Aiming, Pointing, Steering: A Core Task Analysis Framework for Gameplay

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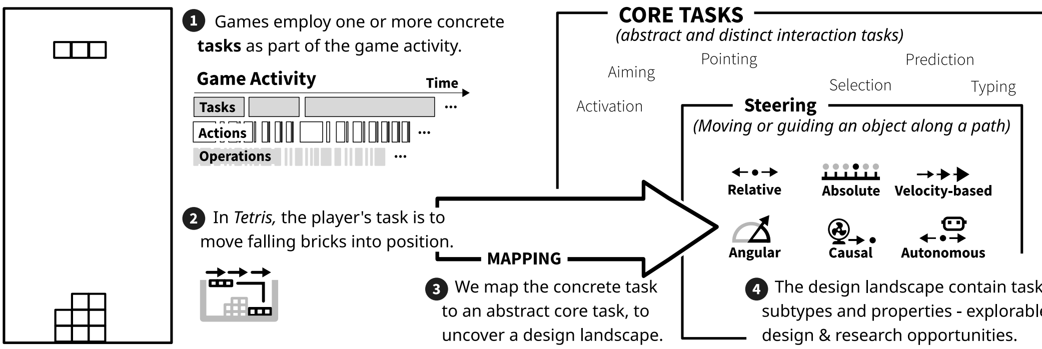

Fig. 1. Gameplay gets mapped to abstract tasks, to uncover design opportunities, here for Tetris [G2]. Our framework builds on core tasks from Flatla et al. [51] and Refai et al.[114].

Underneath their compelling audiovisual surface, games require players to carry out mundane interaction work, such as pointing, typing, or steering. However, many of these underlying building blocks are not defined rigorously, hampering synthesis and analysis. We elaborate on the origin of tasks within human-computer interaction (HCI) and define tasks' relationship to game terminology (game mechanics, goals, and actions). Our framework draws on systemic-structural theory of activity to aid systematic analysis and exploration of game design by mapping gameplay to abstract core tasks. The framework contains four task tools, applicable when 1) uncovering design properties, 2) designing experimental manipulation, 3) creating behavioral measurements, and 4) describing gameplay in literature reviews of game genres and design techniques. We evaluated our framework as a lens to design purposeful games in three case studies within a scientific education. We invite researchers and practitioners to employ the framework as a microscope, to describe and design games rigorously.

CCS Concepts: • **Human-centered computing → HCI theory, concepts and models**; **HCI design and evaluation methods**; *Interaction devices*; **Interaction techniques**.

Additional Key Words and Phrases: Gameplay; Game Design; Mechanics; Core Task; Task analysis; Activity theory; Task Definition; Action; Ontology; Abstraction; Design Landscape; Feedback; Imperative Goals;

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1 Introduction

In a play-centric view of games, *gameplay* consists of players' moment-to-moment interactions within a playful (ludic) experience [49, 65]. Game scholarship often describes gameplay directly through their audiovisual game elements, e.g. Counter-Strike [G40] as a game of combatants walking, running, crouching, and jumping to evade and kill enemies, or Tetris [G2] as landing falling blocks in a field. However, describing gameplay design with no further abstraction from its audiovisual representation makes similar gameplay difficult to trace across publications in game scholarship. Terms like 'walking' and 'landing', and 'driving' all describe similar forms of interaction that fit under a general umbrella-term like *steering* [51, 114]. Thus, interactions in gameplay can be abstracted from their representation and input modalities using overarching umbrella-terms that represent the required underlying *interaction work*. Interaction work refers to the low-level mental and physical tasks players perform that are embodied in the game environment. By scrutinizing gameplay through the lens of task analysis, game designers can design what mental and physical effort players exert repeatedly. This approach was initially explored in an essay by Zimmerman [149] and followed up by work of Flatla et al. and Refai et al. who conceived *core tasks* to examine tasks in gameplay [51, 114]. Core tasks represent "basic motor and perceptual tasks" [114] situated within the cognitive band of human action in Newell's bands of cognition [104]. Refai et al. classified, for instance, moving a player character as a *steering* task and moving a gun as a *pointing* task [114]. Notions like *goals* and *actions* are well-studied in game ontology research, but *tasks* warrant further formal consideration. Task analysis provides an interaction-oriented game design lens that complements existing formal approaches to goals [24], game mechanics [93], game ontologies [40], and semi-formal approaches like game design patterns [15].

Initial game studies have already proved core tasks useful to identify and organize game assistance techniques [114] and design calibration games [51]. Refai et al. used core tasks to identify 27 external game assistance techniques, applicable to games irrespective of their representation [114]. However, while previous work cross-connected game designs with tasks as an organizing term, no work has elaborated on tasks in games or provided rigorous methods to deconstruct gameplay. A knowledge gap concerning the origin, utility and scope of tasks hinders their further use and study in game scholarship. What motivated the task and core task notions? How should scholars dissect steering in Tetris and Counter-Strike across multiple input devices in practice? We address these questions through a three-fold contribution:

(1) A systematic review of the task concept from its origins in the HCI literature to its relation to central game concepts like *game mechanics* [122], *game goals* [24], and concepts from Debus' game ontology [40].
(2) A core task inventory that refines Refai et al. and Flatla et al.'s core task list [51, 114] and maps tasks to a wide range of application areas (Table 1). Our inventory exemplifies their meaning, visually describes them, and provides starting points for future studies .
(3) A set of core task analysis tools (Table 2) along with a demonstration of how to identify task properties, use tasks in game studies, and compare them across games. Three case studies demonstrate the framework's capabilities.

Our framework allows for in-depth modelling and analysis of gameplay interactions across game genres, to help systematic meta-analysis in game scholarship. We elaborate on how to translate between game mechanic inventories [40, 93, 122] and task hierarchies to enable gameplay analysis at higher level, where patterns are more easily observable than in individual actions or mechanics. The consistent abstract terminology we untangle for gameplay interactions becomes crucial when research in games intersects with other fields, as exemplified by the discussions of untangling virtual reality (VR) definitions [42]. Our analytical framework provides a microscope for contexts benefiting from attention to detail, for instance when designing games for novel input modalities (e.g. brain-computer interfaces [16]), experimental protocol games [96], or games for sensitive environments, (e.g. rehabilitation and treatment diagnosis [74]). However, we also highlight task abstraction limitations for scholars who seek to generalize findings or create behavioral measurements (e.g. assessing users' spatial abilities from a steering task). Long-term, we hope that unfolding gameplay with core task analysis into its individual interactions will provide the concise unit of analysis required for experimental manipulations and measurements of player experience [2] to mitigate validity threats [63].

2 Background

In this work, we investigated tasks as descriptive devices to analyze and design moment-to-moment interactions in games. Our study scrutinized tasks as used within HCI and its relationship to games as *specifics* (i.e. conceptual objects) from a ludological viewpoint, which considers games as formal systems [40]. We approached task analysis as a complementary game design method to playtesting as well as other methods like learning hierarchies (popularly referred to as skill chains or core game loops) [36, 70] and game flow [129] (a model of enjoyment in games). The background starts by surveying 1) the origin of tasks as a concept in HCI (Section 2.1), 2) tasks' relationship to game mechanics, goals and gameplay (Section 2.3), and 3) the core task notion as defined in previous game scholarship [51, 114] (Section 2.4). Our survey did not constitute a fully exhaustive literature review, but was scoped to bridge essential concepts to game scholarship.

The literature from the four major outlets of HCI and game scholarship (CHI, DIS, CHI Play, FDG) was surveyed using the keywords *activity theory, core mechanic, gameplay, game taxonomy, literature review* and *task* individually. We skimmed papers if their titles and abstracts suggested the use of any of the above concepts, and applied the same criteria to the references of those papers. After this filtering, we reviewed the resulting 187 publications and identified five publications that contributed to the scientific discourse of the task concept [14, 57, 88, 114, 116]. We grouped the resulting material into three separate topics detailed in Section 2.1- 2.4:

- Section 2.1 reviews tasks' origins, their meaning as interaction work and their known conceptual dimensions within HCI.
- Section 2.2 provides our definition of tasks as a concept for gameplay analysis.
- Section 2.3 relates the meaning of *tasks* to existing game terminology like *mechanics* and *gameplay*, to enable translation from game concepts to task concepts.
- Section 2.4 reviews how game scholarship has used tasks and elaborates on what ontological work is needed to advance the use of the concept.

Based on our literature review, we created a refined list of core tasks and created a framework, which explains the utility and applicability of core tasks to game design and scholarship.

2.1 Origins of Tasks in HCI

The scientific use of concepts like tasks and actions stem from a need to organize human activity and knowledge to understand time, process, function and variability in behavior [44]. The most probable origin of the concepts date back to observations of bricklayers' work methods in the early 1900s [59] with the aim of finding the best way to perform the task to optimize the economical design of work places. The idea of breaking down tasks into their elements to understand human activities in systems became *task analysis* in the human factors and ergonomics field, which emerged as a distinct discipline in the 1950s [127].

Task analysis was first introduced to the sub-field of HCI based on information processing psychology focusing on user-system interaction [84]. Task analysis was used to derive and use objective measurements to compare and evaluate systems based on information processing theory [26]. HCI scholars used predictive models based on GOMS (Goals, Operators, Methods, Selections), such as the Keystroke-Level Model (KLM) to estimate task completion times and other objective criteria to compare and evaluate system designs [26]. These task-analytical approaches enabled hypothetical design and predictions of interaction scenarios down to every keystroke or mouse click. Later in the late 1980s, task analysis became contextualized within activity theory, which considered tasks within human activities and their social context [22]. During this time, scholars defined task hierarchies to deconstruct user activities into tasks and goals in a given context [37, 116].

Unlike HCI's common use of activity theory, our main goal here is not to analyse and understand how people use a given tool in a social context. Instead our goal is to use task analysis to help unfold the game design space of the *interaction work*, which designers want players to carry out. Similar to Wensveen et al.'s framework, which details possibilities for coupling actions with feedback and feedforward [144], we provide designers with game deconstruction tools to model and systematically peruse interaction work possibilities. To this end, we drew on the established and proven task hierarchies from activity theory surveyed by Rind et al. [116]. Moving forward, we build on Cooper's task hierarchy [37] that, according to Rind et al.'s survey, provides the most and explicitly named compositional levels (*goal, activity, task, action, operation*) for analysis [116]. Here, *goals* carry the frame within which users carry out work and set their expectations for the outcomes. *Activity*, *task*, *action* and *operation* represent ever more detailed levels of organization of intermediate steps, which help users reach these goals [37]. The relationships between Cooper's four levels are simple, but the framework does not formally define the levels. To understand them further, we drew on level definitions from the systemic-structural theory of activity (SSTA) [14]. The SSTA is an activity theory tailored to design-oriented research in HCI, which we matched to Cooper's hierarchy, visualized in Fig. 2 and described below:

(1) An **operation** in the SSTA is the smallest atomic act and gets carried out subconsciously by users' motor and mental systems. They are subdivisions of actions, which users carry out consciously [14]. For example, the conscious action of shortly clicking a button can be broken down into three subconscious operations: *depressing*, *holding* and *releasing*.
(2) An **action** is defined in the SSTA as "a discrete element of activity that fulfills an intermediate, conscious goal of an activity" [14]. Actions have temporal dimensions, a starting point, and a result. In the SSTA, motor actions contain motor operations, whereas mental actions contain cognitive and perceptual mental operations with no motor actuation. Examples of actions include pressing a single key on the keyboard (e.g. as part of typing), holding down a mouse button, or moving a mouse in a specific direction.
(3) A **task** comprises a sequence of one or more actions, making up a fragment of an activity in the SSTA [14]. Users may, for example, perform a text editing task in a document, by performing several key and pointing actions.
(4) An **activity** contains one or more tasks, which each represent a potential stage for analysis in the SSTA [14]. For example, the text-editing task above may be one stage in the analysis of the user's document writing activity.
(5) A **goal** directs users in their tasks and activities in the SSTA [14] and are fundamental to understanding user needs in interaction design (the why) [37]. The goal of a text editing task could be to correct misspellings.

Other SSTA concepts like function blocks (a level below operations), activity schemes, or work processes [14] will not be covered in this article, as they extend beyond Cooper's task hierarchy and are not central to our gameplay analysis framework. Instead, we elaborate on the *task* concept itself and what is known about it both within and outside of HCI.

Tasks have received less attention in game scholarship, but more so in other HCI domains like information visualization [18, 88, 116] due to their pivotal utility in design and evaluation [116]. Previous work in information visualization by Rind et al. [116] systematically compared task definitions and usage to derive how tasks conceptually vary within scholarship, described in three dimensions:

(1) **Composition** refers to the number of hierarchical levels into which a task has been broken down [116]. In the example above, the text editing task is broken down into three levels (task, action, operation) and situated within a writing activity. In the SSTA, additional *sub-task* levels can be introduced to analyze complex tasks [14].
(2) **Abstraction** refers to how a task is formulated [116]. Identifying a task as *text editing* is an abstract way to describe interaction work. In contrast, "editing the summary of Mary had a little lamb" is a concrete domain-specific task, which reflects the exact work (*which* text). Task abstraction help research systematically compare artifacts, generate and apply guidelines [103].
(3) **Perspective** refers to whether a task is described from a *how* perspective (how is work carried out) or *why* perspective (the goal/objective of doing the work) [116]. For example, a *text editing task* summarizes the implied work (sequence of actions), while a *correct misspellings task* summarizes the goal (why we are editing text).

To distinguish describing tasks from input or output modalities, we define an additional fourth dimension, **Modality**, relevant for games, which often support multiple unique input- and output devices, like keyboards, joysticks, displays, sound and vibration.

(4) **Modality** refers to whether a task's label reflects the user's interactions with input modalities (*input-level*, e.g. pressing a sequence of buttons on a keyboard) or reflects the outcome perceivable from output modalities (*output-level*, e.g. editing text).

We observe that tasks described by desktop HCI often originate from users' interaction work with input modalities and corresponding visual metaphors in computer interfaces [3, 50, 147]. A *pointing task* could for example involve moving a *pointing device*, like a mouse, which moved a *pointer* (virtual cursor) on the display. Such cases are easy to classify as *pointing* because the motor-mechanical interaction work with the input modality matches the virtual interaction work

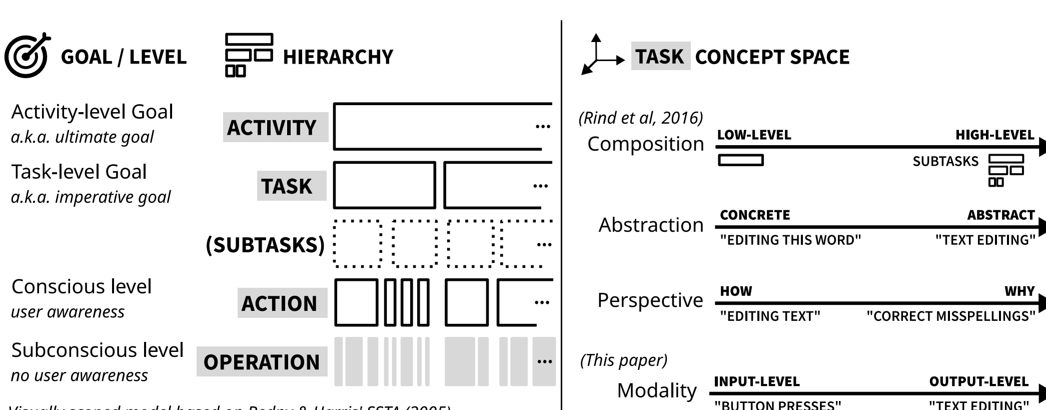


Fig. 2. The task hierarchy by Bedny and Harris, visually scoped to fit this article and annotated with goals and consciousness levels (left). Adaption of Rind et al.'s conceptual space and our additional dimension *modality* annotated with our examples (right).

portrayed by the output modality. However, clarifying the modality is necessary when mismatches occur, for instance, people may use a pointing device to perform a *typing task* with an on-screen keyboard and conversely use a physical keyboard to perform a *pointing task*, where holding down buttons spatially moves the virtual cursor to a target position. In such situations, the analysis goals decide whether input or output-modality analysis is desirable.

For the purpose of deconstructing gameplay, we focus on output-modality analysis of abstract game tasks by how they are perceived by players in the game world. Abstract tasks make it possible to step away from the superficial audiovisual details in games representation and reason about similarities across different games. Output-modality analysis allows for conceptual description of interaction work in gameplay instead of describing a particular play situation with a input device. *Pressing a button* in the physical world becomes *pulling a trigger* in the game world because users match their motor actions to events caused by mechanics within the game world. This intention-action-effect chain creates a sense of agency (the sense of controlling events in the outside world through ones own actions) and action fluency, which has been linked to the flow state [29] and explains the intuitiveness of representational language. Thus, when we refer to a *Steering task* in Tetris [G2] in Fig. 1, we refer to the interaction work observable from Tetris' stereotypical audiovisual gameplay and not to controlling Tetris using a specific input device, like a steering wheel. For convenience and clarification, we created a visual overview in Fig. 2 of all task concepts presented, including relevant elements from Bedny and Harris's task hierarchy [14] and Rind et al.'s task dimensions.

Tasks are frequently used outside of HCI, but follow different conventions. The field of psychology uses tasks to study [30], theorize [120], and measure human cognition [39, 54]. In these fields, tasks are named by their inventor (e.g. *Stroop task* [54]), measurement intention (e.g. *antisaccade task* [54]) or refer to cognitive constructs like memory or attention (e.g. spatial working memory task, attentional blink task [11, 12]). To our knowledge, task names in psychology are not bound by guidelines, but are ad-hoc conventions to compare and synthesize earlier work [116].

2.2 Definitional Statement of Task

The above presentation of the conceptual space highlighted an unclear definition of the task concept and its inconsistent use. Building a design framework for game design requires a definition of the term's meaning and representation in the context of game interactions. Our definition draws on Cooper's four level task hierarchy and matching concepts from Bedny and Harris's SSTA, which delineates each concept's boundary for analysis. As part of accounting for its psychological design, SSTA describes tasks as "some fragment of activity that is organized around a task goal" and as "some situation requiring achievement of a goal under specific conditions" based on Leontyev's theory of human consciousness in genetic psychology [90]. However, such definition is too broad for deconstructing gameplay, and raises new questions (e.g. what is meant by situation and conditions?) instead of providing specific answers (e.g. clearly stating tasks' relationship to goals, activities and actions). While Bedny and Harris focused on creating models of human work in general, we harness their concepts to deconstruct gameplay into models of work players perform. In the context of deconstructing gameplay, we propose the following definition. A task..

(1) ..represents logical divisions of work in an activity.
(2) ..is comprised of one or more actions or subtasks.
(3) ..is organized around a goal (task goal) that directs players.
(4) ..describes work as its reflected in the output-modality (by how the task embeds within the game world).

With this definition, we aim to emphasise tasks as representing work comprised of actions and distinguish the task itself from the its goals. This distinction is important since other contexts may justly consider tasks from goal-based perspectives [116]. For example, modeling tasks as specific work (patterns of actions) is not always useful in daily life activities in which goals can be achieved in countless ways. However, our design framework aims to demonstrate the utility of tasks as work in context of designing game interactions, which are often carefully crafted experiences with narrow solution spaces for which designers have clear visions of how goals should be achieved. Our definition therefore puts emphasis on tasks as representing work, and we will refer to their goals as *task goals*.

2.3 Tasks' Relationship to Game Terminology

Having motivated the relevance of tasks, their hierarchy for HCI and tasks' definition for game analysis, we now review and contrast related notions from the game literature. During gameplay, players perform actions in sequences, which scholars refer to as *interaction loops* [36, 123] and *moment-to-moment activity* [65]. These terms both describe core gameplay, emphasizing:

(1) the repeated sequence of actions games commonly demand players to perform,
(2) the focus on the real-time unfolding of events over their significance for ulterior objectives.

Scholars describe games through *procedures* [55] (what players can do to achieve game goals) or *game mechanics* [122] (the methods available to interact with the game world). These terms focus on games' interaction opportunities rather than players' order of interactions. Historically, scholars made efforts to formalize language and unify the approach of studying games. Bjork and Holopainen introduced *game design patterns* [69] and a structural framework [15] to define and catalogue common phenomena in games, for example the "Invisible Wall" pattern, in which invisible objects blocks the player's path. Efforts have since then identified other patterns to assist game design in domains such as serious games for brain injury [31] or identifying dark patterns in game design [148]. A similar concept to game design patterns is *ludeme* from Koster's *Game Grammar* language, which represents *elements of play* and describe common game phenomena. Game design patterns and ludemes are both practical one-size-fits-all approaches, as opposed to formal game structures which define games beyond their representation.

To create a formal game structure, ontological research in game scholarship seeks to classify and formally define game concepts to understand their relationships and create a stable foundation for analysis [1]. To establish a formal language structure around game elements, Debus reviewed game ontologies to create a meta-ontology named Unifying Game Ontology (UGO) [40], which breaks down games into six formally defined game elements: *time*, *space*, *entities*, *randomness*, *goals* and *mechanics*. The UGO defines formal game elements and demonstrated how they correspond to situations in gameplay. For example, an *activation* mechanic makes it possible to press a button to roll a digital die, while a *navigation* mechanic makes it possible for tokens to move in Ludo. Ontologies like the UGO are working to address the lack of an agreed precise terminology, that consider games beyond their representation layer [24, 93]. The UGO mentions actions and sequences of actions, but focuses on games as formal systems and does neither define nor discuss the action or task concepts needed to describe gameplay from a player-centric viewpoint. To differentiate how task language and game ontology language differ, we need to clarify the relationship of *tasks* with *game mechanics*, and *goals* in the UGO.

2.3.1 *Tasks and Game Mechanics.*

The task language is closely related to loops and game mechanics, of which the latter is more defined, discussed [122] and reviewed [93] in previous work. Some fields, such as computational studies, use 'game mechanics' to refer to logical rules within a game [93], while in HCI studies game mechanics commonly refer to actions afforded by the game's

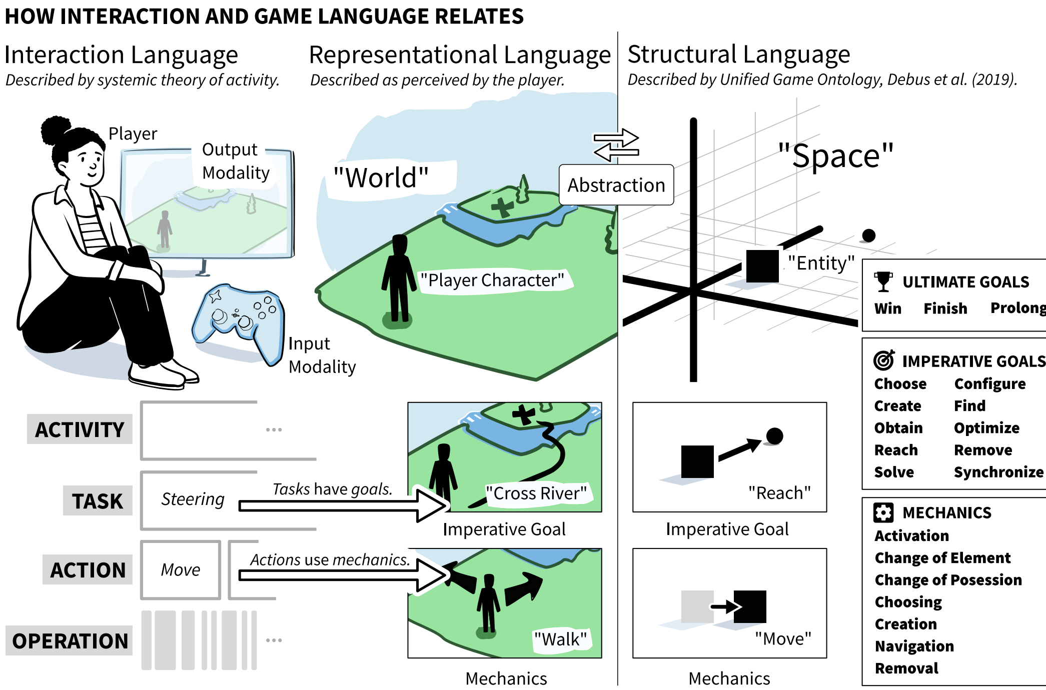


Fig. 3. Players (top left) engage in a game activity using an input (e.g. controller) and receive information from an output (e.g. screen), creating action fluency, which embeds the player in the game world's language (middle), abstracted by the UGO [40] (right).

interface [93]. Sicart formally defined game mechanics as "methods invoked by agents, designed for interaction with the game state" [122]. The definition formally separates game mechanics from game rules and places game mechanics at the same structural level as actions (consciously invoking a mechanic once corresponds to performing an action), visualized in Fig. 3 as 'Actions use Mechanics'. Debus formally defined game mechanic as "the interaction with or alteration of some value in the underlying formal system" [40] and identified seven types of mechanics listed in Fig. 3, right. Hence, players performing a *jump* action, in practice activate a *jump* mechanic which may either be implemented through prescriptive rules or other means like physical laws [40]. Within games, tasks can therefore correspond to the player activating a sequence of mechanics, making it possible to map tasks to mechanics as depicted by the arrow labeled "Actions use mechanics" in Fig. 3. We consider this relationship unidirectional because mapping mechanics back to tasks requires establishing a mental model of user behavior (e.g. analyzing user interactions to establish the likely order users may activate mechanics).

2.3.2 Tasks and Game Goals. Game scholarship also used and discussed *goals*. Game ontology research identified goals on two levels: Ultimate goals (win, finish, prolong) and imperative goals (listed in Fig. 3, right) [24, 40]. Game ontology defined goals using neutral language that avoids domain-specific wording and representational references [24], e.g. the term *removing* represents the formal equivalent of colloquialisms like *killing*, *eating*, and *destroying*. Goals carry similar meaning in games and HCI. They define for which end people act [37]. In essence, the concepts of operation, action, task, and activity describe the *what*, while goals describe the *why*. Thus, goals can be derived at every level of the task hierarchy when modeling a game. As shown in our conceptual model (Fig. 2, left), we consider ultimate goals to represent goals of a game on an activity level and imperative goals to represent goals on a task level. In Fig. 3 we demonstrate how the task and action levels relate to goals and game mechanics, in which a player performs a steering task to reach a destination as the imperative goal, and wins the game as the ultimate goal.

2.3.3 Tasks and Feedback. Like with any interactive medium, *feedback* and *feedforward* are essential elements for designing games' user experience. Game designers spend considerable efforts on multi-modal feedback and feedfoward to achieve the desired game appearances and feels [67]. Game development popularly refers to this process as 'juicing' [68, 121], which consists of adding an abundance of (non-functional) feedback from player actions, to maximize the perception of rewards [68, 121] (e.g. adding visual embellishments). Feedback and feedforward constitute foundational pillars in HCI and interaction design. Vermeulen et al. reviewed and defined feedback and feedforward as [137]:

- **Feedback:** "*Feedback is provided during or after a user's action and informs them about the result of performing their action.*"
- **Feedforward:** "*Feedforward occurs before the user's action and tells users what the result of their action will be.*"

Their definitions articulate feedback and feedforward at the action-level, making them compatible with the systematic deconstruction and analysis of tasks. This paper draws on Vermeulen et al.'s definitions and applies feedback and feedforward to all levels of the task hierarchy (operation, action, task, and activity), which possibly expands Vermeulen's notions.

2.4 The Task Concept in Related Work

Having established the difference between tasks, goals, and mechanics in Section 2.3, we now review how the task concept has so far been used within game scholarship and how we can extend it. Generally, the *task* concept has seen less use in game scholarship, which has more commonly used the *action* concept. In the context of designing game interaction loops (core loops), Schell introduced the *lens of actions* to distinguish between *resultant actions* and *operative actions*. The former describe actions by their relation to goals, while the latter describe them in terms of how they must be performed (the interaction work) [121]. The same action may be considered both as an operative and a resultant action. For example, a resultant action may be to hit targets as fast as possible whereas its corresponding operative action would be moving a cursor to the next target.

So why do we need the concept of *tasks*? In Newell's time scale of human action, actions (in the form of *deliberate acts* and *compound operations*) stretch from 100 milliseconds to the 1 second level (a single reaction might take 2-3 seconds), whereas tasks stretch within 10 seconds, 1 minute and 1 hour level [104]. Thus describing interaction work and its goal on the task-level summarize bigger chunks of interaction where patterns are observable, than individual actions. Designing gameplay based on players' interaction work is not a new idea - Zimmerman explored interaction work as a frame for game design, by designing *LOOP*, a game played through gesture interactions [149]:

> "Rather than asking what the game is about, ask what the player is actually doing from moment to moment as they play. Virtually all games have a *core mechanic*, an action or set of actions that players will repeat over and over as they move through the designed system of a game."

A similar concept to core mechanics was later explored by other authors as *core tasks* [51, 114] or *human computational tasks* [57] to create widely applicable design frameworks for game assistance [114], calibration [51] and serious games [57]. Refai et al. defined core tasks as "The basic motor and perceptual tasks that games require in order to interact with game mechanics." [114]

based on Flatla et al.'s initial definition [51]. Core tasks resemble Rind et al.'s abstract tasks [116] (explained in Section 2.1) and Newell's time scale of human tasks. Refai et al.'s core tasks seek to be *unit tasks* (e.g. non-divisible tasks) and cover lower-level mental and physical skills from the 10ms-1s cognitive band in Newell's bands of cognition [104]. Other scholars did not differentiate abstract tasks in terms of higher or lower level rationalization [11, 12, 57]. Galli proposed a development process for serious games that defined a human computational task as a "unit of work" assigned to a user of a "human computation system" [57], but the psychological foundation does not allow for a clear delineation for their tasks and use of the task concept. Refai et al. used a grounded theory approach to identify core tasks in 54 games from distinct game genres and refined Flatla et al.'s initial task list to 10 core tasks [51]. Refai et al.'s framework demonstrated the usefulness of core tasks as a lens [114]:

> "By organizing video game assistance at a fundamental level, through the lens of core tasks, we assist in the portability and understanding of these techniques across games, regardless of genre or platform."

We searched for "core task" within the 400 publications citing Flatla et al. [51] and Refai et al. [114], which yielded ten papers. Four of these used the *core task* concept [13, 20, 27, 130], but with undisclosed definitions and different semantics from Flatla et al. For example, Budde et al. identified four core tasks within gameful environmental sensing with mobile devices *coverage, touch POI, rendezvous*, and *(correct) sensing* [19, 20]. But judging by Budde's task descriptions, their core tasks stretch beyond Flatla et al.'s scope of core tasks, which focus on basic motor and perceptual unit tasks [51]. Two of ten papers refer to Flatla et al.'s core task definitions without associated use [34, 128]. We thus conclude that core tasks have currently been applied inconsistently and that the concept awaits to be built upon in game scholarship. Refai et al. identified and defined 10 core tasks in commercial game titles, but methodological elaboration is needed to facilitate rigorous core task analysis of games: what specific mental or motor actions would players perform during a core task named *reaction time*? Does a *visual search* task imply any form of motor interaction or is it purely mental actions? Game mediums commonly imply some form of motor action unless controlled by physiological interfaces, but previous work did not make clear distinction between motor and mental core tasks. To make core tasks viable for game task analysis, each core task needs comprehensive refinement and scholars need analytical tools and rigorous methods to aid the systematic modeling and deconstruction of user interactions in gameplay.

3 Refined List of Core Game Tasks

Refai et al.'s core task concept [114] proved broadly compatible with Cooper's task hierarchy [37] and task concepts in the SSTA [14]. We therefore adopted the core task concept and refined Refai et al.'s core task list further in Table 1. We designed our core task list to cover the most commonly observed gameplay interactions and established formal criteria for task inclusion, based on the task concept space introduced on the right side of Fig. 2, Section 2.1:

(1) **Abstraction criterion**: Tasks should be described in abstract phrases to enable wide comparison to other tasks.
(2) **Perspective criterion**: Tasks should be described by interaction work in the *how-perspective* and exclude considerations of goal to keep goal and task distinct concepts.
(3) **Modality criterion**: Tasks should be described from the output modality, focusing on virtual interactions as represented in the game environment (instead of from the input modality, where tasks become platform-specific).

Following these criteria, we filtered and modified Refai et al.'s list of core tasks [114]. The perspective criterion omitted the *reaction time task* [114] because we consider reaction time an imperative goal of any task (e.g. a reaction time task is any task in which the goal is *optimization* [40]). We excluded the *body controls task* [114] because it represented an input modality instead of a distinct type of abstract interaction work (e.g. players could use body controls to solve pointing tasks), thus not passing our modality criterion. We removed mentions of modality from *visual search task* (search task), and shortened *signal detection task* (detection task) and *signal discrimination* (discrimination task) for clarity.

We created new core tasks from tasks we identified in the surveyed literature [12, 57, 91, 147]. We directly imported *typing tasks* [91], found in e.g. text adventure games like Zork [G35] and *drawing tasks* [147], which are found in games involving creation, like Line Rider [G43]. In other cases, tasks were not directly transferable from surveyed literature, due to irrelevancy, wrong abstraction level, or overlap to existing core tasks. We introduced the *configuration task* to cover *ordering* and *clustering* tasks described by Galli [57]. We included a *selection task* to match notions of making choices, like in visual novels such as Hatoful Boyfriend [G19], and a *prediction task* to cover tasks featuring sensorimotor synchronization, like in e.g. rhythm-based games such as Osu! [G14]. To conform to our definitions of tasks and actions as representing users' interaction work, we categorized tasks by whether they imply any motor action. Core tasks denoted with 'mental' in Table 1, in practice must be followed by a motor task in which the player takes action (e.g. performing visual *search*, so that the player knows where to *point*). Mental core tasks cannot be considered interaction work, but we find them reasonable to list since *work* corresponds more to cognitive demand in some game genres. For example, quiz game designers might reasonably spend more time designing the quiz questions (cognitive demand) than how they are answered (the interaction work).

This article provides a brief introduction to each core task listed in Table 1. Appendix A elaborates on the development of each task further, describing task sub-concepts, criteria, and game examples. To demonstrate tasks' meaning, we provide examples of how each core task has been studied in games, HCI and psychology literature, as a guide (summarized in the *Application Areas* column in Table 1). However, we encourage further in-depth definition of tasks in game scholarship, akin to Zabramski and Stuerzlinger's detailed analysis of drawing tasks for scientific experimentation in HCI [147]. They defined drawing tasks in HCI using their W^6 framework (where, when, what who, why, with what) and established drawing tasks by identifying the challenges of modeling drawing with pointing and steering models [3, 50]. Definition and analysis efforts of pointing, steering, and drawing tasks in HCI focused mostly on predictive modeling for scientific experimentation, whereas the broader definitions in our core task list are tailored to analyze and cross-connect gameplay. In the next sections *Core Task Analysis Framework* and *Three Case Studies*), we demonstrate how to analyze and design gameplay with core tasks from Table 1.

Core Task Definition:

"The basic motor and perceptual tasks that games require in order to interact with game mechanics." [114]

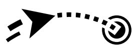
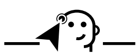
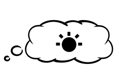
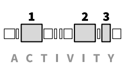
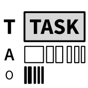
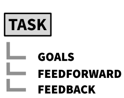
Task	Label	Definition	Application Areas
	Aiming* *motor*	"Accurately pointing at a target (possibly using a device) and/or predicting the collision between two objects, without outcome signification." [114] (rev.)	Aiming assistance [64, 81] (games), sensorimotor coordination for ball throwing [38] (psych.).
	Pointing* *motor*	"Accurately pointing at an accessible target with feedback about current pointing position." [114] (rev.)	Input device throughput [99, 110] (games), interface pointing assistance for older adults [77] (HCI), pointing gesture [66] (linguistics).
	Steering* *motor*	"Moving or guiding an object along a trajectory." [114] (rev.)	Semi-autonomous steering [87], input device preferences for racing games [117, 135] (games), tunnel steering law [3] (HCI).
	Drawing *motor*	"Marking or laying out content in an area." (inspired by [147])	Sketch-based game to motivate practice [145] (games), drawing task framework [147], device evaluation for tracing [146] (HCI).
	Activation *motor*	"Initiating another mechanical system, function, or item." [40] (rev.)	Reaction time task dexterity [82] (games), mid-air, tactile, and touch button performance [106] (HCI).
	Typing *motor*	"Performing a sequence of input activations to enter data."	Input sequence mining [139] (game telemetry), automated stress detection when typing under time pressure [91], Input rate [43] (HCI).
	Selection *mental*	Making a choice. [101] (dictionary, rev.).	Multiple choice task dexterity (reaction time) [82] (games), selection prediction and deductive reasoning [126] (psych.).
	Configuration *mental*	"Arranging items based on a particular criteria (e.g. similarity)."	Colocated digital jigsaw puzzle design [136] (games), Social convention effects on item ordering [60], packing problems [94] (psych.).
	Memory* *mental*	"Memorizing and recalling sets of items, sequences, or mappings." [114] (rev.)	Word recall as a mobile game [46] (games), Free recall [53], serial recall [140] (psych.).
	Spatial Memory* *mental*	"Remembering the location of items in a space without persistent cues." [114] (rev.)	Enhance learners' spatial orientation and memory to solve a treasure hunt steering task [92, 134] (games), spatial ability testing [107] (psych.)
	Detection* *mental*	"Consciously perceiving a stimulus, such as sound, light, or vibration."[114] (rev.)	Effects of aging on a reaction time activation task [112] (psych.).
	Discrimination* *mental*	"Determining that there is a difference between two stimuli (e.g., determining that two colors or two sounds are different)." [114]	Efficiency of visual discrimination in noise patterns [21], inhibition of return effect (psych.) [108].
	Prediction *mental*	"Anticipating an event's occurrence to act on or synchronize with it."	Synchronized movement between players [98], auditory timing effects on exergame performance & sense [5] (games), finger tapping sensorimotor synchronization [115] (psych.).
	Search* *mental*	"Finding a target in a field of distractors; includes pattern recognition (determining the presence of a pattern amongst a field of distractors)." [114] (rev.)	Match-three puzzle games to test visual search ability [33] (games), auditory search [48], visual search strategies [132] (psych.).

Table 1. *Core tasks* represents distinct abstract task categories for gameplay analysis. We created a refined provisional list, based on Refai et al. al [114]'s tasks, which we marked with asterix (*). Appendix A further details each core task with proposed sub-concepts, criteria, applications, and game examples.

4 Core Task Analysis Framework

To support scholars and practitioners in deconstructing gameplay into core tasks, we created the framework in Table 2, consisting of *tools* (top section) and *application areas* (bottom section). Our core task toolkit covers four analytical tools: 1) *identification*, 2) *sequencing*, 3) *composition*, and 4) *examination*. They can be applied to each scientific application area listed in the bottom of Table 2, although their relevance may vary between topics. In the following subsections, we demonstrate how to apply the most relevant tools within each application area.

Core Task Analysis Tools		Guiding Questions
	*Identification* of tasks within the game activity.	What interaction work does the gameplay demand? What are the core task's properties?
	*Sequencing* of core tasks within the game activity.	When does the core task take place? How frequently?
	*Composition* of core tasks to sub-tasks, actions and operations.	Which sub-levels does the task contain? How are task sub-levels ordered/repeated?
	*Examination* of games' core tasks via principles of interaction design.	What is the player's goal of doing this task? Which levels of feedback and feedforward exists within the task?

↓

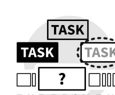
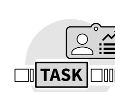
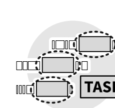
Scientific Application Areas		
Design Properties (Section 4.1) Applying core task tools to find design properties of a task.	How can the task be tweaked and adjusted? What are the implications for underlying actions in the task?	
Game Experiments (Section 4.2) Applying core task tools to tasks in experimental protocol games.	On which level (action/task/activity) are manipulations made and effects measured? What does manipulation on other levels imply?	
Behavioral Measures (Section 4.3) Applying core task tools to develop behavioral measurements.	What construct is implicitly measured? What evidence underlies the task design? Which other measures triangulates results?	
Game Taxonomies (Section 4.4) Applying core task tools to reviews of game genres and techniques.	Which tasks characterize the reviewed topic? How does the tasks vary and why? What does variation mean for the topic?	

Table 2. Our core task framework is an inventory of tools (top) and application areas (bottom) for the core task concept in games literature. Descriptions (left) are accompanied by guiding questions (right) to provide starting points.

4.1 Task Analysis for: Design Properties

Description: The framework's first application area, *design properties*, concerns how core tasks can be tweaked and adjusted. The core tasks list in Table 1 represent generalized basic perceptual or cognitive unit tasks [114], but each task can be implemented differently in practice with different optimal sequences of action. A pointing task in Counter-Strike [G40] imply different optimal sequences of action than a pointing task in Portal [G41], because the games use pointing for different purposes (removing opponents, reaching the exit). Scholars can help uncover each core task's design landscape [133] of task *properties* and document properties' known implications for players' experience. We define *task properties* as the environmental qualities of gameplay which affect players' perception of the task or how they perform it, without alteration to the task goal or nature (akin to *tuning variables* in the design landscape [133]).
Example: To demonstrate how to apply the core task tools in this context, we reviewed a subset of the *pointing task* family, in the literature named *target-to-target pointing tasks*, also called sequential target pointing tasks [79]. In target-to-target pointing tasks, players must aim and hit a target, as fast as possible, as precisely as possible, or within a time duration (an example is illustrated in the top left of Fig. 4). The *target-to-target* prefix indicates that targets appears after another (as opposed to showing all targets at once). We used the tool *Identification* from Table 2 to find the properties of target-to-target pointing tasks, listed in Table 3.

Target-to-Target Pointing Task Properties

Target Quantity: The number of targets in a single session (e.g. level). Increases task duration and can challenge players' ability to sustain attention [80].

Target Appearance Quantity: Targets either appear as *single-target* (only one valid stimulus appears at a time) [62, 79, 124], or *multi-target* (multiple valid targets appear in parallel) [85]. Multi-targets allow for experiential variation because quantities can change and players can choose which order to select them.

Target Location: Targets can be placed in *random target location order* or a *predetermined target location order* [79, 85, 124]. Predetermined location orders can be used to ensure challenging spatial layouts, allowing for consistent movement segment analysis but locations may become predictable to players.

Target Lifetime: Targets may either appear for a *limited lifetime* [85, 124] or remain until having been interacted with (*infinite lifetime*) [79]. The time between the appearance of consecutive targets is called the *target-to-target interval* (TTI) in psychophysiology, [62, 79].

Distractors: The implementation of distractors [85] increases the task difficulty (players must identify the correct target before they can aim for it). If distractors have distinct visual features players perform feature search [132] and if distractors look alike players perform conjunction search (serial search).

Target Movement: Targets may be in movement or static. Static targets may be harder to detect, whereas moving targets attract attention but are difficult to hit and increase chances of overshooting. Moving targets are also affected by latency [95].

Target Size: The size of the target, including *visual size* (visual representation of size) and *hitbox* [89]. Larger sizes lower the difficulty of pointing to the target, according to Fitts's law [50], which predicts performance and has been studied in context of games (e.g. in [8, 17, 110]). Fitts's law is not always applicable, for example when the hitbox and visual size don't correspond, which is often the case in games to compensate for lag and efficient hit calculation [89].

Target Distance: How much distance there is between targets. Higher distances increase traversal time and pointing difficulty according to Fitts's law [50].

Table 3. To exemplify how to identify task properties, we compared the design of target-to-target pointing tasks within HCI literature. The list describes each property, the way the property can vary and the implied consequences for game design.

After uncovering task properties, the *sequencing* tool enables analysis of how properties change over time in each task occurrence (e.g. when players advance to “the next level”). Designers can create variation or increase challenge by changing task properties as tasks repeat by, for example, increasing *target distance*. In addition to adjusting task properties, designers can decompose the task (*composition* tool) and examine feedback and feedforward levels provided by a modality (*examination* tool). We decomposed the pointing task in a Whack-A-Mole VR game [73] into three levels shown in Fig. 4, lower left. To decompose Whack-A-Mole, we first analyzed each conscious atomic act made possible by the game’s mechanics, which became *move* and *activate* actions. A sub-task level *target selection*, was required to group the *move* and *activate* actions together. After decomposition, we *examined* visual feedback opportunities across operation, action, sub-task, task, and activity levels shown in Fig. 4, right. Feedback on the operation-level consists of the subconscious mapping between the movements of the player controller and the displayed cursor in real-time. Whilst performing move actions, the player subconsciously calibrates their visuomotor system to gain control and ownership over the cursor. On the action-level, the player performs either a *move* by moving the controller or an *activation* to attempt a selection by pressing the trigger button. The cursor’s arrival at the destination marks the completion of the move, on which the player decides on subsequent moves (Fig. 4 *Move Feedback*). When attempting selection through activation, the cursor lights up as visual confirmation (Fig. 4 *Activation Feedback*). The action sequence of 1) moving to a correct mole, and 2) taking a shot at it, provides successful binary sub-task feedback (Fig. 4 *Selection Success/Failure*). In addition, the sub-task feedback can encode performance indication such as selection speed or trajectory straightness (Fig. 4 *Selection Intensity*). Feedback on the task-level indicates *task progression* to players and can recognize continuously good performance (Fig. 4 *Subtask Streaks*). At the topmost activity-level, feedback provides closure (Fig. 4 *Game Completion*) and summarizes the player’s performance in solving the tasks (Fig. 4 *Game Score*). As demonstrated by this description, the guiding principle for examining feedback in task models is to consider information at each level in isolation from others - the start and end points of each individual operation, action, task, and activity. Supplementary Material 2 provides two step-by-step guides to show the exact steps in such analysis.

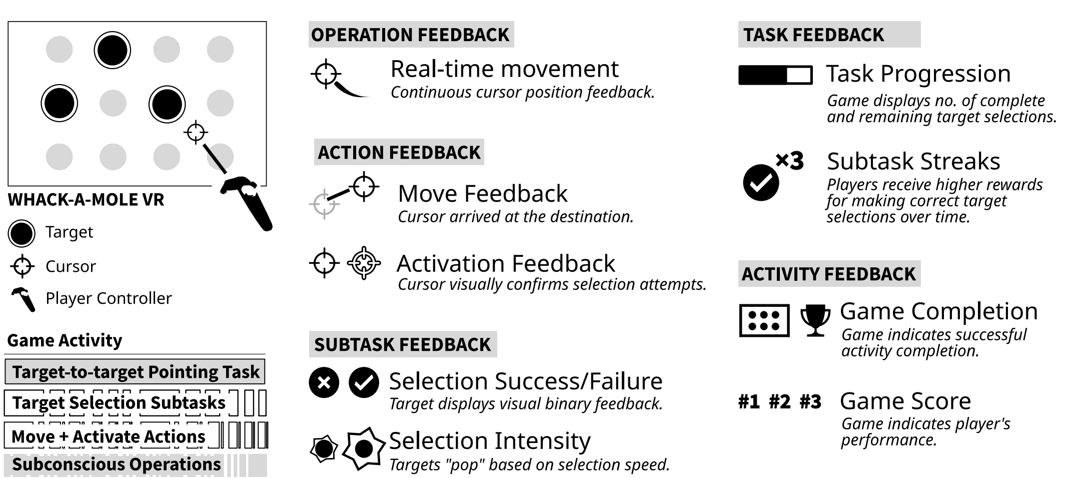


Fig. 4. VR whack-a-mole game by Hougaard et al. [73] (top left) in which a player controls a cursor to hit targets. The game’s core task was *identified* and *decomposed* (lower left). Then we *examined* visual feedback in each task hierarchy and found 9 types (right).

4.2 Task Analysis for: Game Experiments

Description: Scientific experimentation can use core task tools to determine what levels in the task hierarchy to manipulate and measure in games. Scientific experimentation cover many topics: 1) gameplay environment (e.g. co-operative play, co-located play, competitive play) [102, 142], 2) techniques which alter players' experience of gameplay (e.g. game assistance, rewards, difficulty adjustment) [9, 41, 61, 114], and 3) affective state during gameplay (e.g. frustration, motivation, attention) [75, 78, 109]. *Experimental protocol games* refer to games which are used as experimental stimulus to study human behavioral patterns and scientific experimentation [96]. Scholars decide how the studied concept is implemented and/or measured within a chosen type of gameplay for their experimental design. The core task framework supports such decision-making in scientific experimentation by enabling researchers to unfold what measurement and manipulation opportunities exist through task *identification* and *composition*.

Example: To demonstrate, we reviewed a study on dynamic difficulty adjustment (DDA) by Ang and Mitchell [9]. The authors compared player-oriented difficulty adjustments (players press a button to increase/decrease difficulty), system-oriented difficulty adjustments (the system determines difficulty) and a control condition (no adjustment) in a Tetris-like game, exemplified in Fig. 5, left. They adjusted difficulty by altering the Tetris blocks' falling speed. Using core task *identification*, we classified Tetris' gameplay as a *steering* task: In Tetris, players perform sequences of right- and left-movements to accomplish the task of steering each block into the designated spot of their choice. Using core task *composition*, we then uncovered the DDA concept across operation-, action-, task- and activity-levels of Tetris, shown in Fig. 5, right, to study DDA on each level. On the operation-level, adjusting difficulty could, for instance, imply manipulation of players' ability to perceive the game state or make decisions (perception difficulty). On the action-level, adjusting difficulty implies a hindrance to successfully perform each individual move action (moving difficulty). Task-level difficulty adjustments manipulate the difficulty of the sequence of movements to make a block fall into the right place (steering difficulty). Finally, activity-level difficulty adjustments make finishing the game activity is harder, for instance, by introducing more tasks or requiring a higher game score (completion difficulty). Ang and Mitchell's experiment [9] altered the blocks' falling speed, which manipulated the task-level difficulty (steering difficulty), which indirectly affected players' ability to accomplish the activity (completion difficulty). These findings clarify the task-level DDA as the scope of their study and highlights activity-, action-, and operation-level DDA as unexplored potential research avenues.

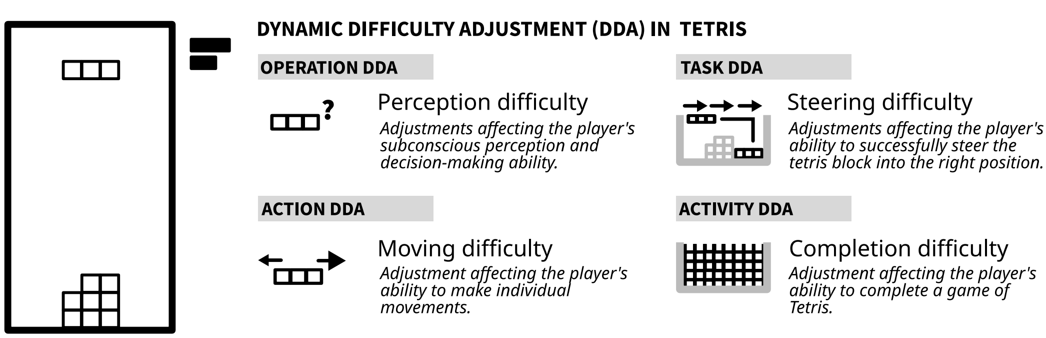


Fig. 5. To exemplify core task *examination* in experimental protocol games, we examined the core task and the task hierarchy in a game of Tetris (left) studied by Ang and Mitchell [9]. Our examination revealed four levels of dynamic difficulty adjustment possibilities (right).

4.3 Task Analysis for: Behavioral Measures

Description: Here we consider core tasks' utility to develop behavioral measurements, like, for instance, comparing how *steering* tasks across a range of games improve users' spatial navigation abilities. Methodological examination of game research revealed improper stimulus control [47], imprecise hypothesis testing [138] and validity threats from experiential complexity [63], which all impede clean experimental manipulation and threatens reproducibility in games research. But could standardized task-based measurements created with our core task framework, address validity and reliability threats in games research? Task and self-report measurements are frequently used and criticized in psychology scholarship. Standardized task-measurements and questionnaires often correlate weakly despite measuring the same presumed construct [39, 54, 143]. Weak correlation could be due to poor reliability of behavioral measures, being designed to provide useful within-subject differences but high error variance [39]. Yet self-report also has subject validity and reliability issues stemming from bias including acquiescence bias [83], demand characteristics bias [105], recall bias and social desirability bias [7]. The jingle-jangle fallacy may also be at play [39] - task-based measurements and self-reported measurements which are believed to measure the same concept might tap different constructs. Studies therefore recommend using both measurement types [54]. Task-based measures may yield insight into a measurement while creating a too well-defined situation with clear goals, optimal conditions and in a short time-span [54]. Self-report measurements yield insight into a measurement while creating a situation of increased self-awareness of cognition, emotion and behavior [54]. Scholars must also be aware of potential transferability limitations between abstract tasks. For example, it may be tempting to expect similar results between two game studies, if each study use games based on the same task. A study by Baniqued et al., attempted to map commercial games into categories, in terms of their cognitive demand, but two situations with similar cognitive demand did not yield similar performance [11, 12].

Example: We visualized a game measurement scenario in Fig. 6, where a steering task in an adventure game with and without landmarks is used to quantify users' spatial abilities (Fig. 6, left). In the scenario, task performance indicators from captured game data are triangulated by measures from self-reported questionnaire measurements and observations (Fig. 6, middle). The indicators could conclude on users' spatial abilities (Fig. 6, right), but 1) results might not generalize to other implementations, 2) there may be test-retest task reliability issues, and 3) users might behave differently because the task is a well-defined situation not akin to other contexts. In summary, if game scholars wish to examine player experience in a given task, considerable care must be taken if the authors wish to articulate generalization towards other implementations. Results from tasks as behavioral measurements or psychometric constructs ought to be triangulated with other measures such as self-reported data or qualitative methods like interviews.

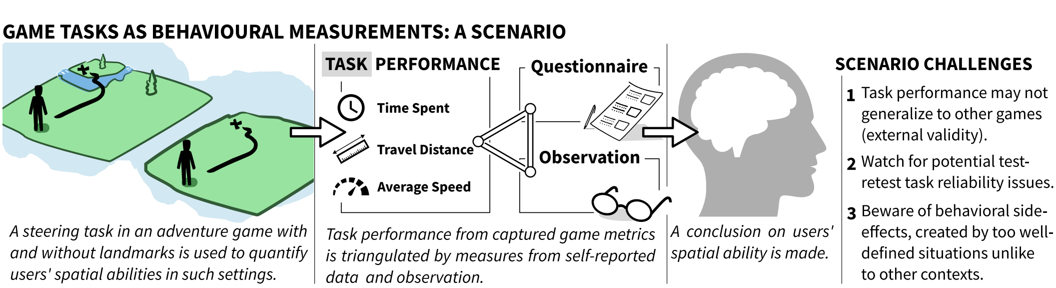


Fig. 6. A hypothetical scenario, which uses steering tasks as a behavioral measurement (left). Three challenges are presented (right).

4.4 Task Analysis for: Game Taxonomies

Description: In game scholarship, literature reviews establish clearly bounded definitions of game genres and concepts to highlight design and study opportunities. Here, the core task framework can be used to organize and review previous scientific work, for example, to *identify* what tasks were used to study a game concept, or what kind of tasks characterize a game genre and its structure.
Example: To demonstrate, we examined applications of the task concept in context of an idle games literature review by Alharthi et al. [6]. The authors identified the characteristics of idle games in terms of game features, play, mechanics, reward and user interface. In the review, the authors applied grounded theory and open coding to 54 games, which they described via a game description, game mechanics, rewards, interface, interactivity level, progress rate and an overview. They identified an interaction spectrum and described the conceptual relationship between incremental games and idle games. We used task *identification* and *sequencing* from the core task framework to examine three game sub-types *clicker*, *minimalist* and *zero-player* from Alharthi et al.'s idle game interaction spectrum. Fig. 7, left describes the three tasks (*rapid activation*, *selection*, and *idle*) that we identified and matched with Cardona-Rivera et al.'s imperative goals [24]. The three game sub-types are characterized by the general composition and sequence of tasks. Players obtain valuables by performing rapid activation tasks, the predominant interaction during clicker games and at the beginning of minimalist games. In minimalist games, once players accumulate enough valuables through rapid activation, they *select* items in exchange for their valuables. The selected items eventually let players idle (leave the game to progress on its own). In zero-player games, idling happens when the game begins or after making initial selections (setup phase). Fig. 7 (right) depicts how such sequences can be visualized based on the authors' provided textual description of the three game sub-types [6]. The intention with visualizing genre sequences is 1) to enable comparison between stereotypical genre structures and structures in specific games and 2) to facilitate a playground for structural invention. Designers can sequence *rapid activation*, *selection* and *idle* tasks to create new forms of idle gameplay. Additionally, the boundaries of what constitutes idle games can be challenged by combining typical idle game tasks with tasks unseen in the genre. Alharthi et al.'s literature review exemplified how to use a game genre as a synthesis basis to understand the genre's scope, its cultural phenomenon, and history. However, to categorize interaction work in games, game genres have less rigour because 1) they represent other concepts than interaction work alone (e.g. 'Puzzle Games'), and 2) often describe games from their representation (e.g. 'First Person Shooter'). Conversely, core tasks offer a representation-agnostic approach to review interaction work across different game designs - a method we imagine could scaffold *design rigor*, which scholars have voiced a need for within HCI literature reviews [118].

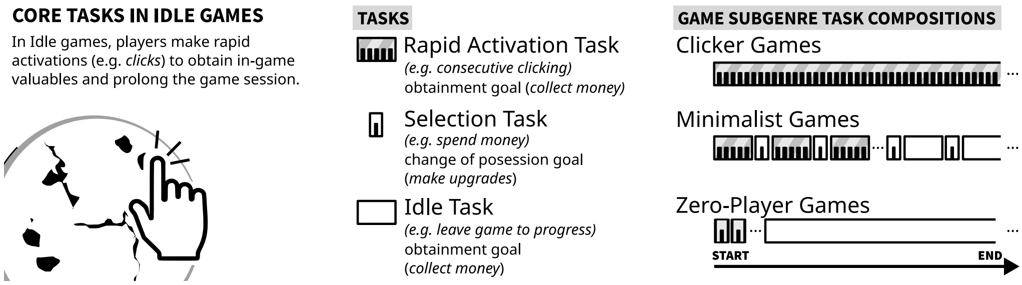


Fig. 7. We studied Alharthi et al. [6]'s literature review of idle games and extended it with core task *identification*. We identified three tasks (middle) and differentiated three sub-genres of idle games by their task sequence and composition (right).

5 Three Case Studies

We undertook three case studies to: 1) understand our framework's practical merits as a game design lens and 2) shed light on its rigor, conceptual challenges, and limitations. Instead of merely designing games for entertainment purposes, the case studies created experimental protocol games [96] which also served as a designer's petri dish to research a game design tension or the impact of a game design decision on users' game experience.

Three master of science student groups (11 students total) volunteered to conduct 5-months regular semester project work under our supervision. The project followed principles of problem-based learning (PBL) and research-based teaching, and did not require ethical approval. Prior to project start, the students received an early revision of this paper without supplementary material which included 1) The task hierarchy and game language overview (Fig. 2 and 3), 2) an early text-only version of the core task list (Table 1), and 3) an early revision of the core task tools in Table 2 without pictures. The groups received a hands-on introduction to the framework through a one hour lecture at the projects' beginning. Each group chose a task to explore from Table 1 as a basis for producing a game. The projects focused on *pointing*, *steering* and *selection* and were instructed to identify games, which related to their chosen core task. Three weeks later, we arranged a design workshop, shown in Fig. 8, left. The students had to organize their identified games (in total 46, see Supplementary Material 1) on a task map by their similarities and differences, to identify task sub-types and task properties. The students studied a self-chosen scientific research question and implemented three game prototypes, which we obtained permission to show in Fig. 8 and summarize.

5.0.1 Thrust to Shoot (Pointing). When games employ pointing tasks, pointing rarely relies on depth movement. Shooting games often employ pointing devices, such as guns, where shooting actions are activated by a trigger (e.g. a button press). *Thrust to Shoot* is a VR pointing exergame, which explored how shooting actions triggered through *thrusting* motions could introduce higher player exertion in shooting games. The students developed motion-based thrusting (where arm movement determines the shooting direction) and wrist-based thrusting (where controller angle determines

Fig. 8. The core task workshop (left), where students jointly reviewed core tasks in commercial games and organized games on A1-size "task maps" (left). The students then designed and implemented three own game prototypes: Thrust to Shoot (middle left), Steering Clear (middle right) and Selection Manipulation (right).

the shooting direction). They developed the target-to-target pointing task in a VR environment, where red humanoid targets appeared to the left and right of the player who was embodied in a blue humanoid body. Their study aimed to compare wrist- and motion-based thrusting in terms of self-reported player agency, amount of upper limb movement measured from controller movement and player performance measured from players' shot accuracy.

5.0.2 Steering Clear (Steering). In upper-limb rehabilitation contexts, patients train by repeating motions, which can lead to boredom and fatigue. Virtual Reality enables motion tracking, which lets games respond to player motions. In this project, the students explored how wrist rotation could control a lateral steering task (steering an entity from side to side), which increased in difficulty over time. They designed an obstacle course in which the player might avoid collision between the obstacles (barrels) and a non-embodied character. They developed three steering methods: 1) letting rotational movement drive the character's lateral movement speed, 2) mapping negative and positive angles directly to different lateral standing positions, and 3) letting rotational movement determine the position of the obstacle course environment around the character, while the character stood still. They studied exertion (how much hand movement was needed), performance (e.g. number of obstacle collisions) and self-reported perceived steering difficulty.

5.0.3 Selection Manipulation (Selection). The project explored how games can affect player decisions in selection tasks through feedforward. The student group's starting point was to explore selection task sub-types, where the group identified *deduction-based selection* (making a selection by logic and reasoning) and *recall-based selection* (making a selection by information kept in memory). They examined properties of these selection sub-types, through the design and implementation of a card game, in which players play against a computer opponent. Additionally, the card game involved a computer-controlled spy ally who instructed players which cards to play against the computer opponent in upcoming rounds ("In round 4, play the 4th choice") and rewarded players if they were able to recall the right cards. The students' study aimed to inform to what extent highlighting cards could assist players with recalling their card, without making the final choice on their behalf. The project aimed to record players' selection time, recall and deduction rate, and (in)correct selections made within the highlighted zone.

5.1 Reflections on Case Studies

The case studies demonstrated the task framework's merits as a design lens across game genres (shooter, endless runner, card game), modalities (gesture-based, VR controller rotation, mouse), and core tasks (pointing, steering, selection). The students' successfully applied core tasks to shed light on interaction work in gameplay, studying either *input-task* relationships (e.g. different transfer functions) or *task-environment* relationships (e.g. the impact of environmental feedback on users' behavior). We conducted semi-structured interviews with group representatives two weeks after the projects' end. Groups internally decided on a representative who participated in the interview on a voluntary basis without compensation. After signing a consent form, the representative was interviewed by a facilitator (primary author of the design framework) for 20-30 minutes, following an interview guide. The facilitator asked students about their experience across three topics: 1) The students' group project, 2) the kick-off workshop and 3) the framework. To facilitate responses the facilitator showed relevant images of the student's group project, the workshop and the framework. We thematically analyzed audio transcriptions of interviews with a representative from each group using open coding analysis [131]. Responses were categorized into themes inductively without external review. We compared responses with our own noted observations from the workshop and supervision meetings:

(1) *Scoping:* Early in the process, the core task list in Table 1 became a focusing device, and we observed that it encouraged students to identify a narrow game design topic early in their process. This was partially facilitated by the design workshop in which students showcased how they had classified commercial game titles within their chosen topic and received oral feedback from peers and us. A student commented on how it affected their game design process: "We ended up making our own [visualization] of the different tasks possible in video games [..]."
(2) *Objectiveness:* The core tasks gave students an informal language that kept their design deliberations to formal language (e.g. is this more *pointing-like* or *aiming-like*?). As one student commented on the core tasks list in Table 1: "it was a way to dissect games and obtain something more objective out of it." He explained that they would previously describe games by their similarity to other games (e.g. *is this Dark Souls-like*?), however this would often dilute thematic aspects with gameplay design in game design discussions.
(3) *Dissection:* Students described that the simplified task hierarchy adopted from the SSTA [14] in Fig. 2 helped them break down gameplay "into something more *bite-sized*" as worded by one student. A student commented: "We could just look at any game, try to break it down according to the methodology you showed us and see what we can tell from that." The task deconstruction process worked well in tandem with creating game design landscapes [133], where students positioned games by finding gameplay similarities through task identification.
(4) *Method Intuition:* When asked about their use of the tools in Table 2 to guide their design process, students described relying most on examples from Section 4.1-4.4 and the oral lecture. They chose not to apply the framework rigorously to every case and consulted the framework mainly in case of doubt. A student commented "[...] we weren't following it with every example or every game we found, but essentially this [the framework] is what we were doing."

Using the framework naturally posed challenges for the students as first-time users who were in a learning process as part of their master of science education. Reaching consensus on modeling and deconstructing complex gameplay in commercial game titles proved difficult at times due to differences in understanding, which at times diverted the design process into discussions of task boundaries (e.g. aiming versus pointing) and what the levels in task hierarchy from the SSTA constituted (e.g. when to consider something as an action or a task). During their background research, students encountered similar terminology with different meaning in other fields, which demanded sharpened analytical sense (e.g. is *consumer choice* relevant to *selection*?). To improve the framework, students suggested 1) a step-by-step guide and 2) multiple examples of each task and of deconstructing gameplay. To address the first suggestion, we created two step-by-step guides in Supplementary Material 2 showcasing how to identify tasks, properties and construct task models, and the introductory Fig. 1. To address the second suggestion we created a video demonstrating task deconstruction across different game titles, created icons of each task in Table 1, and exemplified each task further in Appendix A through task descriptions, game screenshots, and task criteria.

6 Discussion

In this article we reviewed the task concept and its use within game scholarship, to create a core task analysis framework. Our framework follows the underlying philosophy of looking at games scientifically, and their game elements as something weighted, measured, and present for a meaningful purpose. The contribution assumes that players' gameplay experience have during gameplay can be conceptually modeled to inform the design of games as a system. Our contribution considers games as specifics (as implied game objects), following a similar view as the UGO [40]. The language enables us to distinguish between games' infinite representations and their underlying formal systems, with finite ranges of tasks and actions. We can for example, model the interaction work underlying Tetris as a discrete-stepped lateral steering task and differentiate it from Counter-Strike's evasive steering sub-tasks. This makes the core task framework ideal for formal analysis of gameplay, for designers who wish to design on the basis of well-defined and formally structured game concepts from ontological game research like the UGO [40]. In our view this is an advantage to previous frameworks like game design patterns [69] and ludemes [86], where central game concepts like space, elements, and mechanics are ill-defined and conflated, as critiqued by Debus [40]. Our formally structured interaction framework has utility for precise description, which 1) addresses the call for higher rigour and consistency in how games are described in studies [58], and 2) lays foundation for precise research questions that can lead to better statistical rigour in game scholarship [138]. We hope our framework can be of use to game scholarship and game design, the same way task abstraction has served scholarship in information visualization, where e.g. Munzner's framework for analysis and design of information visualization lets designers reason about and compare tasks across different domain-specific data visualization situations [103].

As a lens, the core task framework enables precise temporal descriptions of commonly studied concepts in interaction design, like comparing feedback types. Studies of *positive/negative feedback* can use this lens to indicate when such feedback takes place, which objects are involved and at what level (operation-, action-, task-, activity-feedback). Studies comparing *binary/discrete/continuous* feedback, can clarify whether feedback is continuous with respect to the perceived granularity of the information that users receive or with respect to its temporal occurrence (feedback changes in real-time). In the temporal domain, continuous feedback typically refers to feedback at the operation-level in the task hierarchy.

In our own feedback analysis in Fig. 4, we chose to focus on visual feedback and limited our feedback analysis to Wensveen et al.'s natural action-function couplings [144] in terms of time, location, and expression possible on each level of the task hierarchy. For example, the player moves the cursor in real-time, therefore the cursor is the object of interest for operation feedback and the movement at that very moment is considered. However, unnatural couplings can easily be made in such analysis, too. For example: 1) if instead the operation feedback changed another object's appearance in response to the player's cursor movements (uncoupled location [144]), 2) if the operation feedback changed the cursor, but determined feedback by a player's (aggregate) game score, thus using information beyond what the individual operation unit provided (uncoupled expression [144]). Although natural coupling concerns itself with actions [144], we found that the notion of natural coupling applies equally well to the analysis at other levels in the task hierarchy.

We now turn our attention to edge cases concerning tasks. Our case studies in Section 5 highlighted challenges when bridging the modeled world to real world practice. At the time of running the case studies, no prior games had been designed using the core task framework as a basis, requiring the students to transfer theoretical examples to their own design process. The case studies pointed at potential blurry concept boundaries, for example, where modeling games' interaction work might fit into more than one core task category in Table 1. Rebenitsch and Engle defined, for example, *pointing-based* steering, in which a player perform *pointing* to *steer* through an environment [113], also known as "point and teleport locomotion" [56]. In such cases, core tasks can be modeled as sub-tasking one another (e.g. a steering task containing a number of pointing sub-tasks), although this breaks Refai et al.'s consideration of core tasks as *unit tasks* (non-divisible).

Game designers may find some core tasks similar in definition. *Pointing* and *aiming*, for instance, both involve accurately pointing at a target, but pointing often follows the assumption that the chosen target is immediately hit upon task completion (e.g. shooting with a gun), whereas aiming involves predicting an object's trajectory and collision (e.g. throwing a ball). It raises the question of where to draw the boundary for considering a task distinct enough to be a core task category. To enable clear distinction, we refined our provisional core task list in Table 1 based on their distinguished interaction, their presence in previous work [51, 57, 114] and their observed presence in commercial digital games. We provided additional information and examples of each core task in Appendix A, to help readers identify and distinguish core tasks. In Appendix A, we also describe core tasks from an input modality viewpoint, where actions become e.g. button press, push, tilt, and tasks becomes sequences of them. We did not cover this viewpoint in detail to focus this article on analysing game specifics and games' representation of tasks as defined by output modalities. We refer readers interested in analysis of input modality interactions to other works, like Oulasvirta et al.'s detailed account of button-pressing tasks as an open-loop control problem [106], or Carette and Soraine's list of motor actions (preprint) [25].

Having looked at cases that are difficult to solve, we now turn to cases where new tasks or subtasks are needed. To streamline this process we suggest the following guidelines to navigate the task concept space in Fig. 2:

- **How should new tasks be labeled?** Tasks represent interaction work in the form of a sequence of actions. We suggest that tasks, including core tasks, should be labeled to closely represent the implied interaction work to differentiate it clearly from any goal stretching beyond the work itself. The same task can be performed by players with different goals in mind. Additionally, we advise scholars to label tasks from output modality and input modality viewpoints if their context is gameplay (output) and/or playing a game on a specific input device (input). In easy cases these viewpoints are identical (physical interaction matches virtual representation), while in others, there is a mismatch (e.g. *pointing* with a mouse to virtually *steer* a character).
- **What level of task abstraction should be used?** Game scholarship have already established *core tasks* as a set of abstract unit tasks [114], which provide useful labels to characterize gameplay. However, core tasks are merely distinct categories and do not aim to reflect every variation found in games. For task analysis in gameplay, we suggest authors provide additional details that reveals key characteristics of a task in question. A *Target-to-target pointing task*, for instance, belong to the *pointing* core task family, but the label specifies a sub-type of tasks in which targets appear one after another, which have implications for how players sequence their actions.
- **How detailed should models be in composition?** When modeling gameplay, we advise to strive for as minimal composition as is needed (e.g. use sub-tasks only if they represent meaningful units of analysis). Models are merely structural devices meant to help game designers and scholars understand a problem space.

6.1 Limitations and Future Work

The theoretical contributions presented in this article is fundamentally limited to the extent they have been tested in our case study and by previous literature. All authors of this article have previous experience within game design and scholarship, but the proposed application areas are untested beyond the demonstrated game examples and case studies shown in this article.

In this article, we chose to focus our analysis on 1) simple games, where a single task dominates the game activity, to cover a wider range of game types, and 2) purposeful games, where design precision is needed to fulfill an ulterior goal. Analysis of complex gameplay with many parallel modalities may require describing trimmed segments of the full game activity (the core gameplay) and layering multiple tasks (see e.g. the end of our supplementary video demonstration). Modeling long scenarios can get complex, when analyzing complex gameplay in real-time as one whole.

However our framework may aid game designers dissect segments of complex gameplay to its individual parts that are the unit of analysis to reveal the underlying complexity of interactions, much like a microscope.

We acknowledge that not all game designers may find such added precision useful or needed to solve higher-level game design problems traditionally approached by playtesting and tacit knowledge (*gut feeling*). However, in the design context of purposeful games, our task framework aims to provide a complementary structuring device providing the different levels at which designers, for instance, can place Wensveen et al.'s feedback or feedforward information types [144]. Scholars in ontological game research in need of modeling user interactions, will benefit from the framework, as a bridge from the game terminology in Debus's UGO [40] to Bedny and Harris's task hierarchy in HCI [14]. Game designers developing skill chains [36, 71], can use the design framework to potentially develop skill chain patterns to different core tasks, enabling re-use and analysis across groups of games, e.g. by identifying patterns in how players acquire skills to perform pointing tasks. Our work expands high-level challenges like *physical coordination* or *mastering complex controls* from Adams and McMahon et al.'s challenge framework, by defining and exemplifying 14 motor and mental task categories for preciser gameplay analysis in both input modality and output modality viewpoints.

The framework provides purchases in design and research. Our case studies gave reflective insight into how the students applied our framework in their design work and demonstrated a scientific approach to study game design problems in a human-computer interaction context. We designed our case studies as broad uncontrolled battle tests of the analysis tools and application areas in our framework, laying the groundwork for more focused and rigorous future investigations.

The framework was a helpful focusing device in student design discussions but students called for more examples and step-by-step guides to address challenges in navigating the design process. Whether our now-provided supplementary guides, video and game examples can mitigate such challenges remains an open question to be answered in further work. The case study findings guiding our work were constrained by influencing factors such as the educational context, presence of instructors, diversity and experience level of participating students. These factors collectively affect the ecological validity of our case studies, which we seek to address in future work.

Our conceptual view of games and gameplay may not be suitable for all purposes, just like our used notion of game is based on how games have been studied in the western world. We leave it to other works to understand the task concept in related contexts such as narratology, storytelling or level design. These contexts emphasize narrative and environmental context of interactions more than the exact form of the interactions themselves.

Our framework builds upon a scoped systematic literature review, making the work limited in its depth and precision compared to fully systematic literature review methods. The core task overview in Table 1 provides a provisional list built upon previous work [51, 57, 114]. Each task will need further comprehensive analysis and definition from both predictive modeling [147] and gameplay analysis viewpoints.

In Section 4.3, we warned against using the task concept to generalize over actual players' experiences or assume transferability of behavioral measurements. In addition, Cooper et al. cautioned against solely focusing on tasks in design and not on the goals and users [37]. Cooper's caution is within the context of using task analysis to understand how users use tools to solve real world challenges in social contexts. However, in classic game design contexts, challenges themselves are the subject of design, in which a fully controlled virtual environment determines available solutions. In purposeful game contexts, we suggest game designers focus initially on overarching goals to establish design constraints, and subsequently use task analysis within those constraints.

Refai et al. noted that core tasks intend only to model a subset of skills required in practice to play games, which do not include social or strategic skills [114]. Other authors covered such skills by classifying gameplay through high-level *challenges* like *thinking outside the box* and *strategy, tactics and logistics* [4, 100].

Our case studies provided additional support in the form of design workshops and supervision on top of the provided framework. Further studies are needed to assess the framework's standalone value. Going forward, we believe the case studies can now become useful references for future student supervision and help connecting our framework to real-world design processes. This paper provides the task design framework in textual and theoretical form to give scholars fundamental knowledge in models of game task hierarchies. We aim to support the framework's accessibility and proliferation further in future work, by providing an illustrated overview of key terminologies ('cheatsheet'), or building interactive modeling tools of gameplay as task hierarchies, on our framework website: **https://gametasks.create.aau.dk**. We intend to explore how the framework performs with the proposed aids (case studies, step-by-step guides, interactive tools) in the future for further validation and iteration. This includes evaluating the framework with game industry practitioners to identify its challenges and opportunities to fit into existing design processes and practices, and evaluate its value in produced games. We encourage further definition of core tasks from both input and output modality viewpoints. Similar abstract lists of core actions and operations may be fruitful and we recommend taking UGO's list of mechanics as a starting point [40].

7 Conclusion

In this article, we established how to rigorously map gameplay to abstract tasks for game design and scientific study. Our literature review examined how gameplay can be broken down into a task hierarchy imported from the systemic-structural theory of activity [14], which we contextualized to work within game ontology [24, 40, 122]. Our core task framework bridges task analysis theory into game scholarship, to enable the dissection of what constitutes core gameplay. For game scholars, we demonstrated the core task framework in four scientific application areas: design properties, experiment manipulation, behavioral measures, and literature reviews. For game designers, we demonstrated the framework as a design lens, using its tools to identify, sequence, decompose, and examine gameplay. The framework can be used to analyze interactions in gameplay, invent new undefined gameplay forms, and find novel combinations of core tasks. In three case studies, core tasks proved to be a valuable focusing device to scope project work, but the case studies highlighted classification challenges, which arise when designing games which explore core task boundaries. Going forward, we intend to study how practitioners and scholars find merit in the core task framework as a lens for the game design process. Further studies are needed to validate the application of the core task framework. We advise scholars interested in using core tasks as a framing device for their work to consider our labelling guidelines in the discussion and hope our contribution can inspire further efforts to establish rigor in the design and analysis of gameplay.

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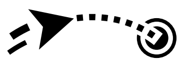
A Appendix of Extended Task Descriptions

This appendix aims to elaborate each core task from the core task list (Table 1 in the main material). This includes the rationale behind each task image, the task criteria used to identify a task, input and output modality task descriptions, and further elaboration of application and definition. The material is designed to be useful as a starting point to further discuss or produce exhaustive reviews of individual core tasks.

(1) **Task Image:** A proposed iconographic image representing the task's main characteristics.
(2) **Task type:** Tasks can be either motor or mental tasks. Mental tasks imply only cognitive work. Motor tasks imply motor control work in addition to cognitive work.
(3) **Proposed Definition:** For each task, the proposed final definition is shown along with other definitions related to the pointing concept. When there are multiple definitions for a term, we show only the most relevant definitions of the concept.
(4) **Sub-concepts:** An explanation of each conceptual element used in the iconographic image of the task and terms related to it.
(5) **Task criteria:** A set of proposed abstract criteria which can be used to identify a given task. The criteria are based on our own evaluations. Lists soft criteria (*"May include.."*) and hard criteria (*"Must include.."*).
(6) **Output/Input Modality Viewpoint:** Tasks can be defined from either an input-device or output-device viewpoint. For example, when defining pointing from an input-device viewpoint, pointing refers to a user's real-world interactions, but not necessarily how the system augments these interactions (for example, pointing using a Nintendo Wii controller). When defining pointing from the output modality viewpoint, it refers to user interactions as they are portrayed on the screen or game. For example, users may point at 2D elements using a virtual cursor controlled by arrow keys instead of a pointing device. The same task may therefore change its definition in input modality viewpoint and output modality viewpoint.
(7) **Application Areas:** Exemplifies how the task concept's has been reviewed, defined and used in HCI and game scholarship.
(8) **Related Definitions/Concepts:** Relevant or closely aligned concepts dictionaries and from the exemplified work (if any).
(9) **Author Notes:** Miscellaneous notes that may elaborate differences to other tasks or what goes beyond scope of the definition.
(10) **Game Examples:** We collected screenshots of games showcasing each core task to contrast different ways the tasks take shape in practice. Where possible, we primarily included games available from web browsers or as free download, to allow readers to test the interactions. The screenshots are shown for education and research purposes only and any depicted visual asset belong to the respective cited copyright holder.

A.1 Aiming Task

Image:



Task Type:
Motor Task

Proposed Definition:
"Accurately pointing at a target (possibly using a device) and/or predicting the collision between two objects, without outcome signification." Definition adapted from Refai et al. [114] with terminological changes.

Sub-concepts:

(1) **Subject:** The controlled object whose trajectory will be determined in the aiming task.
(2) **Target:** *destination, objective*. The object which the user aims to hit with the subject.
(3) **Predicted Trajectory:** *motion*. A line indicating the (invisible) trajectory the subject is predicted to take in the aiming task.
(4) **Speed:** Lines indicating the subject is in movement, as a result of being cast.

Task Criteria:

(1) Must include deciding the subject's course, based on a prediction of collision between the subject and the target without signification of the outcome.
(2) May include searching for a target.
(3) May include explicit subject *activation* (launch), after which its (ballistic) trajectory cannot be manipulated.
(4) May include a temporal delay between aiming and resulting target arrival feedback. During this delay the subject moves on a trajectory towards the target.
(5) May include influence from environment factors such as gravity or wind, hindering accurate predictability of the outcome as known from e.g. pointing tasks.

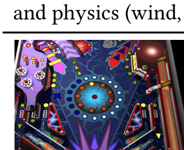
Output Modality Viewpoint:
Aiming refers to an aiming interaction as they are portrayed on the screen or game, where users' aim determines the outcome through an often unknown relationship. Aiming is often used in context of e.g. throwing objects towards other objects with emphasis on the need to determine how to throw the object as being the challenge of the task.

Input Modality Viewpoint:
Aiming refer to users' real-world interactions with devices that facilitate the ability to aim, an interaction mostly present in natural user interfaces like Kinect or with gesture-based interfaces like Nintendo Wii, where it is possible to buy hardware attachments for sports or shooting which afford users to aim (see e.g. McArthur et al. [99]'s comparison).

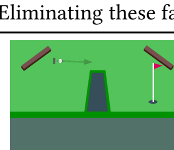
Application Areas:
Aiming has been studied in relation to human sensorimotor coordination in ball throwing in motor neuroscience [38]. Within HCI, game scholarship studied how to assist users in aiming tasks, through environmental changes (e.g. gravity, magnetic force) that makes aiming at targets easier [64, 81]. To our knowledge, only Refai et al. [114] has formally defined aiming. We are not aware of any aiming task literature reviews.

Related Definitions:
"To direct a course." (Dictionary Definition, Merriam Webster)
"Accurately pointing at a target (possibly using a device) and/or predicting the collision between two objects, without feedback." Refai et al. [114].

Author Notes:
The emphasis in *Aiming* is that an object moves from A to B, with a supposed unpredictable course taken between departure and destination and a small to long delay between user activation and feedback. In game environments, these characteristics are represented by virtual tools (darts, arrows, canon balls) in combination with environment and physics (wind, weather, gravity). Eliminating these factors, aiming tasks eventually becomes pointing tasks.



Full Tilt! Pinball [G7]
Players aim by timely activating two flippers to launch a ball towards score-giving targets.



The Skyscraper Minigolf [G38]
Players aim by choosing a direction and power level to fire a golf ball on a minigolf course.

Angry Birds [G18]
Players aim by dragging a slingshot which flings a bird towards a construction site.

A.2 Pointing Task

Image:

Task Type:
Motor Task

Proposed Definition:
"Accurately pointing at an accessible target with feedback about current pointing position." [114]
Adapted from Refai et al. [114] with terminological changes.

Sub-concepts:

(1) **Subject:** *pointer, cursor.* An object which indicates user's current position, often in the form of a an arrow, dot or crosshair.
(2) **Target:** *destination, objective.* The object which the pointer aims to point on.
(3) **Trajectory:** *motion.* A line indicating the distance the pointer has travelled, to indicate that the pointer is in motion.

Task Criteria:

(1) Must include the presence of a pointer to help users assert the trajectory needed and signify the outcome.
(2) Must include the need to move from a current position to the target.
(3) Must include clear general signification of whether pointer position and target position match.
(4) May include searching for a target if its position is unknown.
(5) May include providing confirmation when the user deems the target found.

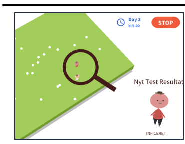
Output Modality Viewpoint:
Pointing refers to user interactions as portrayed in the game. For example, users may point at 2D elements using a virtual cursor controlled by arrow keys. In the output modality viewpoint, this may be done through other means than standard pointing devices.

Input Modality Viewpoint:
Pointing refers to users' real-world interactions, but not necessarily what these interactions are augmented into by the system. For example, pointing at the UI elements using a nintendo Wii controller.

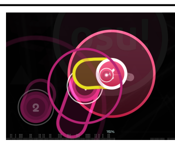
Application Areas:
Pointing is defined in the ISO 9241-9 *"Ergonomic requirements for office work with visual display terminals (VDTs)"* [52], and researched in context of input device throughput using Fitts Law [50] in virtual 2D pointing tasks [99], in 3D pointing tasks [28], and lots of kinematic research [97, 119, 125]. In game contexts, pointing has been evaluated to e.g. compare game hardware like thumbsticks [110] and addons like 'wiimote' gun attachments [99]. Outside HCI contexts, pointing is studied in its gestural form e.g. linguistics [66]. As a task, pointing has mainly been defined through e.g. ISO 9241-9's *point-selection task* and standardized in HCI [125].

Related Definitions:
"To indicate the position or direction of especially by extending a finger." (Dictionary Definition, Merriam Webster)
"[An] operation with a graphic user interface in which an input device is used to move a small display image (such as a pointer) to a specific location on the display". (ISO 9241-9) [52]
"Accurately pointing at a target with feedback about current pointing position." Refai et al. [114]
Related Concepts:
Pointing device: refers to hardware designed to control/solve pointing tasks, like a mouse.
Point-and-click: refers to a game genre in which interactions are made up of pointing and activation.
Target-to-target pointing task [76], Point & teleport locomotion task [56], Point selection task (ISO 9241-9 [52])

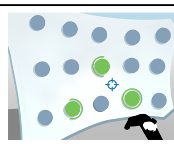
Author Notes:
Unlike Aiming, *Pointing* matches where users' intent to point to where they actually point. The pointing task challenges players in *where* to point and *how fast* to point. Pointing often consists of *Move* actions, optionally followed by an *activation* action to confirm the intended target.



Infection Detective [G17]
Players hover a looking glass over a population to find and isolate infected persons before the infection spreads.



Osu! [G14]
Players move their cursor to hit targets, steer sliders or spin spinners in synchronization to music.



Whack-A-Mole VR [G16]
Players move a crosshair around to point at circular green targets amidst half-circular green distractors.

A.3 Steering Task

Image:

Task Type:
Motor Task

Proposed Definition
"Moving or guiding a subject along a trajectory."
Definition by Refai et al. [114] with terminological changes.

Sub-concepts:

(1) **Subject:** The controlled object being steered, vehicle, movable object or the users' themselves.
(2) **Obstacle:** *obstruction, barrier.* Objects in the environment which constraints or obstructs the path to the users' target.
(3) **Target:** *destination, objective.* The position or direction which users' aim to steer their subject to.
(4) **Trajectory:** *motion.* A line between subject and target indicating that the subject is in motion towards its target.

Task Criteria:

(1) Must include the presence of one or more obstacle constraining the user's path to the chosen target.
(2) Must include the need to move from a current position to a target position or target direction.
(3) Must include clear general signification of whether subject position and target position match.
(4) May include a search for the target prior to or during steering, if its position is not known.
(5) May include providing confirmation when the user believes the target has been found.

Output Modality Viewpoint:
Steering refers to the movement of a user-controlled virtual object to a destination. For example, users may steer a virtual car around a 2D or 3D environment to reach the racing line.

Input Modality Viewpoint:
Steering refers to the users creating motion of themselves or of physical objects. Some Virtual Reality games, for example, require users to physically move around their physical environment.

Application Areas:
In HCI, steering has been systematically explored via the tunnel steering law [3], which applies to 'trajectory-based interactions' such as steering in 2D and 3D space [3]. Within games, various subtopics within steering has been explored, such as semi-autonomous steering [87] (games) and input device preferences for racing games [117, 135].

Related Definitions:
"To control the course of." (Dictionary Definition, Merriam Webster [101]).
""Moving or guiding an object along a path. (Refai et al. [114]).
Described as trajectory producing motion or constrained motion by Accot and Zhai [3].

Related Concepts:
Movement Speed: The speed at which the object being steered moves.
Tunnel width: In tunnel steering, the tunnel width directly impacts the difficulty of a tunnel steering task [3].

Author Notes:
Steering tasks are characterized by obstacles present in the environment, requiring users to consider direction and perform consecutive movement actions to steer around them.

Pixel Dungeon [G42]
Players steer a character through the underground, where time passes with each grid-based move.

X-Moto [G1]
Players steer a motocross by throttling, braking and jerking it in a physically simulated side-view landscape.

Speed Dreams [G39]
Players steer a racing car along a race track whilst being projected as the driver.

A.4 Drawing Task

Image:

Task Type:
Motor Task

Proposed Definition:
"Marking or laying out content in an area."
Simplified description from Zabramski and Stuerzlinger [147].

Sub-concepts:

(1) **Subject:** *pointer, cursor, tool.* the object which manipulates the environment.
(2) **Target:** *destination, objective.* an area or position in the environment being manipulated.
(3) **Content:** *depiction.* That, which is added, removed, or changed within the environment.

Task Criteria:

(1) Must include the presence of a subject (cursor) controlled by the user, which manipulates the environment.
(2) Must include moving and activating the subject to consecutively to create content.
(3) May include an intention to create patterns which can be recognized as a depiction of an object of interest.

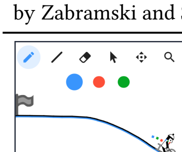
Output Modality Viewpoint:
Drawing refers to the task of visually laying out virtual elements in an area using a virtual tool capable of manipulating the virtual environment, by adding, removing or changing it.

Input Modality Viewpoint:
Refers to users' interacting with a virtual drawing board, by holding a pen-like input device, mimicking the act of drawing with regular pen and paper by recording sensing position.

Application Areas:
In HCI, Zabramski and Stuerzlinger [147] have reviewed drawing tasks in terms their formal boundary, their use in HCI. They demonstrated how to analyse drawing tasks by employing the W^6 framework. Their definition describes the use of a tool applied onto a medium. They evaluated suitable input devices for drawing tasks [146]. Their review of drawing tasks does not explicitly consider drawing from input and output modality viewpoints. In game scholarship, sketch-based gameplay has been used to motivate sketching practice [145] (games).

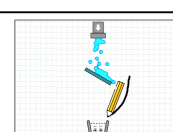
Related Definitions:
"To create a likeness or a picture in outlines." (Dictionary definition, Merriam Webster)
"The spatio-temporal interaction foregrounding the trace of a trajectory performed by the user-controlled tool on a medium." (Zabramski and Stuerzlinger [147])

Author Notes:
Drawing requires perfoming a series of well thought-through movements to arrive at a desired visual arrangement. Although Accot and Zhai [3] claim their steering law applies to writing and drawing, this is later rejected by Zabramski and Stuerzlinger [147] in their review of drawing tasks.



Line Rider [G43]
Players draw lines to form a landscape, on which a character will ride a sled.

Quick, Draw! [G12]
Players draw an object while a machine attempts to guess it in a limited timeframe.



Happy Glass [G37]
Players draw lines strategically to guide as much water as possible into a glass.

A.5 Activation Task

Image:

Task Type:

Motor Task

Proposed Definition:

"Initiating another mechanical system, function, or item."
Adapted from UGO's activation mechanic [40].

Sub-concepts:

(1) **Subject:** *pointer, cursor, signifier.* The object which performs the activation.
(2) **Target:** *objective.* The object being activated.
(3) **Inactive Target:** An alternative target which has not been activated.
(4) **Target Feedback:** The targets response to becoming activated.

Task Criteria:

(1) Must include a target which affords activation.
(2) Must include that users perform at minimum one or more actions that altogether results in activation.
(3) May include the need to make a selection if more than one target is available.
(4) May include feedback from the target, when it's activated, reflecting the change in state.

Output Modality Viewpoint:

Activation refers to the act of initiating something (e.g. game mechanic) in the environment, like pressing a virtual button.

Input Modality Viewpoint:

Refers to users' press of a button to send a single command or input to the system.

Application Areas:

In HCI, activation has been reviewed from an input device viewpoint, examining the neuromechanics of buttons by Oulasvirta et al. [106]. In games, activation has been used with respect to making assessments of player reaction time [82]. In the UGO, activation is a formally defined game mechanic, covering any type of binary initiation of a mechanical system [40].

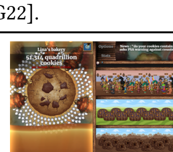
Related Definitions:

"To make active or more active." (Merriam-Webster Dictionary [101]).
"Physical buttons are electromechanical devices that make or break a signal when pushed, then return to initial (or re-pushable) state when released." (Oulasvirta et al. [106]).
"The mere initiation of another mechanical system, function, or item." (Debus [40]).

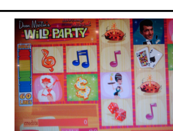
Author Notes:

This core task category represents the single button press, a motor task often used in context of mental tasks like selection. Activation often takes place at the action-level as part of a different task, instead of being a task of its own. However, some games classify as activation tasks, because their interaction work consists of many consecutive activations, like e.g. Cookie Clicker [G22].

All My Dice [G33]
Players roll their dice until all dice show the same number faster than the opponent.



Cookie Clicker [G22]
An incremental game in which players continuously clicks to earn income, which they can spend to increase passive income.



Slot machines
Digitized one-armed bandits are chance-based games involving a single activation, to gamble money. Image is "Dean Martin's Wild Party" by NoirDamedotCom (CC-BY-SA 2.0).

A.6 Typing Task

Image:

Task Type:
Motor Task

Proposed Definition:
"Performing a sequence of input activations to enter data."
Our own definition based on Merriam-Webster [101].

Sub-concepts:

(1) **Subject:** *pointer, cursor, indicator.* An object indicating the position adjacent to where typing takes place.
(2) AB **Data:** *text.* The resulting data shown as a result of the typing.

Task Criteria:

(1) Must include a sequence of activation actions in an environment where users input data.
(2) May include the construction of words, phrases, code, commands or other situationally meaningful data to the environment.
(3) May include involve deletion/modification of data.

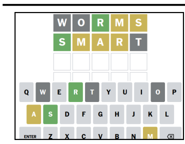
Output Modality Viewpoint:
Typing refers to the sequential occurrence of data (e.g. letters) on a screen in response to input activations performed by users, usually through a keyboard-like (virtual) interface.

Input Modality Viewpoint:
Refers to the act of pressing input buttons (e.g. letters, numbers) on touch- or button-based keyboard hardware.

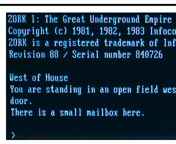
Application Areas:
Typing may have originated from the act of writing with typewriters, which has since transitioned to describe writing by operating a keyboard (e.g. *typist*) [45]. The act of typing has been explored and compared to other input modes like handwriting, printing, marking and keying in terms of input rate [43]. KLM is a model in the GOMS family of activity theory specifically designed to model typing performance [23]. Typing tasks were explored in HCI, for example in contexts of input sequence mining [139] and stress detection when typing under pressure [91].

Related Definitions:
"To write something on a typewriter or enter data into a computer by way of a keyboard." (Merriam-Webster Dictionary [101]).
"The arranging of type in an appropriate manner to suit a particular purpose." (Eckersley et al. [45], Typography).
"(I) A person who sets type, either the keyboard operator (who is essentially a typist) or the compositor (who is responsible for interpreting the type specifications and encoding the manuscript)." (Eckersley et al. [45], Typesetter).

Author Notes:
Typing tasks typically occur on keyboards, but also occur on virtual keyboards, when no keyboard hardware is available. Typing in games is well-known in text-based adventure games like Zork.



Wordle [G21]
Wordle is a word guessing game. For each typed word, hints are given as to which types letters were correct or wrong, informing the next guess.



Zork [G35]
Zork is a text adventure game, in which players types commands to interact with the game. Image by Marcin Wichary (CC-BY 2.0) ⓘ.

Type Off [G30]
In Type Off, letters move from left to right and players must type each letter before they reach the end of screen.

A.7 Selection Task

Image:

Task Type:
Mental Task

Proposed Definition:
"Making a choice."
Adapted from Merriam Webster [101].

Sub-concepts:

(1) **Mental:** *cognitive*. This task takes place in the mind.
(2) **B Selection:** *choice*. An option, emphasized to indicate the user's decision to select it.
(3) **AB Options:** Non-emphasized options which indicate the presence of alternative options to the user's chosen option.

Task Criteria:

(1) Must include the presence of options from which a selection needs to be made.
(2) May include the use of deduction, hypothesis evaluation or other forms of reasoning [126].

Output Modality Viewpoint:
Selection is made in context in which options are presented in an environment (e.g. "which meaningful outcome should I choose?").

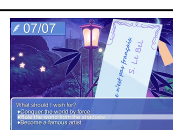
Input Modality Viewpoint:
Selection is made in context of operating an input device (e.g. "which button should I press?") or interacting with the user's physical environment (e.g. "which physical movement should I perform?").

Application Areas:
The notion of selection (or making a choice) has been studied and reviewed in psychology contexts, such as: 1) in relation to phenomenon like choice overload [32] (e.g. Hick's Law), 2) in relation to the grounds in which the selection is made (based on e.g. deduction or hypothesis evaluation [126]), and 3) as tasks like e.g. the Wason Selection Task [141]. In game scholarship, Jiang et al. studied gamers' reaction time when solving multiple choice tasks [82].

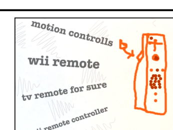
Related Definitions:
"To make a choice." (Merriam Webster Dictionary [101]).

Author Notes:
Notably prominent in Quiz games and card games, where the nature of the selection (the basis of which you make your selection) becomes more important than the interaction of articulating the choice itself.

Kahoot! [G3]
Players make a selection to correctly answer quiz questions and receive points in a competition against others.



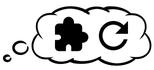
Hatoful Boyfriend [G19]
Players make selections to make progress in a narrative, and influence their relationship to other characters.



Drawful [G20]
Players first describe a drawing's resemblance, then select among self-proposed answers and receive points for selecting the most voted option.

A.8 Configuration Task

Image:



Task Type:
Mental Task

Proposed Definition:
"Arranging items based on particular criteria (e.g. similarity)." Our own definition, inspired by Galli [57].

Sub-concept:

(1) **Mental:** *cognitive*. This task takes place in the mind.
(2) **Item:** *element, piece*. The object which is thought to be configured.
(3) **Operation:** The operation which is mentally imagined to meet the task criteria (goal), e.g. rotating, positioning, or ordering.

Task Criteria:

(1) Must include the presence of one or more items on which the configuration is attempted.
(2) Must include the possibility of spatial or temporal operations that can be mentally imagined on the item in question.
(3) May include the presence of an environment (other objects), to which the item is being configured in relation to.

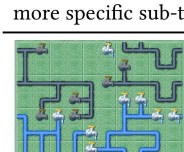
Output Modality Viewpoint:
Configuration of virtual elements, based on features simulated within a virtual environment.

Input Modality Viewpoint:
Configuration of physical elements in the context of an input device that require it for interaction.

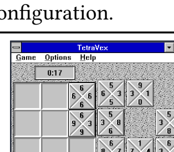
Application Areas:
Configuration refers to the mental work of solving visuospatial challenges, like packing problems [94] found in e.g. jigsaw puzzles or tangram puzzles or sorting problems, which involves item arrangement, including *ordering* and *clustering* tasks [57], which we for the time being cover within *configuration* until differences are better understood. In game scholarship, configuration tasks can for instance, be observed in Vayanou et al.'s study of designing collaborative jigsaw puzzle game design [136]. Our review did not yield configuration tasks to be a formally established in HCI or game scholarship.

Related Definitions:
"Relative arrangement of parts or elements" (Merriam Webster Dictionary [101]).
"Grouping a set of objects in such a way that objects in the same group (called cluster) are more similar (in some sense or another) to each other than to those in other groups (clusters)." (Galli [57], Clustering).
"Arranging items of the same kind, class, nature, etc. in some ordered sequence, based on a particular criterion." (Galli [57], Ordering).

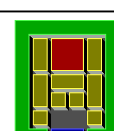
Author Notes:
The *configuration task* aims to cover *ordering* and *clustering* tasks [57]. We chose to merge these two tasks to a broader covering task that covers any kind of arrangement, that does address any specific criteria for arrangement, such as order and sequence. Also, we do not want to encode a specific purpose, where ordering and clustering both imply a specific kind of data and a specific expected outcome. However, ordering and clustering could be considered more specific sub-task categories of configuration.



PipeWalker [G34]
Players configure pipes to create complete circuits.



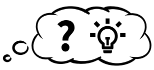
Tetravex [G11]
An edge-matching puzzle where players configure numbered cubes in a square grid by matching numbers on each side.



Klotski [G9]
Players slide blocks horizontally or vertically using as few moves as possible to arrive at the configuration required.

A.9 Memory Task

Image:



Task Type:
Mental Task

Proposed Definition:
"Memorizing and recalling sets of items, sequences, or mappings."
Definition adapted from Refai et al. [114] with terminological changes.

Sub-concepts:

(1) **Mental:** *cognitive*. This task takes place in the mind.
(2) **Search and Retreive:** Metaphor for the mental search and retreival associated with remembering.

Task Criteria:

(1) Must include the presence of a cue, indicating the need to retreive or memorize an item.
(2) May include the presence of information to retain in either short- or long-term memory.

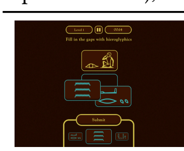
Output Modality Viewpoint:
The memory task is about memorizing or retreiving information as required by the virtual environment, for example a username.

Input Modality Viewpoint:
The memory task relates to the needs of interacting with an input device, for example remembering the mapping between a pressing button and a corresponding action outcome.

Application Areas:
The workings of short-term memory and long-term memory has been studied extensively in psychology, under a variety of tasks like 1) the *free recall memory task* [53] in which subjects read a list and instructed to report as many as possible in no particular order or 2) the *serial recall task*, in which items must be reported back in a specific order [140]. In game scholarship, El Agroudy et al. studied how to turn memory experiments like e.g. word recall into entertaining mobile games [46].

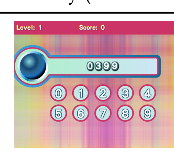
Related Definitions:
"A particular act of recall or recollection" (Merriam Webster Dictionary [101]).
"Memorizing and/or retrieving sets of items, sequences, and/or mappings." (Refai et al. [114])

Author Notes:
Memory tasks are closely related to spatial memory tasks, but cover tasks where the spatial information does not play the key role. They also relate closely to selection tasks, but as tasks, they emphasize the nature of the recall, which does not necessarily require selection, just like selection does not have to rely on recall. The memory task is a high-level category, but can be conceptually divided further down by subtype, like e.g. episodic memory (recalling specific events), semantic memory (recalling factual knowledge), or implicit memory (unconscious habits).



Hieroctive [G10]
Players memorize Egyptian glyphs and are subsequently challenged in their ability to form sentences.

The New One [G27]
Players memorize shapes to identify the new shape previously not present.



Sequence Memory [G26]
Players memorize presented numbers and are challenged to enter each number in order afterwards.

A.10 Spatial Memory Task

Image:

Task Type:
Mental Task

Proposed Definition:
"Remembering the location of items in a space without persistent cues." Definition adapted from Refai et al. [114] with terminological changes.

Sub-concepts:

(1) **Mental:** *cognitive*. This task takes place in the mind.
(2) **Location:** Metaphor for an object's position in space.

Task Criteria:

(1) Must include the presence of an already known item, whose location needs to be identified or stored.
(2) Must include the presence of a spatial grid featuring one or more dimensions, within which the items' location can be pinpointed.

Output Modality Viewpoint:
The spatial memory task involves memorizing or retreiving spatial information, as defined by the virtual environment and its spatial dimensions perceived by the user.

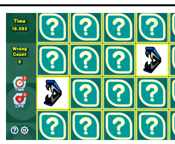
Input Modality Viewpoint:
The spatial memory task involves the spatial location of information on an input device, such as identifying or memorizing the location of a button to interact.

Application Areas:
Psychology has studied and used games as medium to assess and practice spatial ability. Games like the "Simon" game require players to memorize sequences of colors, appearing in four different locations on a circle. Lin et al. and Van de Weijer-Bergsma et al. studied how to develop a game to let players practice spatial orientation [92, 134]. They did not formally define spatial memory, but Lin et al. relied on a measure of spatial ability from The Nine Box Maze Test [107].

Related Definitions:
"[...] to detect or reason about relationships within or between objects in space." (APA Dictionary of Psychology on spatial ability [10]).
"[...] spatial memory includes storage of information about objects and their location." [107] (used by Lin et al. [92]).

Author Notes:
Spatial memory games are e.g. games where users are prompted to remember locations of two matching items. In these games, designing the spatial memory task becomes equally important as designing the motor task in which users articulate their recall. Spatial memory and memory is often closely tied together - we suggest categorizing one or the other by how meaningful the spatial information is to the task at hand.

Simon [G4]
Players memorize a sequence of colored buttons appearing in four different locations and repeat the shown sequence by pressing them.

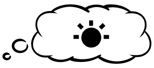


Memory [G25]
A game of concentration in which players memorize locations of cards to pair them as quickly as possible.

Blind Spot [G24]
Players memorize locations of dissapearing shapes and subsequently estimate what used to be each shape's center-most point.

A.11 Detection Task

Image:



Task Type:
Mental Task

Proposed Definition:
"Consciously perceiving a stimulus, such as sound, light, or vibration." Adapted from Refai et al. [114].

Sub-concepts:

(1) **Mental:** *cognitive*. This task takes place in the mind.
(2) **Stimulus:** An object in question whose change in state is to be detected (e.g. a lightbulb lighting up).

Task Criteria:

(1) Implies a stimulus which may or may not be present, for example in the form of an object changing state.
(2) May imply subsequent recognition, classification and identification.
(3) Used as a sub-task in a motor task to drive interactions.

Output Modality Viewpoint:
Detection tasks involve detecting stimuli in the virtual environment. (e.g. detecting the presence of a virtual menu button).

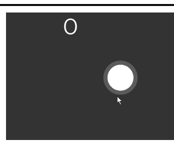
Input Modality Viewpoint:
Detection tasks involve detecting stimuli in the physical environment, to facilitate interaction with the virtual environment (e.g. detecting the presence of a physical button).

Application Areas:
In cognitive psychology, simple reaction time measures involving detection are used as a way to measure human information processing times [35]. For example, Ratcliff et al. measured the effects of aging on reaction times in two activation tasks [112], which are based on "signal detection paradigms" showing either a low or high number of symbols on a computer screen.

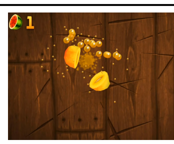
Related Definitions:
"To discover or determine the existence, presence, or fact of" (Merriam Webster Dictionary [101]).

Author Notes:
This definition is scoped to conscious human sensory detection. Detection is also used conceptually to describe e.g. as unconscious detection (e.g. body reflexes), and machine-based detection (e.g. sensors).

Quickdraw [G28]
The player must fire in response to a cue as fast as possible before an opponent does.



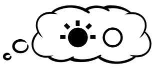
POP [G15]
Players must pop each growing bubble before they grow beyond a specific size.



Fruit Ninja [G13]
Players slice fruit as they appear on the screen to survive. Different fruits have different properties when sliced.

A.12 Discrimination Task

Image:



Task Type:
Mental Task

Proposed Definition:
"Determining that there is a difference between two stimuli (e.g., determining that two colors or two sounds are different)."
Definition imported from Refai et al. [114].

Sub-concepts:

(1) **Mental:** *cognitive*. This task takes place in the mind.
(2) **Stimulus:** An object in question whose change in state is to be detected (e.g. a lightbulb lighting up).
(3) **Comparator:** An object whose state is compared to the stimulus to assert whether discrimination is possible (e.g. an unlit lightbulb).

Task Criteria:

(1) Implies a stimulus which may or may not be present, for example in the form of an object changing state.
(2) Implies the presence of one or more other stimuli (comparators) or an environment whose state is compared to the stimulus.
(3) May imply subsequent recognition, classification and identification.
(4) Used as a sub-task in a motor task to drive interactions.

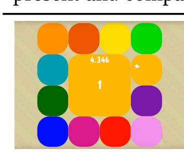
Output Modality Viewpoint:
Discrimination tasks involves discriminating between stimuli within the virtual environment.

Input Modality Viewpoint:
Discrimination tasks involve discriminating between stimuli in the physical environment, e.g. discriminating between two buttons on an input device.

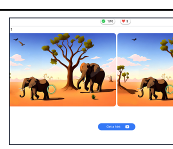
Application Areas:
Widely used and reviewed in psychology. There is a large body of work in cognitive psychology on visual discrimination tasks and related effects like for example inhibition of return [108] (a bias towards attending an already attended location) or visual discrimination efficiency (e.g. determining how small differences can be detected by humans when looking at noise patterns) [21].

Related Definitions:
"The act of making or perceiving a difference" (Merriam Webster Dictionary [101]).

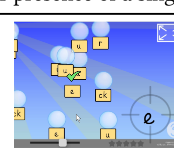
Author Notes:
The main differentiator between discrimination and detection, is that for discrimination two or more stimuli are present and compared, whereas detection concerns itself with the absence or presence of a single stimulus.



Color React [G6]
Players must determine which outermost color corresponds to the innermost color as fast as possible.



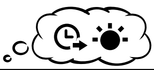
Find The Difference [G31]
Players are tasked to visually compare two images and mark their differences.



Phonics Pop [G5]
Players identify letters appearing on balloon based on a reference letter shown visually and pronounced.

A.13 Prediction Task

Image:



Task Type:

Motor Task

Proposed Definition:

"Anticipating an event's occurrence to act on or synchronize with it." Our own task definition.

Sub-concepts:

(1) **Mental:** *cognitive*. This task takes place in the mind.
(2) **Prediction:** The imagined moment in time an occurance is expected to happen.
(3) **Stimulus:** An object in question whose change in state is predicted (e.g. anticipating when the lightbulb lights up).

Task Criteria:

(1) Implies a stimulus to be predicted, for example in the form of an object changing state.
(2) Used as a sub-task in a motor task to drive interactions.

Output Modality Viewpoint:

Prediction refers to anticipating an event in a virtual environment with the intention to match an action to the event.

Input Modality Viewpoint:

Prediction refers to anticipating an event in the physical environment with the intention to match an action to the event.

Application Areas:

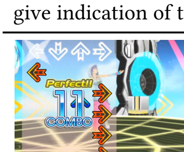
Prediction is often studied in relation to rhythm or synchronization within HCI and game scholarship. Rhythmic coordination is also called sensorimotor synchronization and has, for example, been studied as finger tapping to auditory stimuli in psychology [115]. In game scholarship, rhythmic coordination has been studied as a motivational factor to e.g. play co-located games (movement synchrony, like dancing together) [98] or exergames (motor-auditory synchrony, e.g. performing actions in synchrony to a song in Beatsaber) [5].

Related Definitions:

"The temporal coordination of a motor rhythm with an external rhythm." (Repp [115]).
"To declare or indicate in advance" (Merriam-Webster Dictionary, Predicting).
"The ability to select the precise moment for doing something for optimum effect" (Merriam-Webster Dictionary, Timing).

Author Notes:

The proposed prediction task definition implies a near-term response, as is suitable for most gameplay and HCI analysis (unlike other contexts like e.g. forecasting weather). Prediction is characteristic of reaction time tasks, where reaction time is determined by letting users detect a stimuli followed by a motor task like simple activation to give indication of the detection.



Dance Dance Revolution [G23]
Players predict the onset between moving arrows and corresponding stationary arrows.

Rope Skipper [G8]
Players make a character jump, predicting the onset of a rope swung under the character's feet.

Parappa The Rapper [G29]
Players predict the onset of their own rap line timely matching another character's rap line.

A.14 Search Task

Image:

Task Type:
Mental Task

Proposed Definition:
Finding a target in a set field of distractors; includes pattern recognition (determining the presence of a pattern amongst a field of distractors). Definition imported from Refai et al. [114], adapted to make it applicable to non-visual search tasks.

Sub-concepts:

(1) **Mental:** *cognitive*. This task takes place in the mind.
(2) **Looking Glass:** A visual metaphor which represents the act of searching.

Task Criteria:

(1) Search tasks contains a target to be searched for.
(2) Requires that the target has not yet been found.
(3) Search is not tied to a particular modality, it covers, for example, auditory, visual and haptic searches.

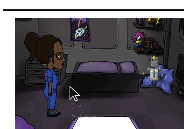
Output Modality Viewpoint:
The user performs search within the virtual environment.

Input Modality Viewpoint:
The user performs search in their physical environment.

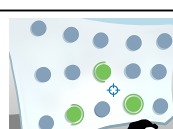
Application Areas:
In psychology, search tasks have been studied in the form of identifying auditory features in auditory searches [48] and identifying search strategies within visual searches, like e.g. feature and conjunction searches [132]. For example, Treisman and Gelade quantified visual search efficiency in human subjects by asking participants to press a button as soon as they located a specific letter among other letters on a white card [132]. In game scholarship, puzzle games have been created to make assessments of visual search ability [33] and pattern recognition ability [33]. Chesham et al. created a *search and match* task, in which users upon identifying their target, had to swap two tiles on a puzzle board. Raptis and Katsini studied the influence of field dependence-independence on visual searches by measuring eye trajectories in players who identified simple shapes within complex shapes in a game based on the *group embedded figures test* [111].

Related Definitions:
"To look into or over carefully or thoroughly in an effort to find or discover something" (Merriam Webster Dictionary [101]).
"Visual search is the ability to find target objects in complex visual scenes in everyday life." (Chesham et al.'s formulation [33], referencing Horowitz [72]).
(On developing the visual search paradigm) "The visual search paradigm allows us to define a target either by its separate features or by their conjunction." (Treisman and Gelade [132]).

Author Notes:
Search, as a task, also has other higher-level meanings beyond the low-level perceptual task implied by core tasks, like information search (e.g. finding information on the internet) or exploratory search (e.g. discovery something without a specific target in mind) and related concepts like search queries, and browsing. Performing such higher-level tasks still involves lower-level mental and motor core tasks.



2080 [G32]
Players search for items, clues and locations to advance in the story.



Whack-A-Mole VR [G16]
Players search for a valid greven circular target amidst distracting green half-circular targets.

Sound Horn [G36]
Players search for the origin of different sounds in a virtual environment and can play, record and swap sounds made by nearby objects.

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