 2020. Designing Player Interdependence to Enhance Players' Social Experience in Multiplayer Games. In *The Digital Gaming Handbook*, Roberto Dillon (Ed.). CRC Press, 19–35.

[16] EscapeRoomGames.de. 2018. *Country Cottage Escape Yotreat*. Game [Windows]. EscapeRoomGames.de. https://www.escaperoomgames.de/escape-games-online-country-cottage-escape. Last played December 2020.

[17] Nickolas Falkner, Raja Sooriamurthi, and Zbigniew Michalewicz. 2010. Puzzle-based learning for engineering and computer science. *Computer* 43, 4 (2010), 20–28.

[18] Fireproof Studios. 2012. *The Room*. Game [iOS]. Fireproof Studios, Guildford, UK. Last played December 2020.

[19] Fireproof Studios. 2013. *The Room Two*. Game [iOS]. Fireproof Studios, Guildford, UK. Last played December 2020.

[20] Fireproof Studios. 2015. *The Room Three*. Game [iOS]. Fireproof Studios, Guildford, UK. Last played December 2020.

[21] Fireproof Studios. 2018. *The Room: Old Sins*. Game [iOS]. Fireproof Studios, Guildford, UK. Last played December 2020.

[22] Fireproof Studios. 2020. *The Room VR: A Dark Matter*. Game [Oculus Quest]. Fireproof Studios, Guildford, UK. Last played December 2020.

[23] Panagiotis Fotaris and Theodoros Mastoras. 2019. Escape rooms for learning: A systematic review. In *ECGBL 2019 13th European Conference on Game-Based Learning*. Academic Conferences and publishing limited Denmark.

[24] Miguel Gomez. 2020. A COVID-19 Intervention: Using Digital Escape Rooms to Provide Professional Development to Alternative Certification Educators. *Journal of Technology and Teacher Education* 28, 2 (2020), 425–432.

[25] Outi Heikkinen, Julia Shumeyko, et al. 2016. Designing an escape room with the experience pyramid model. (2016).

[26] Robin Hunicke, Marc Leblanc, and Robert Zubek. 2004. MDA: A formal approach to game design and game research. In *Proceedings of the Challenges in Games AI Workshop, Nineteenth National Conference of Artificial Intelligence*. Press, 1–5.

[27] Saverio Iacono, Daniele Zolezzi, and Gianni Vercelli. 2018. Virtual Reality Arcade Game in Game-Based Learning for Cultural Heritage. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*. Springer, 383–391.

[28] Jonna Järveläinen and Eriikka Paavilainen-Mäntymäki. 2019. Escape Room as Game-Based Learning Process: Causation-Effectuation Perspective. In *Proceedings of the 52nd Hawaii International Conference on System Sciences*.

[29] Zoi Karageorgiou, Panagiotis Fotaris, and Eirini Mavrommati. 2020. Escape Rooms for STEAM Education: Comparing Design Phases. In *ECGBL 2020 14th European Conference on Game-Based Learning*. Academic Conferences limited, 287.

[30] Ralf Klamma, Daniel Sous, Benedikt Hensen, and István Koren. 2020. Educational Escape Games for Mixed Reality. In *European Conference on Technology Enhanced Learning*. Springer, 437–442.

[31] Andrey Krekhov, Sebastian Cmentowski, Katharina Emmerich, and Jens Krüger. 2019. Beyond Human: Animals as an Escape from Stereotype Avatars in Virtual Reality Games. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*. 439–451.

[32] Andrey Krekhov and Katharina Emmerich. 2020. Player Locomotion in Virtual Reality Games. In *The Digital Gaming Handbook*, Roberto Dillon (Ed.). CRC Press, 313–329.

[33] Jiabao Li, Honghao Deng, and Panagiotis Michalatos. 2017. CatEscape: An Asymmetrical Multiplatform Game Connecting Virtual, Augmented and Physical World. In *Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play*. 585–590.

[34] Conor Linehan, George Bellord, Ben Kirman, Zachary H. Morford, and Bryan Roche. 2014. Learning Curves: Analysing Pace and Challenge in Four Successful Puzzle Games. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-Human Interaction in Play* (Toronto, Ontario, Canada) *(CHI PLAY '14)*. Association for Computing Machinery, New York, NY, USA, 181–190. https://doi.org/10.1145/2658537.2658695

[35] Sonsoles López-Pernas, Aldo Gordillo, Enrique Barra, and Juan Quemada. 2019. Examining the use of an educational escape room for teaching programming in a higher education setting. *IEEE Access* 7 (2019), 31723–31737.

[36] Lee-Fay Low and Errol Elumir. 2018. 2018 Escape Room Enthusiast Survey. https://thecodex.ca/wp-content/uploads/2018/09/2018EREnthusiastSurveyV1_1.pdf. The Codex: A secret community of Escape Room Enthusiasts.

[37] Lee-Fay Low and Errol Elumir. 2019. 2019 Escape Room Enthusiast Survey. https://www.thecodex.ca/2019EREnthusiastSurveyV1_2.pdf. The Codex: A secret community of Escape Room Enthusiasts.

[38] Alberto Marradi et al. 1990. Classification, typology, taxonomy. *Quality and Quantity* 24, 2 (1990), 129–157.

[39] Rachel Menzies. 2019. Unlocking Accessible Escape Rooms. In *The 21st International ACM SIGACCESS Conference on Computers and Accessibility* (Pittsburgh, PA, USA) *(ASSETS '19)*. Association for Computing Machinery, New York, NY, USA, 510–512. https://doi.org/10.1145/3308561.3354602

[40] Mahdi Nabiyouni, Ayshwarya Saktheeswaran, Doug A Bowman, and Ambika Karanth. 2015. Comparing the performance of natural, semi-natural, and non-natural locomotion techniques in virtual reality. In *2015 IEEE Symposium on 3D User Interfaces (3DUI)*. IEEE, 3–10.

[41] Scott Nicholson. 2015. Peeking behind the locked door: A survey of escape room facilities. *Pozyskano z http://scottnicholson. com/pubs/erfacwhite. pdf* (2015).

[42] Federica Pallavicini, Ambra Ferrari, Alessandro Pepe, Giacomo Garcea, Andrea Zanacchi, and Fabrizia Mantovani. 2018. Effectiveness of virtual reality survival horror games for the emotional elicitation: Preliminary insights using Resident Evil 7: Biohazard. In *International Conference on Universal Access in Human-Computer Interaction*. Springer, 87–101.

[43] Rui Pan, Henry Lo, and Carman Neustaedter. 2017. Collaboration, awareness, and communication in real-life escape rooms. In *Proceedings of the 2017 Conference on Designing Interactive Systems*. 1353–1364.

[44] Ulka Chandini Pendit, Muhaimin Bin Mahzan, Mohamad Danial Fadzly Bin Mohd Basir, Mazlan Bin Mahadzir, and Siti Noraishah binti Musa. 2017. Virtual reality escape room: The last breakout. In *2017 2nd International Conference on Information Technology (INCIT)*. IEEE, 1–4.

[45] Pillow Castle. 2020. *Superliminal*. Game [Windows]. Pillow Castle, Seattle, USA. Last played December 2020.

[46] Daniel Pohlandt, Bernhard Preim, and Patrick Saalfeld. 2019. Supporting Anatomy Education with a 3D Puzzle in a Virtual Reality Environment. *Mensch und Computer 2019-Tagungsband* (2019).

[47] Jesse Schell. 2008. *The Art of Game Design: A book of lenses*. Morgan Kaufmann.

[48] Schell Games. 2017. *I expect you to die*. Game [Windows]. Schell Games, Pittsburgh, USA. Last played December 2020.

[49] Stefan Seebauer, Sabrina Jahn, and Jürgen Mottok. 2020. Learning from Escape Rooms? A Study Design Concept Measuring the Effect of a Cryptography Educational Escape Room. In *2020 IEEE Global Engineering Education Conference (EDUCON)*. IEEE, 1684–1685.

[50] Hanieh Shakeri, Samarth Singhal, Rui Pan, Carman Neustaedter, and Anthony Tang. 2017. Escaping together: the design and evaluation of a distributed real-life escape room. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*. 115–128.

[51] Sanna Tarssanen and M Kylänen. 2009. Handbook for experience stagers. *Lapland Center of Expertise for the Experience Industry, OY Sevenprint Ltd, Rovaniemi* (2009).

[52] Alice Veldkamp, Liesbeth van de Grint, Marie-Christine P.J. Knippels, and Wouter R. van Joolingen. 2020. Escape education: A systematic review on escape rooms in education. *Educational Research Review* 31 (2020), 100364. https://doi.org/10.1016/j.edurev.2020.100364

[53] Monica Visani Scozzi, Ioanna Iacovides, and Conor Linehan. 2017. A Mixed Method Approach for Evaluating and Improving the Design of Learning in Puzzle Games. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Amsterdam, The Netherlands) *(CHI PLAY '17)*. Association for Computing Machinery, New York, NY, USA, 217–228. https://doi.org/10.1145/3116595.3116628

[54] Harald Warmelink, Igor Mayer, Jessika Weber, Bram Heijligers, Mata Haggis, Erwin Peters, and Max Louwerse. 2017. AMELIO: Evaluating the team-building potential of a mixed reality escape room game. In *Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play*. 111–123.

[55] Josef Wideström, Ann-Sofie Axelsson, Ralph Schroeder, Alexander Nilsson, Ilona Heldal, and Åsa Abelin. 2000. The collaborative cube puzzle: a comparison of virtual and real environments. In *Proceedings of the third international conference on Collaborative virtual environments*. 165–171.

[56] Markus Wiemker, Errol Elumir, and Adam Clare. 2015. Escape room games. *Game Based Learning* 55 (2015).

[57] Samira Yeasmin and Layla Abdulrahman Albabtain. 2020. Escape The Countries: A VR Escape Room Game. In *2020 3rd International Conference on Computer Applications & Information Security (ICCAIS)*. IEEE, 1–6.

[58] Xiyuan Zhang, Jing-Qi Lu, and Kyoungju Park. 2018. Interaction Design for Room Escape Virtual Reality Games. *TECHART: Journal of Arts and Imaging Science* 5, 4 (2018), 24–29.

[59] Y. Zhang, Z. Shen, and Y. Zhang. 2019. Research on the Design of Puzzle Games Based on Unity 3D. In *2019 IEEE 2nd International Conference on Knowledge Innovation and Invention (ICKII)*. 145–148. https://doi.org/10.1109/ICKII46306.2019.9042694

[60] Zhenjun Zhou and Lili Wu. 2012. The study of principles of Puzzle game design. In *2012 International Symposium on Information Technologies in Medicine and Education*, Vol. 2. 1079–1083. https://doi.org/10.1109/ITiME.2012.6291487

A APPENDIX

A.1 List of Analyzed Escape Room Games

A.1.1 Real-Life Escape Rooms.

- Teamescape Münster (https://teamescape.com/muenster/de/escape-room-muenster.html)
- Exit Games Dortmund (https://exit-dortmund.de)
- Thinksquare Bochum (https://www.think-square.de)
- Rätselraum Ruhrpott (https://raetselraum.de)
- Ruhrescape Essen (https://www.ruhrescape.de)
- Lippescape Lünen (https://www.lippescape.de)
- Lock Room Wuppertal (https://lockroom.de)
- Verschlussache Castrop-Rauxel (https://www.verschlusssache-escape.de)

A.1.2 Physical Board/Card Games.

- Escape Tales: The Awakening (by KOSMOS)
- Escape Room: The Game (by Noris Games)
  - Prison Break
  - Virus
  - Nuclear Countdown
  - Temple of the Aztec
- Exit: The Game (by KOSMOS)
  - The Mysterious Museum
  - The Secret Lab
- Unlock!: Escape Adventures (by Space Cowboys)
  - The Formula
  - Squeek & Sausage
  - The Island of Dr. Goorse
- Deckscape: A Pocket Escape Room Game (by ABACUSSPIELE)
  - Test Time
  - The Fate of London
- Escape Room In A Box: The Werewolf Experiment (by Mattel)
- Escape Room Stories: Das magische Siegel (by Rätselraum Ruhrpott)
- Quest Pyramide (by Escapewelt)

A.1.3 Digital Mobile/Desktop Games.

- Jan Albartus. 2008. *Mystery Of Time And Space (MOTAS)*. Game [Windows]. Albartus, Jan. http://www.albartus.com/motas/. Last played December 2020.
- Fireproof Studios. 2012. *The Room*. Game [iOS]. Fireproof Studios, Guildford, UK. Last played December 2020.
- Fireproof Studios. 2013. *The Room Two*. Game [iOS]. Fireproof Studios, Guildford, UK. Last played December 2020.

- Fireproof Studios. 2015. *The Room Three*. Game [iOS]. Fireproof Studios, Guildford, UK. Last played December 2020.
- Fireproof Studios. 2018. *The Room: Old Sins*. Game [iOS]. Fireproof Studios, Guildford, UK. Last played December 2020.
- 365 Escape. [n.d.]. *Room Escape Games* (Collection). Game [Windows]. 365 Escape. https://www.365escape.com/. Last played December 2020.
- EscapeRoomGames.de. [n.d.]. *Country Cottage Escape Yotreat*. Game [Windows]. EscapeRoomGames.de. https://www.escaperoomgames.de/escape-games-online-country-cottage-escape. Last played December 2020.
- EscapeRoomGames.de. [n.d.]. *Underground Guest Room Escape*. Game [Windows]. EscapeRoomGames.de. https://www.escaperoomgames.de/escape-games-online-underground-guest-room. Last played December 2020.
- Dream Holdings. 2016. *Crimson Room Decade*. Game [Windows]. Degica, Tokyo, Japan. Last played December 2020.
- Pillow Castle. 2020. *Superliminal*. Game [Windows]. Pillow Castle, Seattle, USA. Last played December 2020.

A.1.4 VR Escape Rooms.

- Fireproof Studios. 2020. *The Room VR: A Dark Matter*. Game [Oculus Quest]. Fireproof Studios, Guildford, UK. Last played December 2020.
- Amata K.K. 2019. *Last Labyrinth*. Game [Windows]. Amata K.K., Tokyo, Japan. Last played December 2020.
- AJRPG. 2020. *ANDERSON*. Game [Windows]. AJRPG, California, USA. Last played December 2020.
- Schell Games. 2017. *I expect you to die*. Game [Windows]. Schell Games, Pittsburgh, USA. Last played December 2020.
- Aoga Tech. 2018. *18 Floors*. Game [Windows]. Winking Entertainment Corporation, Shanghai, China. Last played December 2020.
- Top Right Corner. 2017. *Belko VR: An Escape Room Experiment*. Game [Windows]. Top Right Corner, Los Angeles, USA. Last played December 2020.

A.2 Exemplary Puzzle Breakdown in VR Escape Rooms

The Room VR [22]

Chapter 1 – Office: *Correlation/Logic, Mirror/Magnifier/Light, Object Movement/Alignment*
Chapter 2 – Museum Storeroom: *Observation/Searching, Pattern Recognition, Memorization/Reproduction, Mirror/Magnifier/Light, Object Movement/Alignment, Combination*
Chapter 3 – Village Chapel: *Observation/Searching, Correlation/Logic, Pattern Recognition, Memorization/*
Reproduction, Mirror/Magnifier/Light, Knowledge, Object Movement/Alignment,
Combination, Damaging/Destruction
Chapter 4 – Remote Cottage: *Observation/Searching, Correlation/Logic, Pattern Recognition, Memorization/*
Reproduction, Mirror/Magnifier/Light, Object Movement/Alignment,
Combination, Connection
Chapter 5 – Desert Dig Site:
Observation/Searching, Mirror/Magnifier/Light, Object Movement/Alignment

Last Labyrinth [1]

Train Room 1: *Correlation/Logic, Pattern Recognition, Object Movement/Alignment*
Color Panel Room: *Pattern Recognition, Memorization/Reproduction, Object Movement/Alignment*
Projector Room 1: *Pattern Recognition, Memorization/Reproduction, Object Movement/Alignment*
Box Room 1: *Observation/Searching, Pattern Recognition, Object Movement/Alignment*
Phantom Attack: *Observation/Searching, Object Movement/Alignment*
Organ Room: *Pattern Recognition, Memorization/Reproduction, Object Movement/Alignment*
Scale Room: *Correlation/Logic, Calculation/Math, Object Movement/Alignment*
Red Board Room: *Correlation/Logic, Object Movement/Alignment*
Animal Checkers: *Correlation/Logic, Deduction, Object Movement/Alignment*
Train Room 2: *Correlation/Logic, Pattern Recognition, Object Movement/Alignment*
Projector Room 2: *Pattern Recognition, Memorization/Reproduction, Object Movement/Alignment*
Box Room 2: *Observation/Searching, Pattern Recognition, Mirror/Magnifier/Light, Object Movement/Alignment*
Cut The Rope Room: *Correlation/Logic, Disentanglement/Disassembly*
Lava Room: *Observation/Searching, Correlation/Logic, Pattern Recognition, Memorization/Reproduction, Comparison/Distinction, Object Movement/Alignment, Combination*
Light And Mirror Room: *Correlation/Logic, Pattern Recognition, Object Movement/Alignment*
Note: During the entire game, there player is also faced with an emotional challenge: *Overcoming Fear/Disgust*

I Expect You To Die [48]

Friendly Skies: *Observation/Searching, Pattern Recognition, Knowledge, Object Movement/Alignment, Combination, Self-Motion/Agility, Disentanglement/Disassembly, Damaging/Destruction*
Squeaky Clean: *Observation/Searching, Pattern Recognition, Deduction, Object Movement/Alignment, Combination, Disentanglement/Disassembly, Damaging/Destruction*
Deep Dive: *Observation/Searching, Knowledge, Object Movement/Alignment, Combination, Connection, Self-Motion/Agility*
Winter Break: *Observation/Searching, Object Movement/Alignment, Combination, Self-Motion/Agility, Damaging/Destruction*
First Class Vacation: *Observation/Searching, Pattern Recognition, Object Movement/Alignment, Self-Motion/Agility, Damaging/Destruction*

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