



HAL
open science

Clarifying and differentiating discoverability

Eva Mackamul, Géry Casiez, Sylvain Malacria

► **To cite this version:**

Eva Mackamul, Géry Casiez, Sylvain Malacria. Clarifying and differentiating discoverability. Human-Computer Interaction, 2024, pp.1 - 26. 10.1080/07370024.2024.2364606 . hal-04613102

HAL Id: hal-04613102

<https://inria.hal.science/hal-04613102v1>

Submitted on 15 Jun 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

Clarifying and Differentiating Discoverability

Eva Mackamul
Univ. Lille, Inria, CNRS, Centrale Lille,
UMR 9189 CRISTAL
France
eva.mackamul@inria.fr

Géry Casiez
Univ. Lille, CNRS, Inria, Centrale Lille,
UMR 9189 CRISTAL
France
gery.casiez@univ-lille.fr

Sylvain Malacria
Univ. Lille, Inria, CNRS, Centrale Lille,
UMR 9189 CRISTAL
France
sylvain.malacria@inria.fr

ABSTRACT

Everyday users are confronted with increasingly complex technologies, be that novel introductions or ever-changing and expanding familiar interfaces. This creates the challenge of users needing to perpetually discover new functionality and interactivity, which is rarely addressed when novel technology is proposed. A possible contributing factor for this, is the variety of, often inconsistently defined, associated concepts and a consequent lack of clarity on how to address these problems. We examine usage and definitions of discoverability as well as related concepts and offer clarifications where definitions are ambiguous while highlighting focus areas and limitations. In doing so, we provide a clear definition of discoverability, underscore the separation of system, feature and interaction discoverability and elucidate how other concepts focused on initial interactions differ.

KEYWORDS

Discoverability, Initial interaction, Terminology, Learnability, Communicability

Reference Format:

Eva Mackamul, Géry Casiez, and Sylvain Malacria. 2024. Clarifying and Differentiating Discoverability. In *Human-Computer Interaction*. 1–26. <https://doi.org/10.1080/07370024.2024.2364606>

1 INTRODUCTION

In an increasingly complex technological world, the first condition for allowing one to operate interactive systems is the ability to detect and properly interpret what we are confronted with. This is reflected in usability guidelines highlighting how important it is for users to be able to “figure out what actions are possible [with a system] and where and how to perform them” [94] or stating that “I should be able to “get it” — what it is and how to use it — without expending any effort thinking about it” [63]. According to these guidelines, systems should be designed to support the users’ initial recognition and comprehension of its features. However, modern computing systems often fail to support their own discovery. This is exemplified by a New York Times article stating the majority of users were not using the iPhones 3D touch capacity, simply because

they were unaware of it, highlighting “it’s not something you can really see [...] people don’t understand it” [41]. Subsequently, the 3D touch functionality was phased out and, in 2019, replaced with “haptic touch”. This illustrates how novel interaction methods, that do not facilitate their own discovery, may fail to be adopted in commercial products.

Such commercial products as well as HCI research increase the prevalence of the discoverability problem by perpetually proposing novel interaction devices, techniques, applications and functionalities, without, or with little, consideration of how their future users would know how to utilize them. Instead, research focuses primarily on the feasibility of reliable interaction recognition on the system side [48, 69, 108] rather than the user’s awareness and comprehension of the technique itself. As the iOS 3D touch example shows, this might prove detrimental for widespread adoption. While such considerations may not be the priority of research publications, the introduction of novel interaction methods without any regard of how the user would become aware of them, disregards an important factor of how this interaction would work outside of a lab setting. Be it in research papers or commercial products, system and interaction design generally overlooks how users initially recognize and perform interactions with proposed novel input techniques and functionalities. While this consideration may be most pertinent in products being introduced to a large audience, it should be made at all stages of development. This does not necessarily imply an all encompassing need for design changes, but a need for deliberate examinations of the design and how its functionality is conveyed to intended users.

However, this need is difficult to address, as there is little knowledge of how initial interaction¹ with these novel systems, input techniques and functionalities should be facilitated.

A possible reason for this knowledge gap lies in the wide variety of technical terms used in this context such as affordance [60], learnability [46] and discoverability [94], which have frequently been defined in fuzzy ways. While some of these have been clarified through extensive surveys [46, 84], their inconsistent usage persists. Additionally, the variety of terminology complicates the collection of relevant related work. This illustrates the importance of semantics and terminology, as [50] highlights “the terms we use for concepts are not inherently important, but the semantics behind the terminology commands our attention”.

The term learnability has been investigated in depth, however its considerations often focus on specific aspects related to performance while also covering a timeframe beyond initial interactions. Similarly, discoverability has been primarily investigated in very

Author’s version.

¹In the remaining of the document, we may use the term “initial interaction” alone to refer to the first time a user successfully interacts with a novel system, input technique or functionality.

narrow contexts such as public displays or voice and gesture user interfaces as well as in conjunction with learnability. By often being considered solely as a means to achieve learnability [35, 39], discoverability does not receive the attention nor the holistic investigation its pervasive effects should command.

In an attempt to clarify this situation, we review discoverability and its usage in the context of HCI. We then expand our survey to incorporate other concepts concerned with the initial stages of first-time interactions and found various terms are used to describe related interaction phenomena. To clarify these terms, with often ambiguous usage or definitions, we analyse how they have been utilized. We then contrast the surveyed terms in order to elucidate and highlight their different focal points, which address specific interaction problems, as well as their limitations and relation to one another.

In doing so, we provide an extensive literature review of discoverability, illustrating its many different application areas in HCI and, through highlighting the differentiation of *what* needs to be discovered, emphasize its importance. We offer a clear and comprehensive definition. Further, we highlight the variance of semantically related terms that have been used interchangeably and advocate for their separate consideration. Consequently, we show how the importance of supporting discovery is a well known problem, which suffers a lack of recognition due to a lack of clarity, which we aim to provide.

2 THE PROGRESSION OF INITIAL INTERACTIONS

First time interactions with something that is novel to a user follows a given path. We present a basic timeline in Figure 1 in order to clearly communicate which part of an interaction we refer to in later sections.

First, an interaction needs to be triggered. This can happen through multiple factors, for example internally through a goal to interact, curiosity, happenstance or errors, as well as externally through examples, word of mouth or instructions. For example, seeing someone else use a feature might trigger a user to seek out said feature, or a user might accidentally encounter new interaction methods by failing to perform another one correctly (e.g. trying to tap a button but lingering too long and performing a long-press instead). As the final example suggests, for some interaction triggers the encounter with an object happens simultaneously while for others, like the first example, an encounter follows the interaction trigger. This is then followed by perception which depends on the sensory affordance [50] of the object in question as well as considerations of attention and awareness. If the user perceives the object, they then process what they perceive [21]. Given they arrive at an accurate conclusion of what they are perceiving, they *comprehend* what they are interacting with. To illustrate, consider the previous example of a user lingering on a button for too long. They may *perceive* a difference in feedback to the intended "tap" interaction. To successfully *discover* the interaction method, they need to then *comprehend* that the difference in outcome was caused by the difference in their input. This then allows users to consciously interact with something and, depending on the difficulty of the interaction, immediately or eventually successfully interact with

the object. While interactions like a variance in touch duration can be performed successfully immediately upon comprehension, other interactions like gestures [13, 77] or input sequences [110] may require repeated attempts.

3 DISCOVERY IN HCI

The initial discovery of interaction possibilities is the basis that allows users to engage with and utilize interactive technology. Such discoveries rely, before all else, on the potential user's ability to *perceive* relevant parts of the system, *comprehend* them as such and interpret their functionality correctly.

However, initial perception and comprehension of systems and interactivity are inhibited by progressively more complex technology, which allows for a wide variety of functions and different input methods. This is exacerbated as visual guidance is reduced to avoid cluttering interfaces [99, 100]. Consequently, initial, intuitive perception and understanding of interaction opportunities and features is progressively harder to achieve. The resulting lack of comprehension of, or complete obliviousness to, the tools available to a potential user can lead to either complete disregard of a system or missed opportunities to use a system to its full potential [6, 55]. This creates a significant issue, not only for designers wanting their system to be used, but also for potential users that would benefit from, or are required to interact with, a system they fail to recognize or comprehend.

In an effort to investigate the persistence of discovery problems and possible solutions, we survey the concept of *discoverability*, its application areas and proposed definitions.

3.1 Surveying Discoverability

Definitions and application of the term *discoverability* vary, but generally describe users encountering something new that they were not previously aware of, therefore *discovering* it.

The concept of discoverability is widely used in the context of content discovery within search engines, databases and library systems [74, 85]. This focuses on improving the likelihood of users encountering content relevant to them such as media, websites, datasets, social media profiles or academic research without searching for it specifically. However, our focus is on discoverability that facilitates and improves interactions. In the context of usability and human-computer interaction, the term discoverability was popularized by Don Norman, who describes it through the following question:

"Is it possible to even figure out what actions are possible and where and how to perform them?" [94, p.3]

However, this definition incorporates multiple concepts both through the questions *what*, *where* and *how* and the fact that actions can be performed by both the user and the system, making the focus of this definition ambiguous. In the context of HCI, discoverability can be split into three different focus areas: System, Interaction and Feature. System discoverability is focused on whether potential users notice the overall system and recognize it as something they can interact with, for example that a public display is interactive in a mall. Interaction discoverability is concerned with whether users can identify and comprehend novel interaction and input methods when they encounter them without instruction or guidance, for

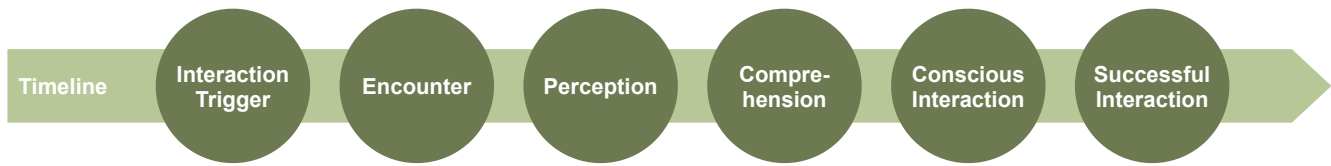


Figure 1: Conceptual timeline of the different stages of initial interaction, moving from before the interaction is initiated to successful interaction.

example that a force press can be performed on an iOS icon to reveal a menu. Finally, feature discoverability covers the user’s ability to discover features or functionality they were previously unaware of while using a system, for example a new tool in a graphics editor like Adobe Photoshop.

While this separation between different discoverabilities has been implicit with research specifying a focus on interaction discoverability [23] or feature discoverability [112], these focus areas have not been collated and considered in relation to one another. This is unfortunate given that, even though they are separate considerations, they are interconnected. System discoverability is a precondition for users to discover different aspects of said system. Similarly, features can only be accessed and discovered if the user is able to successfully interact with the system by being able to discover the interaction methods available to them. Furthermore, while features may be accessible through a variety of input methods, often times novel input methods also reveal new features linked to them exclusively. For example, the shake-to-undo function on iOS previously was the only way to activate system-level undo, making the discovery of the *interaction* method (shaking) crucial to the discovery of the *undo feature*. The clarification of *what* needs to be discovered is essential when examining the connection of different discoveries since they may not always be facilitated through the same measures.

To summarize, discoverability is always concerned with the user becoming aware of and comprehending something. *What* a user can or should discover can be separated into 3 categories illustrated figure 2. The following sections consider these different focal points of discoverability in more detail.

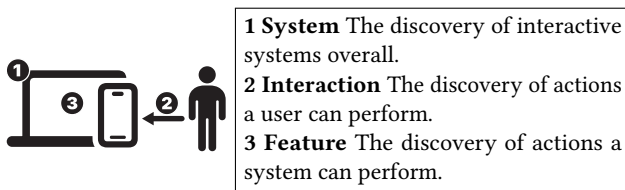


Figure 2: Separation of three types of discoveries

System Discoverability. In the context of complete systems, the term discoverability is often used to describe the user’s overall awareness of a system’s existence and interactivity. As such it is commonly considered in the context of sensing systems [14] and public displays aiming to attract users. [23] describes the discoverability process for large public displays as “*the process through which a user transitions from being unaware of the system to interacting with*

it to, eventually, effectively using the system”, with the particular aim to focus on the earlier stages of display interaction. Their work focuses on capturing attention and consequently guiding interactions [25], appropriate methodology to study attraction power of interactive public displays [26] and ultimately how to increase casual engagement with large, public interactive displays [24]. Other examples of system discoverability investigations include public polling interfaces [52], multiplayer games [29] and the transition between implicit and explicit interaction [121].

Similar research has been conducted without explicitly referencing discoverability, including investigations of “*how passers-by notice the interactivity of public displays*” [89] by evaluating how visual feedback to incidental movements by potential users in front of the display effectively communicates interactivity and invites interaction.

Once investigations of discoverability go past initially attracting users, getting their attention and making them aware of the system, research can move into the territory of interaction discoverability as designers want potential users to understand how to interact with their system.

Interaction Discoverability. Interaction discoverability describes the ability of users to notice and identify interaction and input possibilities they were previously unaware of. As such, the focus of interaction discoverability research is often on overall novel interfaces such as Voice User Interfaces (VUIs) [39, 61, 73, 103] or Embodied Interactions [19, 20, 40]. Other examples are interactions with, among others, tabletops [49], mid-air gestures [77, 123], interactive touch surfaces [42–44], VR objects [91] or smart textiles [97]. Notably, both VUIs and embodied interactions commonly lack visual signifiers suggesting the possible interactions to new users. These examples indicate that the discoverability of interaction methods is primarily studied if researchers or designers, proposing a new method, already presume discoverability to be an issue. However, novel interactions in traditional interfaces, that users are not aware of, such as keyboard shortcuts on desktop, force-press on mobile and gestures on both, similarly present discoverability problems that designers commonly overlook. Further, the majority of interaction methods examined are yet to be established with a wide user base and therefore lack the advantage of similar interactions with other devices aiding the discoverability of the input methods in question. Meanwhile the discoverability of generally established interactions, that may be novel to users due to unfamiliar context, is generally ignored. As public displays also commonly employ less established interaction techniques than devices designed for personal use, research about their design often includes considerations of how to communicate their interaction possibilities and

functionalities. In this context, a lack of interaction discoverability has also been termed *interaction blindness* [96], while systems with well supported system and interaction discoverability have been termed walk-up-and-use systems [31, 80], implying the perception and comprehension of interaction to be inherent to the system.

Feature Discoverability. Feature discoverability describes the ability of users to discover individual parts and features of a system they were previously unaware of.

Reports [47, 116] suggest that only around 20% of features within applications are commonly used. While this can partially be attributed to some features not being of any interest or use to some of the users, other features are simply never discovered. This discovery is often times hindered by the fact that the system is functional and the user is able to perform a majority of their intended actions without being aware of all features at their disposal. This can especially be the case if users are not encouraged to explore further options because, what a new feature offers, can be achieved in another, potentially more strenuous, way that the user is already aware of. On the other hand, if users are not at all aware of the existence of a function in the system they are interacting with, their lack of expectation and familiarity may lead to them overlooking potential signifiers. Another example of features suffering discoverability problems are items hidden deep in the hierarchical menus [2] which are not explored by users or features that are simply overlooked because they are not essential to the user.

While feature discoverability has not been addressed in a holistic fashion, it has been explored in specific areas. For example, research in this category considers issues in software development [33, 35, 78, 101, 118] or the discoverability of applications [54] and menus [111] in public displays. Similarly, the discoverability of existing and new functionality for operating systems [98] and applications [86] is explored.

Furthermore, feature discoverability is considered without explicit reference to the concept, for example, by [27]. They describe *vocabulary extension* (for example increasing knowledge of keyboard shortcuts) as one domain of performance improvement. Under this term they consider ways to help users broaden their knowledge of the range of available functions in an interface, which mirrors feature discoverability when successfully implemented.

3.2 Defining Discoverability

While considering the same notion and process, all of the “discoverabilities” identified are focused on different aspects of an interaction (i.e. system interactivity overall, possible user actions or possible system actions). This illustrates how varied the understanding, of what discoverability describes, is. Despite these discrepancies, discoverability is rarely specified or defined.

The definitions that are offered in the literature vary widely in scope and specificity. Some offer loose explanations of discoverability such as “*the effort required to locate or “discover” an application amongst others*” [54] or “*the ability for users to find and execute features through a user interface*” [61]. Others define discoverability specifically for their context like noting how “*the “invisible” nature of VUIs can challenge users’ ability to discover its capabilities and limitations*” [39] or how gestural interfaces “*are not discoverable*

in the sense that it is hard to know what gesture to do and we often cannot look it up in the way we would look at a menu to see what options are on it” [40].

Two comprehensive definitions that inform our understanding of discoverability come from [22] and [114]. Cardello described discoverability as users encountering “*new content or functionality that they were not aware of previously*”. Srinivasan et al. consider discoverability in the context of speech input commands and make the important distinction of what discoverability entails in their interpretation: “*Discoverability, in this context, entails: (1) awareness — making users aware of the operations that can be performed using speech; and (2) understanding — educating users on how requests should be phrased so the system can interpret them correctly*” [114]. Combining these approaches, we consider discoverability as:

The ability for users to perceive and comprehend a system, function or input method as such when encountering it, despite a lack of previous awareness or knowledge. This may be through intentional effort or serendipitously.

As such, discoverability covers the time period from interaction being triggered, the user encountering and perceiving the system, function or input method to the user comprehending what they have encountered.

3.3 Designing for Discoverability

The varying definitions of the term discoverability have led to a lack of clarity on how to design for it and even a discussion on whether designing for discoverability is possible or desirable.

[39] look at improving design for discoverability of VUIs by surveying previous projects with the same aim. Notably all surveyed projects resort to converging purely voice-based interfaces with visual assistance to improve discoverability, exemplifying the challenge of discovering interactivity that is not visually communicated. They identify the characteristics “*Visualizing what can be done*”, “*Visualizing what can be said*”, “*Visualizing New Discoveries*” and “*Contextual Relevance*”. Notably the differentiation of “*what can be done*” and “*what can be said*” mirrors the discovery of features and interactions while “*visualizing new discoveries*” and “*contextual relevance*” can be seen as general principles when designing for discoverability in VUIs.

The *VoiceNavigator* [28] included in this review, revealed an established discoverability problem that accompanies the benefits of visualization - clutter. When the display showed too many supposedly helpful prompts, these discovery prompts fought for the users’ attention and caused confusion and frustration rather than easing the interaction. This problem is also discussed by [15] who suggests that discoverability overall is a myth by arguing that if everything is discoverable - nothing is. Maybe speaking hyperbolically when making this initial argument he then goes on to discuss the problem statement of clutter and makes the argument to prioritize discoverability of important and essential features over others. This reasoning suggests not the absence or non-viability of discoverability but the importance of a *hierarchy of discovery* and proposes a prioritization according to how commonly things are used by how many people. He notes that there are exceptions to such hierarchies like essential tasks not often needed but enabling overall use or safety as well as emergency features that, while hopefully not

required, should be immediately discoverable and accessible should the need arise. Although prioritization is an important guideline, it should be noted that the one offered here is oversimplified as many tasks can be achieved in multiple ways. Similarly, if a newly introduced feature suffers from bad discoverability, it may be used by very few people simply because potential users are not aware of the option. While Berkun's considerations are certainly relevant and inform *what* should be prioritized for discovery, they only graze the question of *how* to make it discoverable by providing a list of resources that can be utilized to “emphasize” things.

[111] note the scarcity of research focusing directly on designing for discoverability in public displays. They reviewed existing literature and found that written instructions near the display aided successful discovery (of the system as well as available interactions and features) while also considering that ambiguity in design can entice users to engage by appealing to their natural curiosity. Gradual discovery, through scaffolding of continuously revealed elements, was identified as a way not to overwhelm users and therefore ease discoverability [56, 125]. This finding again supports the notion that clutter or too much visual representation at once does not benefit discovery. Additionally, they found that subtle animation can be helpful to suggest to users that objects can be manipulated in a certain way. They also noted, that touch gestures particularly suffer from bad discoverability due to a lack of visible controls affording manipulation [53]. Notably, such subtle animation has since been implemented for Instagram Reels (Version 285.0.0.25.62), where the possibility to swipe up to see the next video is occasionally suggested by a small animation of the next video moving in from the bottom. Seto et al. confirm the statement that animation can be helpful to suggest interactions in their own experiment and add the design recommendations, that interface elements be discernible by utilizing universal GUI elements, and giving immediate feedback to exploratory interactions.

Furthermore, their consideration of written instructions touches on the use of external sources supporting discovery. Especially complex systems designed for expert users are difficult to make independently discoverable. Therefore, designers circumvent having everything discoverable by itself through the use of instructive material like manuals. This creates different problems due to the non-use of manuals [16]. There are attempts to rectify this issue, while utilizing the benefits of formal instructions, by incorporating instructive material in the system. One way to do so while avoiding permanent changes is the temporary inclusion of UI elements focused on aiding understanding. An example of this is the discontinued Microsoft Office Assistant attempt “Clippy” that offered context-related tips. [58] describes this as onboarding, defining it as “*the process of getting users familiar with a new interface, using dedicated flows and UI elements that are not part of the regular app interface*”. They do, however, highlight that “*instructional onboarding should not be used to supplement poor design*”. While these methods of supplementary material can be useful and are a necessary consideration in novel user interfaces, inherent discoverability should not be disregarded in favor of defaulting to discovery support through explicit instructions of how to use a system. Rather designers should aim to make the system *communicate* its interaction possibilities independently wherever feasible.

Investigating this, [83] examined how novel input techniques for smartphones can best be communicated to users and identified *depiction* (visualizing input techniques through icons), *pop-up* (modal dialog shown when the technique is available) and *tutorial* (centralized explanation of all available input techniques). Their study revealed that depiction was preferred. However, they comment that the most appropriate communication method depends on the context of the interaction. Nonetheless, the preference for depiction further supports the notion that instructive material is not a sufficient, or popular, replacement of visual signifiers supporting discovery.

Considering depictions, [66] investigated the understandability of different visual presentation of single-handed *microgestures* and extracted design guidelines on which features of such gestures should be represented. Notably, they observed which microgesture users thought to be possible given a visual representation, without any prior knowledge of the available gestures. Their conclusion is that in order to optimize understandability, the interface should not present only the trajectory of the microgesture, but also the *actuator* (the finger initiating the microgesture).

To assess how similar the discussed academic recommendations are to practical applications, we reviewed tips and guidelines provided for interaction, usability and UX design to support discoverability. We limited our search of non-academic guidelines to immediate search engine results for the terms “designing for discoverability” and simply “discoverability” to identify practical advice that was commonly available and most likely to be accessed, read and utilized widely. Through this we found and compared 4 articles advising readers, two of which were quite detailed with 15 [126] and 12 [12] tips respectively. The other two articles, took more direct, feature focused, approaches and in doing so offered 5 [38] and 3 [117] recommendations. The 2 more detailed articles had 5 overlapping recommendations, one of which was mirrored by another of the shorter articles. They are as follows:

Design familiar interfaces: Follow universally accepted standards and design conventions to ease recognition for the user.

Group elements logically: Items with strong relationships or similar functions should be grouped together.

Simplify: Reduce the number of available options to prioritize important content over superfluous extras.

Consider size: Size interface elements appropriately to direct attention towards key information. Both [126] and [38] note that bigger elements are easier to discover.

Provide visual cues: Guide users towards what to do and see next.

These, as well as other parts of the full articles, have significant overlap with the previously considered findings. Examples of recommendations or challenges identified are clutter [12, 15, 28], use of hints and tips [58, 126], animation [12, 111] and prioritization of what to emphasize [12, 15]. Notably, some of these guidelines, such as a hierarchy of prioritization or grouping and simplifying options, mainly apply to feature discoverability.

3.4 Research Addressing Discoverability

The HCI research community frequently proposes novel features and ways of interacting without considering how users would discover this functionality (e.g. [7, 11, 45, 48, 69, 107, 108, 129]). However, rare exceptions exist of authors who consider how to alleviate this problem, although not always with explicit reference to the concept of discoverability. These considerations take the form of either attempting to make proposed novel interaction methods discoverable from the beginning [8, 9, 37, 43, 123] or improving the discoverability of existing features and input methods [43, 72, 81, 82, 111]. Additionally, existing designs are compared and evaluated [39, 59, 111], adapted design procedures are suggested [19] and study methodologies proposed [24, 26] in an effort to improve discoverability.

For example, [8, 9] introduced the novel undo mechanism *Dwell-and-Spring* and considered whether users would discover the technique. They found a lower discovery rate than expected and concluded that there may be a trade off between the stronger feedforward required to improve discovery and the design aim of making the mechanism easy to discard. [37] attempted to adapt hotkey use for touch-based devices by testing different designs and found their designs were discoverable and yielded efficient performance. [123] explored how initial mid-air gestures on public displays may best be revealed to potential users, fostering their discovery. They found that *temporal division*, in which the running application is interrupted to show the gesture on the full screen was most successful and noted that the discovery of gestures was aided by imitation of other users and competition within a group. Another approach is taken by [77], who recognise the discoverability challenge for around-device input and explore the feasibility of context aware hints. They found that this guidance helped users discover their interaction method.

While these explorations focus on the discoverability of interactions they themselves introduce, other research focuses on improving existing designs. [43] aim to improve the discoverability of force sensitive text selection and introduce techniques that provide improved feedback through visualization. Although they compare the discoverability of their designs to the normal iOS design, they informed participants beforehand that the touchscreen had force sensing capabilities and found that all overall techniques were discovered by participants while parts of them remained unclear to some. [81] created *Patina*, a system visualizing usage data in order to replicate usage clues through wear and tear in physical objects. One of the benefits of the displayed usage heatmaps they consider is *“exposing functionality relevant to a specific document”*, which in turn eases the discovery of these functionalities. While a short-term internal deployment had users reporting increased exploration out of curiosity what others were using, the limitations of the study make it unclear whether these effects would persist. Nonetheless the study results, similarly to [123], point towards a social component of discoverability. [34] built a puzzle game in an effort to improve learning through discovery-based games. The design aimed to incentivize the users independent discovery of different features within Photoshop through gamification. Furthermore, command recommendation systems have been explored [72, 82] which suggest unused or novel commands relevant to the user or task

in an attempt to improve and foster the discoverability of these commands. Finally, [19] consider how design methodology can be optimized to elicit discoverable full body interaction movements.

Additionally, some studies include partial considerations of discoverability. [17] consider whether different feedback successfully communicates the success of the interaction but do not expand on or study whether this feedback and feedforward aids in the discovery of the methods. [42] claim the design of their technique improved discoverability, but do not include a study confirming that assertion. [1] list discoverability as one of their goals and gave participants time for independent discovery within their study before being introduced to the remaining functionality that was not discovered. They report *“encouraging”* results that participants were able to discover functionality on their own but do not share any concrete data regarding discovery.

While these considerations confirm the continued consideration and relevance of discoverability, they are rare in comparison to the number of novel interaction techniques and systems proposed every year, not to mention persisting discoverability problems in existing systems.

4 RELATED INTERACTION CONCEPTS

Given the prevalence of difficulties with initial interactions, but also the lack of clear characterization, significant research has been conducted to examine, ease and improve the beginning phases of interaction. This research uses and introduces a range of terms to summarise these difficulties which, like discoverability, have been used with varying definitions and interpretations. This has resulted in differing interaction concepts being used to describe overlapping problem statements. Their close semantic relation and them being applied to similar interaction contexts, have further led to confusion, with these terms being used in conjunction or even interchangeably [39, 61, 87]. Consequently, which term is being used to describe a specific problem may vary between researchers, making a comprehensive look at the problem statement, and research addressing it, difficult. As [5] point out when considering *“intuitive”*, which is yet another word often used with inconsistent definitions when describing initial interaction goals, *“a rich and evokative word [...] is wasted as long as it sits in a fog of uncertain association”*. The following section will examine how various concepts, which are important to initial interactions and related to discovery, have been used and defined. Further it will highlight how their different focus points differentiate them from discoverability and one another and why their separate consideration matters.

The lack of consistency in how discoverability is defined and used as well as the overlap with concepts considered here led us to approach the problem through a scoping review [65, 102] in order to explore which concepts are used as well as why and how they differ. We combined multiple methods to identify relevant terms. Due to the vast amount of interaction concepts connected to discovery, we limited this investigation to interaction research concepts that describe the users *ability* to interact with and comprehend a system initially. Following an exploratory approach we first identified concepts that were commonly linked with discoverability within the literature identified when clarifying discoverability (e.g. learnability and findability [22, 38, 126]). We then expanded our search

to definitions of concepts in standard work that closely resemble definitions of discoverability (e.g. navigability [105]). In addition, we examined semantically related words to the verb discover. *Find*, *learn* and *notice* all appear alongside multiple other synonyms. We then confirmed whether these terms are used within HCI literature to describe problems around initial interactions and identified findability, learnability, noticeability as proposed concepts whose definitions and usage overlaps with discoverability. Finally, we identified terms that appeared repeatedly in the literature examining discovery and the initial stages of interaction (e.g. guessability and communicability). Subsequently, we examined the validity of our selection through investigating definitions and usages of the identified concepts.

While this selection of concepts is broad and highlights how many approaches focus on different aspects of initial interactions, we make no claim to cover *all* relevant interaction concepts. Nonetheless, the following section covers the concepts most frequently overlapping with, or considered alongside, discoverability.

4.1 Learnability

In HCI, the beginning phases of interaction have been primarily examined in the context of *learning* how to interact with the system. Consequently, learnability is the most commonly used term to describe the users' first understanding and subsequent improvement when using an interactive system.

The [46] survey of learnability research found that, while there was an agreement among researchers that learnability is an important aspect of usability, there was a lack of consensus in the definition, evaluation and improvement of learnability in user interfaces. They grouped definitions into two main categories: *initial learnability* and *extended learnability*. The definitions falling under *initial learnability* concerning themselves with new users gaining proficiency with a system and *extended learnability* definitions expanding this, to incorporate long-term learning and mastering a system. A brief survey of literature related to learnability since then shows that definitions widely appear to still align with the categorization established by Grossman et al., with some publications focusing on initial learnability [4, 39, 87] and others on extended learnability [3, 36, 71, 79]. Some also directly cite this survey [36, 39, 71, 79, 87], suggesting that the compilation and clarification of learnability definitions has been embraced and utilized. The scope of these definitions has been discussed, with [79] as well as [109] arguing that the assessment of initial learnability, while crucial for the study of the system, at best represents a measure of the system's *intuitiveness*. Notably, Santos and Badre's considerations predate Grossman et al.'s survey. They use the term "initial learnability" to describe learnability for first-time users. Neither they nor Marrella and Catarci explicitly define intuitiveness. Nonetheless, the separation of learnability into *initial* and *extended* illustrates the broad use of the term in both time frame and scope.

When specifically considering initial interactions, initial learnability is the pertinent consideration and a part of the success of those interactions. Initial learnability is commonly used as a performance measure for interaction occurring for the first time. Literature examining it concerns itself with users performing well in a task [4, 39] and how initial usage may be easily facilitated and

improved. Notably, initial learnability often does not address the first identification of a system, function or input method as such and largely fails to address interactions happening without specific intent.

Nonetheless, learnability is often mentioned in conjunction or synonymously with discoverability [39, 61, 87]. Many of the offered explanations of discoverability either allude to or directly reference *learnability* by referring to discoverability as "*a means to achieve learnability*" [39] or describing discoverability as a challenge one is confronted with then trying to *learn* a system [35]. Furthermore, definitions of discoverability as, for example, "*the ability with which a user can find features of the system to increase proficiency over time*" [101] resemble those offered for learnability. It is therefore no surprise that the differentiation of the terms can be ambiguous.

Differentiation between Discoverability and Learnability. Since the concepts of discoverability and learnability have often been used in conjunction or defined interchangeably, it is pertinent to highlight their differences to emphasize the importance of separate considerations of discoverability. To elucidate these differences, Figure 3 depicts a timeline of initial interactions and where each concept applies.

As an example, a user we name Alice, who is taking pictures on her phone, tries to swat away a fly that keeps landing on it. In the process she twists the phone twice, triggering the "Switch Camera" function, changing from the main camera to the front facing-camera. The unintentional action *triggers* the interaction and leads to her first *encounter* with the function. Notified by the vibration of the phone, she realizes something happened and inspects her phone, noticing the camera view has switched - her first *perception* of the function. If she is able to deduce that the movement of her hand has triggered the function (*comprehension*) she has successfully discovered it. If she does not understand this connection, she finishes this interaction without discovering the feature. The actual interaction with or usage of the feature is not part of discoverability. Her ability to utilize this feature is covered by learnability. There is a separation between conscious and successful interaction since, depending on the complexity of the interaction, successful interaction may require skills beyond the simple understanding of the action. Initial learning covers how to first consciously and intentionally use the feature successfully, while extended learning covers perfecting its usage by incorporating it seamlessly into her usual interaction.

When considering the abstract sequence in Figure 3, note that, while it depicts one isolated interaction, discoveries and learning can happen continuously and concurrently as users encounter new interactivity within a system and during other interactions. Furthermore, although the diagram suggests a strict separation between serendipitous and intentional interaction, these commonly overlap. Discoverability and learnability are each more applicable to the circumstance they are placed in, but they can both occur serendipitously or intentionally.

To elucidate how this timeline applies in an intentional context, we again use Alice as an example user. After she discovered the "Switch Camera" function, she is now curious if there is other functionality she doesn't know about. The interaction overall is triggered by her curiosity rather than the previous accident. Through this the entire discovery phase falls into the category of *Conscious*

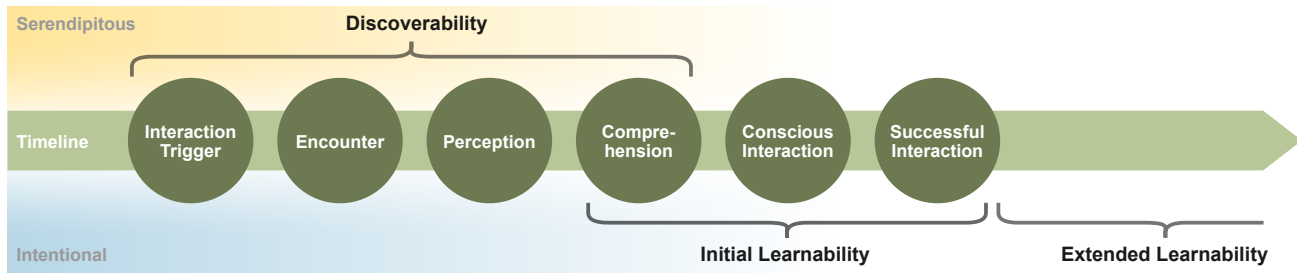


Figure 3: Timeline of progressing initial interaction. Both discoverability and learnability apply during this timeframe and influence the interaction’s occurrence and success.

Interaction. She encounters a "More settings" button and discovers the option to use gestures on the volume keys and double taps on the screen to optimize her camera usage. As she is consciously exploring and seeking out functionality, encounter and perception are likely to coincide and immediately followed by comprehension. The functionality is displayed (*encounter*) and as she is consciously exploring she immediately sees (*perceives*) it. In the case of functionality in menus (such as this example) this is most likely followed by immediate comprehension.

While both examples here involve direct interaction, in other cases external interaction triggers such as examples may lead to discovery without any action from the user as they encounter functionality passively through someone else’s action. If they still perceive the action and reaction and comprehend their connection they may discover functionality without ever interacting.

Overall, discoverability precedes and triggers learning. If a potential user encounters functionality but does not notice or comprehend it as such, they are unlikely to interact with it consciously or retain information that would allow improvement of the interaction. However, learnability exceeds discoverability in both scope and time frame as it continues long beyond the initial interaction. Even initial learnability, which is generally focused on the interactions of first-time users, succeeds the discovery phase by encompassing the user’s ability to perform the interaction *successfully*. As Berkun notes, “*discoverability does not guarantee success*” [15]. He argues that simply being able to discover something, does not necessarily mean people can, or know how to, use it. For example, users being confronted with a keyboard and being able to understand that they can press the WASD keys to interact with a desktop game does not guarantee they will deduce how to use said controls to play a game. Additionally, if the interaction through those keys in the game is challenging, the sole discovery of the interaction method does not facilitate successful usage. Thus, discoverability is not a measure of efficiency or improvement. In contrast, learnability is often considered in the context of performance. Accordingly, considerations of it generally assume the users know how to perform certain interactions even when encountering the system for the first time. Consequently discoverability is a precondition for the learnability of interactions and features the user is unfamiliar with. In order to learn how to use something, one has to first become aware of and comprehend its existence.

When learnability is examined as a whole, this often incorporates discoverability. However the prevalence of interaction failures

due to discovery problems shows that the two concepts should be considered independently before any conjoined examinations. Nonetheless both phenomena occur within a similar timeframe of initial interaction and occur successively. They may therefore be influenced by similar factors.

4.2 Communicability

Communicability as a concept within Human Computer Interaction originated in the context of Semiotic Engineering by Clarisse de Souza. [32] describe communicability as “*the distinctive quality of interactive computer-based systems that communicate efficiently and effectively to users their underlying design intent and interactive principles*”. In an earlier publication [104] describe a communicability evaluation method aimed at “*measuring whether the software successfully conveys the users the designers’ intentions and interactive principles*”. How such system communication is presented was investigated by [83] and is discussed in Section 3.3.

In summary, communicability describes the system’s ability to communicate its purpose and interactivity to the user. It presents a system perspective of the discovery and comprehension process but without actually focusing on whether or not users will perceive these principles.

Differentiation from Discoverability. Communicability, in contrast to discoverability presents a solely system based approach. As such it considers how a system communicates with the user but is not focused on a specific phase of interaction. Furthermore, discoverability includes interaction triggers in the environment, user characteristics as well as the context of interactions occurring which communicability, due to its system focus, does not.

4.3 Navigability

Due to the spatial connotation of the word “navigate”, navigability has been used substantially in literature concerned with navigable media such as 3D environments and how to create them [30, 122, 124]. However, it has also been defined in broader terms. [105] describe navigability with the question “*Is it obvious what to do and where to go in an interface?*” while [115] define navigability simply as “*Ease of navigation*” (of webpages). This discrepancy and vagueness present an issue when considering that a substantial amount of literature mentioning or focused on navigability does not offer a definition [51, 67, 68, 113].

Given the differences in definition it is necessary to clarify that we consider navigability as the ability of a system to communicate to the user how to (optimally) move through it considering location and timing in the context of this work. Whether a system successfully guides a user through which options are available to them at a given time and aids them in moving towards intended interactions, influences the success of initial interactions. This is especially due to the user's initial lack of independent knowledge of available content and what to do when.

Generally, navigation assumes a destination, leading to this term being primarily used when describing users with concrete intentions and purpose. Navigating without a concrete goal e.g. surveying in a leisurely and casual manner has been described as *browsing* (Oxford Languages) and relies on similar characteristics.

Differentiation from Discoverability. While there is no evidence of these concepts having been used interchangeably, the proximity and relation of their focus points make their conjoined consideration helpful to clarify how they differ. While discoverability includes considerations of awareness and how users notice interactions, navigability is focused on how to move through a system considering timing and location. Consequently good navigability can aid discoverability by easing access to different parts of a system and emphasizing those relevant to the interaction context. Notably navigability is especially relevant when considering the discovery of features.

4.4 Findability

In HCI findability was introduced in the context of finding individual websites on the internet by [88] and has since been adapted to a much broader scope of describing “*the degree to which a particular object is easy to discover or locate*” [105] or “*how easy is it to navigate and locate objects in the system*” [95]. [22] defines findability as “*users can easily find content or functionality that they assume is present in a website*”.

For the understanding of findability in this context we adapt Cardello, to include other functionalities and usage contexts than websites, and consider findability as the ability to locate or come upon a system, feature or input method the user knows or assumes to exist within their current usage context through conscious effort. As such it requires the previous knowledge or assumption of the user that something they want to *find* is present somewhere in the system. It therefore presumes the user knows *what* they are looking for, and is concerned with how they know *where* to find it. As such, navigability enables findability by allowing potential users to move through a system to locate what they are searching for.

Overall, the ability to locate a system, feature or input method greatly influences the user's ability to begin interacting with it since if they fail to do so, they never encounter the interaction in question.

Differentiation from Discoverability. [22] differentiates discoverability and findability through the users previous knowledge and awareness, defining findability as “*users can easily find content or functionality that they assume is present in a website*”, and contrasting it with discoverability defined as “*users encounter new content or functionality that they were not aware of previously*”. Findability,

through the implication of searching to find, is intentional while discoverability can be both intentional and serendipitous. Additionally findability assumes the awareness of the user and their conscious pursuit of a goal.

4.5 Guessability

Guessability has been defined as a quality “*of symbols which allows a user to access intended referents via those symbols despite a lack of knowledge of those symbols*” [127] as well as a measure, considering it as “*the effectiveness, efficiency and satisfaction with which specified users can complete specified tasks with a particular product for the first time*” [57]. However, guessability is most commonly used in the context of *guessability studies* who often focus on gesture-based interactions [70, 92, 106, 120, 128]. [120] describe “*Guessability or user-elicitation studies*” as useful as their results “*allow building general taxonomies or specific gestures when a high agreement rate is observed among participants*” who are “*prompted to create gestures for a particular action, with no given training or feedback*”.

Consequently, guessability is frequently being considered as a methodology to evaluate other usability principles or inform the design process rather than a principle to be defined separately. However, when considered as an independent concept, as the definitions provided show, guessability has been used to describe both, a quality of a system, and a measure of how well this quality facilitates interaction.

We follow Wobbrock et al.'s definition of guessability as a quality, but extend it past the original definition focused on symbols, to incorporate all parts of a system. Consequently, we consider guessability as the quality of the system allowing first time users to estimate the function of systems, features or input methods they encounter despite a lack of prior knowledge of them. This definition makes the importance of guessability to initial interactions obvious as it is explicitly focused on initial, or first, interaction. The ability of the user to guess the functionality of what they are presented with alleviates the difficulties unique to initial interaction and increases the likelihood of a successful interaction.

Guessability can aid discoverability, learnability, navigability and findability by making it easier for users to approximate how to interact with and navigate the system. It also contributes to the overall communicability of the system.

Differentiation from Discoverability. In contrast to discoverability, guessability does not incorporate considerations of awareness or interaction context. It solely considers whether in the moment of perception, the user can estimate the meaning of what they are presented with without extended consideration, previous knowledge or outside help. While this moment of perception necessarily includes context, as users do not encounter anything in a vacuum, guessability is focused on the immediate impression of the user rather than a careful consideration of context. As such it aids discoverability but does not include considerations of how the encounter in question came to be or what its outcome will be.

4.6 Noticeability

Noticeability describes the likelihood of something being *noticed* i.e. capturing someones attention and making them conscious of something's existence. In HCI, noticeability has been explored primarily

in the context of notifications and interactivity. Considerations around notifications commonly explore the impact of visual features like size, color and motion of notifications as well as location in the context of differing factors such as background [90], resemblance with a primary task [76], AR HMDs [64] and gaze contingent positioning [62]. Explorations of noticeability of interactivity often occur in the context of public displays, with both the system itself and its interactivity needing to be *noticed* which is then followed by thoughts on enticing engagement and facilitating understanding [26, 90, 111]. However these considerations do not always explicitly refer to the concept of noticeability. [123] measure a “noticeability rate” which they define as the percentage of users that notice a provided hint about interactivity on a public display. They explicitly separate this noticeability from comprehensibility which they define as the percentage of users that understand the presented interaction technique.

Differentiation from Discoverability. Noticeability, while possibly a part of discoverability by focusing on the potential users perception and attracting their attention, does not include considerations of comprehension. As such, noticeability is often considered in connection with system or interaction discoverability, especially in the context of public displays. These examinations often explicitly separate noticeability from comprehensibility [123] or understanding [89].

4.7 Elucidating Differences - How Do These Concepts Compare

As is shown in the previous sections, various interaction concepts have been used with inconsistent and overlapping interpretations due to their semantic closeness and being applicable to a similar timeframe. This section aims to elucidate the different focus areas these concepts represent and how they relate to one another.

Figure 4 shows an expanded version of the sequence of actions considered in Figure 3 in an aim to visualize the different focal points and overlaps. While this is not a definitive classification, it provides guidance for the general parts of initial interactions, different concepts focus on. However, specific parts of the timeline may vary depending on context. Additionally, while this selection of terms is extensive, it is, by no means, exhaustive. Not only are different terms introduced and redefined constantly, other concepts are often used to describe similar problem statements from different perspectives.

In contrast to all other concepts considered, communicability applies to the entire timeframe presented in the sequence of actions, however it presents a focus on the system capabilities and how they are communicated rather than the user interaction itself. As such, it presents an overarching concept that highlights the importance of system design aimed at communicating interaction possibilities and outcomes to users, but does not focus explicitly on initial interactions and the context surrounding and enabling the interaction.

Navigability is focused on the comprehension of *where* and *when* in order to facilitate movement through a system considering location and timing. Consequently, a sufficient level of navigability is necessary to enable findability. Without a comprehension of how

to move through a system, it would be impossible to locate specific parts of it which are not immediately presented in the user interface.

While discoverability and findability cover a very similar timeframe, findability focuses on specific circumstances where the interaction trigger is invariably the users’ previous knowledge of the interaction possibility and conscious desire to locate and utilize it. As such all concerned interactions happen intentionally and focus on the comprehension of *where* the desired feature is located. The comprehension of *what* predates and motivates the interaction, while questions of *how* exceed the focus of findability.

Noticeability tends to focus on facilitating or promoting perception of specific systems or system components. It does not include considerations of comprehension or interaction and is generally considered separate from understanding or enticing engagement. Nonetheless, noticeability is crucial in enabling all other interaction concepts as perception is a precondition for further consideration and engagement.

Guessability reflects the aim to have comprehension occur concurrently with perception. As such it is not concerned with how a user encounters or eventually uses an interaction possibility, but is solely concerned with whether the user can estimate the meaning of what they are presented with. Consequently, good guessability increases the likelihood of discovery and generally successful interaction by focusing on easing the comprehension of *what* one is confronted with.

Sorting these concepts along the presented timeline elucidates their different focus areas while also highlighting why their usage varies and differentiation is difficult. As they are all focused on aspects of initial interactions, they apply concurrently or in close proximity and the successful implementation of focused concepts, such as guessability, positively impacts all broader concepts covering that interaction timeframe.

5 DISCUSSION

In this paper, we surveyed and clarified the different usages of discoverability, how it has been defined and which contexts it is applied to. In doing so, we introduced the separation of system, interaction and feature discoverability. Subsequently, we surveyed associated interaction concepts like learnability and contrasted them with discoverability to highlight the significant overlap in the usage of the terms while elucidating how they differ.

Through this we provide a broad overview of the many concepts concerned with the ability to engage with technology without previous knowledge or supplementary material and highlight the different focal points previous research has considered.

While the selection of terms is extensive, it is, by no means, exhaustive. Not only are different terms introduced and redefined constantly, but other concepts are often used to describe similar problem statements from different perspectives, making an exhaustive list not only not feasible but also incomprehensible. We may fail to include niche or yet-to-be-established concepts. However, the breakdown of discoverability and initial interactions in more elementary concepts, as well as the clarification of their temporal articulation, paves the way for future explorations that can easily incorporate additional terms, should they become established.

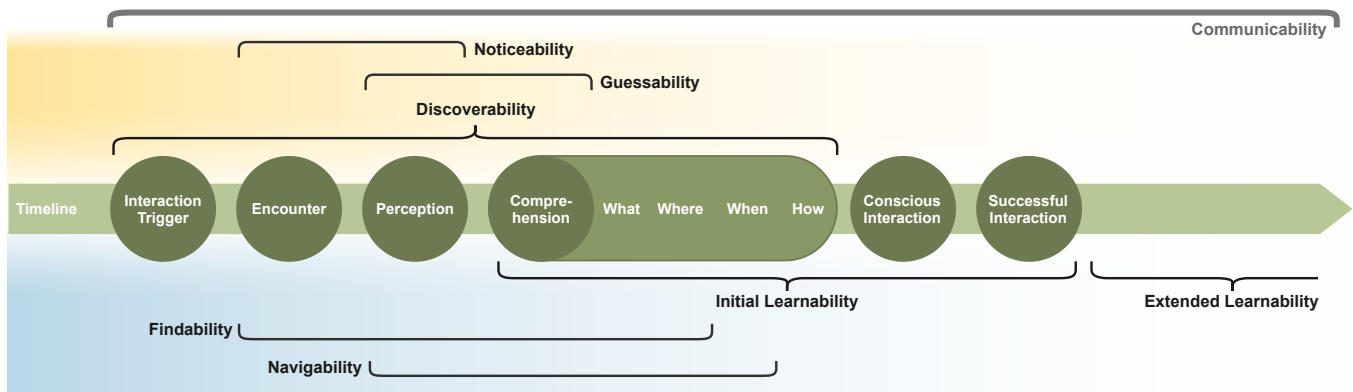


Figure 4: Timeline of interactions showing at which points different interaction concepts apply. While this generic timeline presents a lot of overlap with all concepts including some form of comprehension, they may only apply to very specific interactions which is not visually represented here.

5.1 Importance of Clear Terminology for Discoverability

Given the constant increase of technology in everyday life, as well as the constant introduction of progressively complex and disparate interaction methods, understanding and easing the discovery of features and interactions is imperative. Despite extensive research around “learning” and “affordances” this problem has not been resolved, suggesting it is not sufficiently addressed through these concepts. We argue that the clarification of concepts and terms used in this context can contribute to both theoretical discourse and practical design implications. As an example, affordances in HCI were clarified by [84] breaking down the difference between Gibsonian affordances and Norman’s perceived affordances. This was expanded upon by [50] proposing a separation into cognitive, physical, sensory and functional affordances, suggesting both the usefulness of overarching concepts as well as the need to clarify and break them down.

While the clear separation of different terms may appear trivial on the surface, clear and shared terminology is crucial when defining and exploring a research area. As [5] state, “*There is no such thing as just semantics. Semantics is all about the very meanings of the words we use, the intention with which we use them, and the understanding they create in our audience. In communication, nothing is more important than semantics.*” When the aim is to address a widely established yet fuzzily defined problem such as discoverability, we share the view of [50] that “*shared meanings and representations (through common language) are an absolute must.*”

The differentiation and clarification of discoverability and related terms helps to consolidate relevant research that uses varying terms to describe similar problem statements while also exploring the different focuses and approaches these terms originate from and how they relate. As such, while not introducing novel concepts, this review provides clear definitions and separations. These can aid future research to clearly define the specific focal points of their explorations and provide a convenient overview of concepts worth looking into when exploring related work.

5.2 Impacting Factors

Having clarified the concept of discoverability, future research should investigate more carefully which system or interaction design factors play a significant role in the discovery process. Previous work includes broad concepts aimed generally on the user’s overall understanding (e.g. perceived affordances [93], cognitive affordances [50]) as well as how the system may facilitate such an understanding (e.g. signifiers [94], suggested interactivity [18] and feedforward [119]). However these considerations do not provide a holistic overview of factors that may impact initial interactions and discoverability beyond their specific focal points.

5.3 Designing Discoverability Studies

While this paper provides a significant review of relevant definitions and concepts, it also reveals a distinct lack of clearly established and validated discoverability evaluation methodology. Among the papers that do aim to examine discoverability, methodology varies significantly, and, oftentimes the study design itself impacts the discoverability it aims to measure.

Discoverability studies often focus around comparing the discoverability of different conditions [43, 111, 123]. They are conducted as observational studies of publicly deployed prototypes [111, 123], within tasks performed in laboratory settings [43] or on online crowd-working platforms [37] as well as self-reported discovery and perceived discoverability in surveys [100]. These studies, at times, include results that show both the difficulty of achieving as well as measuring discoverability, with [43] highlighting that no participants discovered a particular feature within an interaction method but “*all participants suggested during the interview, however, that they would have stumbled upon these features and eventually figure them out.*” [75] highlight how their study, investigating the impact of signifiers for specific interactions on the perception of affordances, does not measure discoverability as participants are introduced to all interaction methods in question previously. This, as well as the variance in approaches highlights the difficulty of studying discoverability, with some studies including only vague

observational data [1, 43], priming the participants towards discovery by giving them tasks that reveal visual signifiers [8] or telling participants about the presence of the targeted interaction method [43, 75]. These concessions, which are likely made in an effort to gather relevant data, however do mean that some studies claiming to investigate discoverability, fail to do so. Studying discoverability presents an inherent dichotomy between collecting relevant data and increasing discovery through the study setup. If discovery is necessary to complete a task, the overall input method is suggested, participants are asked directly or given a task that strongly encourages exploration, researchers are more likely to collect meaningful results. However, these results do not truly reflect discoverability as the interaction trigger, encounter and at times perception are imposed through the study. Given these problem statements and the lack of an existing benchmark, a more comprehensive review of existing methods to evaluate the discovery of interactions and features would be beneficial. This could lead to the elaboration of dedicated experimental procedures tailored to the evaluation of discoverability depending on circumstances and the researchers specific interest areas. Finally, where current methodology falls short, new approaches should be investigated to evaluate specifically initial interactions and discoverability more systematically.

6 CONCLUSION

Considering the frequency at which users have to discover novel interactive systems or input methods, the fact that this problem receives such little attention is troubling. Potentially, the problem is deemed as not significant enough, or interaction designers still believe that users will “eventually figure it out”. However, research and commercial use suggest that the assumption of discovery being inevitable is unsubstantiated [10, 41, 100]. We suggest the HCI research community should avoid the continued postponing or marginalizing of discoverability problems and rather, allocate it the attention and significance it necessitates. To initiate progress, it is crucial to acknowledge the significance of small contributions pertaining to discoverability. This is especially important considering that research inherently evolves through incremental steps, steadily advancing with each small stride. Discoverability is a broad problem, justifying the necessity to clarify it and break it down into smaller, more understandable concepts. By clarifying discoverability and associated initial interaction concepts, we provide a basis for communication and highlight focus areas of future research. We provide an extensive literature review focused on discoverability and initial interactions, highlighting its importance and application areas and in doing so offer a clear classification of *what* is to be discovered as well as a definition. In addition, we draw attention to the multiplicity of closely related terms that have been used interchangeably. We differentiate these concepts by emphasizing their distinct focus points and limitations, advocating for their separate consideration. Finally, we discuss future research directions to improve the discoverability of systems, interaction and features.

ACKNOWLEDGMENTS

This work was supported by the Agence Nationale de la Recherche project Discovery (ANR-19-CE33-0006).

REFERENCES

- [1] Anand Agarawala and Ravin Balakrishnan. 2006. Keepin’ It Real: Pushing the Desktop Metaphor with Physics, Piles and the Pen. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Montréal, Québec, Canada) (CHI ’06). Association for Computing Machinery, New York, NY, USA, 1283–1292. <https://doi.org/10.1145/1124772.1124965>
- [2] David Ahlström, Andy Cockburn, Carl Gutwin, and Pourang Irani. 2010. Why It’s Quick to Be Square: Modelling New and Existing Hierarchical Menu Designs. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1371–1380. <https://doi.org/10.1145/1753326.1753534>
- [3] Mendoza G. Alfredo, J. Alvarez R. Francisco, Muñoz A. Jaime, Cristian Rusu, Acosta E. Francisco, and Mendoza G. Ricardo. 2016. A Cooperative Process for a Learnability Study with Down Syndrome Children. In *Proceedings of the XVII International Conference on Human Computer Interaction* (Salamanca, Spain) (Interacción ’16). Association for Computing Machinery, New York, NY, USA, Article 7, 5 pages. <https://doi.org/10.1145/2998626.2998636>
- [4] Mendoza G. Alfredo, J. Alvarez R. Francisco, Mendoza G. Ricardo, Acosta E. Francisco, and Muñoz A. Jaime. 2015. Analyzing Learnability of Common Mobile Gestures Used by Down Syndrome Users. In *Proceedings of the XVI International Conference on Human Computer Interaction* (Vilanova i la Geltru, Spain) (Interacción ’15). Association for Computing Machinery, New York, NY, USA, Article 1, 8 pages. <https://doi.org/10.1145/2829875.2829876>
- [5] Bruce G Allen and Elizabeth Buie. 2002. What’s in a word? The semantics of usability. *Interactions* 9, 2 (2002), 17–21.
- [6] Rui Alves and Nuno Jardim Nunes. 2016. Ceiling and threshold of paas tools: the role of learnability in tool adoption. In *Human-Centered and Error-Resilient Systems Development*. Springer, 335–347.
- [7] Axel Antoine, Sylvain Malacria, and Géry Casiez. 2017. ForceEdge: Controlling Autoscroll on Both Desktop and Mobile Computers Using the Force. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 3281–3292. <https://doi.org/10.1145/3025453.3025605>
- [8] Caroline Appert, Olivier Chapuis, and Emmanuel Pietriga. 2012. Dwell-and-Spring: Undo for Direct Manipulation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) (CHI ’12). Association for Computing Machinery, New York, NY, USA, 1957–1966. <https://doi.org/10.1145/2207676.2208339>
- [9] Caroline Appert, Olivier Chapuis, Emmanuel Pietriga, and Maria-Jesús Lobo. 2015. Reciprocal Drag-and-Drop. *ACM Trans. Comput.-Hum. Interact.* 22, 6, Article 29 (sep 2015), 36 pages. <https://doi.org/10.1145/2785670>
- [10] Jeff Avery and Edward Lank. 2016. Surveying Expert-Level Gesture Use and Adoption on Multi-Touch Tablets. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (Brisbane, QLD, Australia) (DIS ’16). ACM, New York, NY, USA, 577–581. <https://doi.org/10.1145/2901790.2901895>
- [11] Jeff Avery, Sylvain Malacria, Mathieu Nancel, Géry Casiez, and Edward Lank. 2018. Introducing Transient Gestures to Improve Pan and Zoom on Touch Surfaces. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–8. <https://doi.org/10.1145/3173574.3173599>
- [12] Nick Babich. 2020. Tips to Improve Discoverability in UX: Adobe XD Ideas. Retrieved January 27th, 2022 from <https://xd.adobe.com/ideas/process/information-architecture/tips-to-improve-discoverability-in-ux/>.
- [13] Thomas Baudel and Michel Beaudouin-Lafon. 1993. Charade: remote control of objects using free-hand gestures. *Commun. ACM* 36, 7 (jul 1993), 28–35. <https://doi.org/10.1145/159544.159562>
- [14] Victoria Bellotti, Maribeth Back, W. Keith Edwards, Rebecca E. Grinter, Austin Henderson, and Cristina Lopes. 2002. Making sense of sensing systems: five questions for designers and researchers. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Minneapolis, Minnesota, USA) (CHI ’02). Association for Computing Machinery, New York, NY, USA, 415–422. <https://doi.org/10.1145/503376.503450>
- [15] Scott Berkun. 2012. The myth of discoverability. Retrieved December 9th, 2021 from <https://scottberkun.com/essays/26-the-myth-of-discoverability/>.
- [16] Alethea L Blackler, Rafael Gomez, Vesna Popovic, and M Helen Thompson. 2016. Life is too short to RTFM: how users relate to documentation and excess features in consumer products. *Interacting with Computers* 28, 1 (2016), 27–46.
- [17] David Bonnet, Caroline Appert, and Michel Beaudouin-Lafon. 2013. Extending the Vocabulary of Touch Events with ThumbRock. In *Proceedings of Graphics Interface 2013* (Regina, Saskatchewan, Canada) (GI ’13). Canadian Information Processing Society, CAN, 221–228.
- [18] Jeremy Boy, Louis Eveillard, Françoise Detienne, and Jean-Daniel Fekete. 2015. Suggested interactivity: Seeking perceived affordances for information visualization. *IEEE transactions on visualization and computer graphics* 22, 1 (2015), 639–648.
- [19] Francesco Cafaro, Leilah Lyons, and Alissa N. Antle. 2018. Framed Guessability: Improving the Discoverability of Gestures and Body Movements for Full-Body

- Interaction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–12. <https://doi.org/10.1145/3173574.3174167>
- [20] Francesco Cafaro, Milka Trajkova, and A'aeshah Alhakamy. 2019. Designing Embodied Interactions for Informal Learning: Two Open Research Challenges. In *Proceedings of the 8th ACM International Symposium on Pervasive Displays* (Palermo, Italy) (*PerDis '19*). Association for Computing Machinery, New York, NY, USA, Article 28, 2 pages. <https://doi.org/10.1145/3321335.3329688>
- [21] Stuart Card, Thomas P. Moran, and Allen Newell. 1986. The model human processor- An engineering model of human performance. *Handbook of perception and human performance*. 2, 45–1 (1986).
- [22] Jennifer Cardello. 2014 updated 2019. Low findability and discoverability: Four testing methods to identify the causes. Retrieved December 9th, 2021 from <https://www.nngroup.com/articles/navigation-ia-tests/>.
- [23] Victor Cheung. 2014. Improving Interaction Discoverability in Large Public Interactive Displays. In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces* (Dresden, Germany) (*ITS '14*). Association for Computing Machinery, New York, NY, USA, 467–472. <https://doi.org/10.1145/2669485.2669489>
- [24] Victor Cheung. 2016. *Increasing passersby engagement with public large interactive surfaces*. Ph.D. Dissertation. University of Waterloo.
- [25] Victor Cheung and Stacey D. Scott. 2013. Investigating Attraction and Engagement of Animation on Large Interactive Walls in Public Settings. In *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces* (St. Andrews, Scotland, United Kingdom) (*ITS '13*). Association for Computing Machinery, New York, NY, USA, 381–384. <https://doi.org/10.1145/2512349.2512404>
- [26] Victor Cheung and Stacey D. Scott. 2015. A Laboratory-Based Study Methodology to Investigate Attraction Power of Large Public Interactive Displays. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Osaka, Japan) (*UbiComp '15*). Association for Computing Machinery, New York, NY, USA, 1239–1250. <https://doi.org/10.1145/2750858.2805842>
- [27] Andy Cockburn, Carl Gutwin, Joey Scarr, and Sylvain Malacria. 2014. Supporting Novice to Expert Transitions in User Interfaces. *ACM Comput. Surv.* 47, 2, Article 31 (nov 2014), 36 pages. <https://doi.org/10.1145/2659796>
- [28] Eric Corbett and Astrid Weber. 2016. What Can I Say? Addressing User Experience Challenges of a Mobile Voice User Interface for Accessibility. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Florence, Italy) (*MobileHCI '16*). Association for Computing Machinery, New York, NY, USA, 72–82. <https://doi.org/10.1145/2935334.2935386>
- [29] Travis Cox, Marcus Carter, and Eduardo Velloso. 2016. Public DISPLAY: Social Games on Interactive Public Screens. In *Proceedings of the 28th Australian Conference on Computer-Human Interaction* (Launceston, Tasmania, Australia) (*OzCHI '16*). Association for Computing Machinery, New York, NY, USA, 371–380. <https://doi.org/10.1145/3010915.3010917>
- [30] Lucia D'Acunto, Jorrit van den Berg, Emmanuel Thomas, and Omar Niamut. 2016. Using MPEG DASH SRD for Zoomable and Navigable Video. In *Proceedings of the 7th International Conference on Multimedia Systems* (Klagenfurt, Austria) (*MMSys '16*). Association for Computing Machinery, New York, NY, USA, Article 34, 4 pages. <https://doi.org/10.1145/2910017.2910634>
- [31] Lavinia Andreea Danielescu. 2019. *Discoverable Free Space Gesture Sets for Walk-Up-and-Use Interactions*. Ph.D. Dissertation. Arizona State University.
- [32] Clarisse Sieckenius De Souza, Bonnie A Nardi, Victor Kaptelinin, and Kirsten A Foot. 2005. *The semiotic engineering of human-computer interaction*. MIT Press.
- [33] Mário Rosado de Souza, Robert Haines, Markel Vigo, and Caroline Jay. 2019. What Makes Research Software Sustainable? An Interview Study with Research Software Engineers. In *Proceedings of the 12th International Workshop on Cooperative and Human Aspects of Software Engineering* (Montreal, Quebec, Canada) (*CHASE '19*). IEEE Press, 135–138. <https://doi.org/10.1109/CHASE.2019.00039>
- [34] Tao Dong, Mira Dontcheva, Diana Joseph, Karrie Karahalios, Mark Newman, and Mark Ackerman. 2012. Discovery-Based Games for Learning Software. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) (*CHI '12*). Association for Computing Machinery, New York, NY, USA, 2083–2086. <https://doi.org/10.1145/2207676.2208358>
- [35] Ekwa Duala-Ekoko and Martin P. Robillard. 2011. Using Structure-Based Recommendations to Facilitate Discoverability in APIs. In *Proceedings of the 25th European Conference on Object-Oriented Programming* (Lancaster, UK) (*ECOOP '11*). Springer-Verlag, Berlin, Heidelberg, 79–104.
- [36] Elias Fares, Victor Cheung, and Audrey Girouard. 2017. Effects of Bend Gesture Training on Learnability and Memorability in a Mobile Game. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces* (Brighton, United Kingdom) (*ISS '17*). Association for Computing Machinery, New York, NY, USA, 240–245. <https://doi.org/10.1145/3132272.3134142>
- [37] Katherine Fennedy, Angad Srivastava, Sylvain Malacria, and Simon T. Perrault. 2022. Towards a Unified and Efficient Command Selection Mechanism for Touch-Based Devices Using Soft Keyboard Hotkeys. *ACM Trans. Comput.-Hum. Interact.* 29, 1, Article 4 (jan 2022), 39 pages. <https://doi.org/10.1145/3476510>
- [38] The Interaction Design Foundation. 2020. Make it Easy on the User: Designing for Discoverability within Mobile Apps. Retrieved January 27th, 2022 from <https://www.interaction-design.org/literature/article/make-it-easy-on-the-user-designing-for-discoverability-within-mobile-apps>.
- [39] Anushay Furqan, Chelsea Myers, and Jichen Zhu. 2017. Learnability through Adaptive Discovery Tools in Voice User Interfaces. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (Denver, Colorado, USA) (*CHI EA '17*). Association for Computing Machinery, New York, NY, USA, 1617–1623. <https://doi.org/10.1145/3027063.3053166>
- [40] Marco Gillies. 2016. What is Movement Interaction in Virtual Reality For?. In *Proceedings of the 3rd International Symposium on Movement and Computing* (Thessaloniki, GA, Greece) (*MOCO '16*). Association for Computing Machinery, New York, NY, USA, Article 31, 4 pages. <https://doi.org/10.1145/2948910.2948951>
- [41] Vindu Goel. 2017. Apple Piles On the Features and Users Say, 'Enough!'. Retrieved December 9th, 2021 from <https://www.nytimes.com/2017/06/02/technology/apple-iphone-developer-conference.html>.
- [42] Alix Goguey, Géry Casiez, Daniel Vogel, Fanny Chevalier, Thomas Pietrzak, and Nicolas Roussel. 2014. A Three-Step Interaction Pattern for Improving Discoverability in Finger Identification Techniques. In *Proceedings of the Adjunct Publication of the 27th Annual ACM Symposium on User Interface Software and Technology* (Honolulu, Hawaii, USA) (*UIST '14 Adjunct*). Association for Computing Machinery, New York, NY, USA, 33–34. <https://doi.org/10.1145/2658779.2659100>
- [43] Alix Goguey, Sylvain Malacria, and Carl Gutwin. 2018. Improving Discoverability and Expert Performance in Force-Sensitive Text Selection for Touch Devices with Mode Gauges. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–12. <https://doi.org/10.1145/3173574.3174051>
- [44] Alix Goguey, Daniel Vogel, Fanny Chevalier, Thomas Pietrzak, Nicolas Roussel, and Géry Casiez. 2017. Leveraging finger identification to integrate multi-touch command selection and parameter manipulation. *IJHCS* 99 (2017), 21–36. <https://doi.org/10.1016/j.ijhcs.2016.11.002>
- [45] Jun Gong, Aakar Gupta, and Hrvoje Benko. 2020. Acustico: Surface Tap Detection and Localization Using Wrist-Based Acoustic TDOA Sensing. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology* (Virtual Event, USA) (*UIST '20*). Association for Computing Machinery, New York, NY, USA, 406–419. <https://doi.org/10.1145/3379337.3415901>
- [46] Tovi Grossman, George Fitzmaurice, and Ramtin Attar. 2009. A Survey of Software Learnability: Metrics, Methodologies and Guidelines. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 649–658. <https://doi.org/10.1145/1518701.1518803>
- [47] The Standish Group. 2010. Modernization: Clearing a Pathway to Success.
- [48] Chris Harrison, Julia Schwarz, and Scott E. Hudson. 2011. TapSense: Enhancing Finger Interaction on Touch Surfaces. In *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology* (Santa Barbara, California, USA) (*UIST '11*). Association for Computing Machinery, New York, NY, USA, 627–636. <https://doi.org/10.1145/2047196.2047279>
- [49] Björn Hartmann, Meredith Ringel Morris, Hrvoje Benko, and Andrew D. Wilson. 2010. Pictionary: Supporting Collaborative Design Work by Integrating Physical and Digital Artifacts. In *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work* (Savannah, Georgia, USA) (*CSCW '10*). Association for Computing Machinery, New York, NY, USA, 421–424. <https://doi.org/10.1145/1718918.1718989>
- [50] Rex Hartson. 2003. Cognitive, physical, sensory, and functional affordances in interaction design. *Behaviour & information technology* 22, 5 (2003), 315–338.
- [51] Denis Helic, Sebastian Wilhelm, Ilire Hasani-Mavriqi, and Markus Strohmaier. 2011. The Effects of Navigation Tools on the Navigability of Web-Based Information Systems. In *Proceedings of the 11th International Conference on Knowledge Management and Knowledge Technologies* (Graz, Austria) (*i-KNOW '11*). Association for Computing Machinery, New York, NY, USA, Article 16, 8 pages. <https://doi.org/10.1145/2024288.2024308>
- [52] Luke Hespagnol, Martin Tomitsch, Ian McArthur, Joel Fredericks, Ronald Schroeter, and Marcus Foth. 2015. Vote as You Go: Blending Interfaces for Community Engagement into the Urban Space. In *Proceedings of the 7th International Conference on Communities and Technologies* (Limerick, Ireland). Association for Computing Machinery, New York, NY, USA, 29–37. <https://doi.org/10.1145/2768545.2768553>
- [53] Eva Hornecker. 2008. "I don't understand it either, but it is cool" - visitor interactions with a multi-touch table in a museum. In *2008 3rd IEEE International Workshop on Horizontal Interactive Human Computer Systems*. 113–120. <https://doi.org/10.1109/TABLETOP.2008.4660193>
- [54] Simo Hosio, Jorge Goncalves, and Vassilis Kostakos. 2013. Application Discoverability on Multipurpose Public Displays: Popularity Comes at a Price. In *Proceedings of the 2nd ACM International Symposium on Pervasive Displays* (Mountain View, California) (*PerDis '13*). Association for Computing Machinery, New York, NY, USA, 31–36. <https://doi.org/10.1145/2491568.2491576>
- [55] Samia Ibtasam, Hamid Mehmood, Lubna Razaq, Jennifer Webster, Sarah Yu, and Richard Anderson. 2017. An Exploration of Smartphone Based Mobile Money

- Applications in Pakistan. In *Proceedings of the Ninth International Conference on Information and Communication Technologies and Development* (Lahore, Pakistan) (ICTD '17). Association for Computing Machinery, New York, NY, USA, Article 1, 11 pages. <https://doi.org/10.1145/3136560.3136571>
- [56] Giulio Jacucci, Ann Morrison, Gabriela T. Richard, Jari Kleimola, Peter Peltonen, Lorenza Parisi, and Toni Laitinen. 2010. Worlds of Information: Designing for Engagement at a Public Multi-Touch Display. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 2267–2276. <https://doi.org/10.1145/1753326.1753669>
- [57] Patrick W Jordan, Stephen W Draper, Kirsteen K MacFarlane, and Shirley-Anne McNulty. 1991. Guessability, learnability, and experienced user performance. In *People and Computers VI - Proceedings of the HCI '91 Conference*. Cambridge University Press.
- [58] Alita Joyce. 2020. Mobile-App Onboarding: An Analysis of Components and Techniques. Retrieved January 27th, 2022 from <https://www.nngroup.com/articles/mobile-app-onboarding/>.
- [59] Hyo Jeong Kang, Jung-hye Shin, and Kevin Ponto. 2020. A Comparative Analysis of 3D User Interaction: How to Move Virtual Objects in Mixed Reality. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 275–284. <https://doi.org/10.1109/VR46266.2020.00047>
- [60] Victor Kaptelinin and Bonnie Nardi. 2012. Affordances in HCI: Toward a Mediated Action Perspective. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 967–976. <https://doi.org/10.1145/2207676.2208541>
- [61] Philipp Kirschthaler, Martin Porcheron, and Joel E. Fischer. 2020. What Can I Say? Effects of Discoverability in VUs on Task Performance and User Experience. In *Proceedings of the 2nd Conference on Conversational User Interfaces* (Bilbao, Spain) (CUI '20). Association for Computing Machinery, New York, NY, USA, Article 9, 9 pages. <https://doi.org/10.1145/3405755.3406119>
- [62] Michaela Klauk, Yusuke Sugano, and Andreas Bulling. 2017. Noticeable or Distractive? A Design Space for Gaze-Contingent User Interface Notifications. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (Denver, Colorado, USA) (CHI EA '17). Association for Computing Machinery, New York, NY, USA, 1779–1786. <https://doi.org/10.1145/3027063.3053085>
- [63] Steve Krug. 2013. *Don't Make Me Think, Revisited: A Common Sense Approach to Web Usability* (3rd edition ed.). New Riders.
- [64] Ernst Kruijff, Jason Orlosky, Naohiro Kishishita, Christina Trepkowski, and Kiyoshi Kiyokawa. 2018. The influence of label design on search performance and noticeability in wide field of view augmented reality displays. *IEEE transactions on visualization and computer graphics* 25, 9 (2018), 2821–2837.
- [65] Lynn Kysh. 2013. What's in a name? The difference between a systematic review and a literature review and why it matters. In *Poster presented at Medical Library Group of Southern California & Arizona (MLGSCA) and the Northern California and Nevada Medical Library Group (NCNMLG) Joint Meeting, La Jolla, CA*. Retrieved from <http://libguides.sjsu.edu/c.php>.
- [66] Vincent Lambert, Adrien Chaffangeon Caillet, Alix Goguey, Sylvain Malacria, and Laurence Nigay. 2023. Studying the Visual Representation of Microgestures. *Proc. ACM Hum.-Comput. Interact.* 7, MHCI, Article 225 (2023). <https://doi.org/10.1145/3604272>
- [67] Daniel Lamprecht, Dimitar Dimitrov, Denis Helic, and Markus Strohmaier. 2016. Evaluating and Improving Navigability of Wikipedia: A Comparative Study of Eight Language Editions. In *Proceedings of the 12th International Symposium on Open Collaboration* (Berlin, Germany) (OpenSym '16). Association for Computing Machinery, New York, NY, USA, Article 17, 10 pages. <https://doi.org/10.1145/2957792.2957813>
- [68] Daniel Lamprecht, Florian Geigl, Tomas Karas, Simon Walk, Denis Helic, and Markus Strohmaier. 2015. Improving Recommender System Navigability through Diversification: A Case Study of IMDb. In *Proceedings of the 15th International Conference on Knowledge Technologies and Data-Driven Business* (Graz, Austria) (i-KNOW '15). Association for Computing Machinery, New York, NY, USA, Article 21, 8 pages. <https://doi.org/10.1145/2809563.2809603>
- [69] Huy Viet Le, Sven Mayer, and Niels Henze. 2020. Imprint-Based Input Techniques for Touch-Based Mobile Devices. In *19th International Conference on Mobile and Ubiquitous Multimedia* (Essen, Germany) (MUM 2020). Association for Computing Machinery, New York, NY, USA, 32–41. <https://doi.org/10.1145/3428361.3428393>
- [70] Gun A Lee, Jonathan Wong, Hye Sun Park, Jin Sung Choi, Chang Joon Park, and Mark Billinghurst. 2015. User defined gestures for augmented virtual mirrors: a guessability study. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*. 959–964.
- [71] Rock Leung, Leah Findlater, Joanna McGrenere, Peter Graf, and Justine Yang. 2010. Multi-Layered Interfaces to Improve Older Adults' Initial Learnability of Mobile Applications. *ACM Trans. Access. Comput.* 3, 1, Article 1 (sep 2010), 30 pages. <https://doi.org/10.1145/1838562.1838563>
- [72] Wei Li, Justin Matejka, Tovi Grossman, Joseph A. Konstan, and George Fitzmaurice. 2011. Design and Evaluation of a Command Recommendation System for Software Applications. *ACM Trans. Comput.-Hum. Interact.* 18, 2, Article 6 (jul 2011), 35 pages. <https://doi.org/10.1145/1970378.1970380>
- [73] Tomáš Macek, Martin Labský, Jan Vystrčil, David Luksch, Tereza Kašparová, Ladislav Kunc, and Jan Kleindienst. 2014. Interactive Car Owner's Manual User Study. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Seattle, WA, USA) (AutomotiveUI '14). Association for Computing Machinery, New York, NY, USA, 1–4. <https://doi.org/10.1145/2667317.2667412>
- [74] Renáta Máchová, Miloslav Hub, and Martin Lnenicka. 2018. Usability evaluation of open data portals: Evaluating data discoverability, accessibility, and reusability from a stakeholders' perspective. *Aslib Journal of Information Management* (2018).
- [75] Eva Mackamul, Géry Casiez, and Sylvain Malacria. 2023. Exploring Visual Signifier Characteristics to Improve the Perception of Affordances of In-Place Touch Inputs. *Proc. ACM Hum.-Comput. Interact.* 7, MHCI, Article 210 (sep 2023), 32 pages. <https://doi.org/10.1145/3604257>
- [76] Aristides Mairena, Carl Gutwin, and Andy Cockburn. 2019. Peripheral Notifications in Large Displays: Effects of Feature Combination and Task Interference. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) (CHI '19). Association for Computing Machinery, New York, NY, USA, 1–12. <https://doi.org/10.1145/3290605.3300870>
- [77] Marium-E-Jannat, Xing-Dong Yang, and Khalad Hasan. 2023. Around-device finger input on commodity smartwatches with learning guidance through discoverability. *International Journal of Human-Computer Studies* 179 (2023), 103105. <https://doi.org/10.1016/j.ijhcs.2023.103105>
- [78] Stefan Marr and Benoit Daloz. 2018. Few Versatile vs. Many Specialized Collections: How to Design a Collection Library for Exploratory Programming?. In *Conference Companion of the 2nd International Conference on Art, Science, and Engineering of Programming* (Nice, France) (Programming'18 Companion). Association for Computing Machinery, New York, NY, USA, 135–143. <https://doi.org/10.1145/3191697.3214334>
- [79] Andrea Marrella and Tiziana Catarci. 2018. Measuring the Learnability of Interactive Systems Using a Petri Net Based Approach. In *Proceedings of the 2018 Designing Interactive Systems Conference* (Hong Kong, China) (DIS '18). Association for Computing Machinery, New York, NY, USA, 1309–1319. <https://doi.org/10.1145/3196709.3196744>
- [80] Paul Marshall, Richard Morris, Yvonne Rogers, Stefan Kreitmayer, and Matt Davies. 2011. Rethinking 'multi-user' an in-the-wild study of how groups approach a walk-up-and-use tabletop interface. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 3033–3042.
- [81] Justin Matejka, Tovi Grossman, and George Fitzmaurice. 2013. Patina: Dynamic Heatmaps for Visualizing Application Usage. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 3227–3236. <https://doi.org/10.1145/2470654.2466442>
- [82] Justin Matejka, Wei Li, Tovi Grossman, and George Fitzmaurice. 2009. Community Commands: Command Recommendations for Software Applications. In *Proceedings of the 22nd Annual ACM Symposium on User Interface Software and Technology* (Victoria, BC, Canada) (UIST '09). Association for Computing Machinery, New York, NY, USA, 193–202. <https://doi.org/10.1145/1622176.1622214>
- [83] Sven Mayer, Lars Lischke, Adrian Lankswert, Huy Viet Le, and Niels Henze. 2018. How to Communicate New Input Techniques. In *Proceedings of the 10th Nordic Conference on Human-Computer Interaction* (Oslo, Norway) (NordCHI '18). Association for Computing Machinery, New York, NY, USA, 460–472. <https://doi.org/10.1145/3240167.3240176>
- [84] Joanna McGrenere and Wayne Ho. 2000. Affordances: Clarifying and evolving a concept. In *Graphics interface*, Vol. 2000. 179–186.
- [85] Fenwick McKelvey and Robert Hunt. 2019. Discoverability: Toward a definition of content discovery through platforms. *Social Media+ Society* 5, 1 (2019), 2056305118819188.
- [86] Ron Mendoza and Kaari Peterson. 2004. From Tools to Tasks: Discoverability and Adobe Acrobat 6.0. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems* (Vienna, Austria) (CHI EA '04). Association for Computing Machinery, New York, NY, USA, 912–927. <https://doi.org/10.1145/985921.985949>
- [87] Martin Mihajlov, Mark Springett, and Effie Lai-Chong Law. 2019. Learning to Drag: The Effects of Social Interactions in Touch Gestures Learnability for Older Adults. In *Proceedings of the 2019 ACM International Conference on Interactive Surfaces and Spaces* (Daejeon, Republic of Korea) (ISS '19). Association for Computing Machinery, New York, NY, USA, 205–215. <https://doi.org/10.1145/3343055.3359716>
- [88] Peter Morville. 2005. *Ambient findability: What we find changes who we become*. O'Reilly Media, Inc.
- [89] Joerg Mueller, Robert Walter, Gilles Bailly, Michael Nischt, and Florian Alt. 2012. Looking glass: a field study on noticing interactivity of a shop window. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '12). Association for Computing Machinery, 1465–1466. <https://doi.org/10.1145/2212776.2212488>

- [90] Philipp Müller, Sander Staal, Mihai Băce, and Andreas Bulling. 2022. Designing for Noticeability: Understanding the Impact of Visual Importance on Desktop Notifications. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) (CHI '22). Association for Computing Machinery, New York, NY, USA, Article 472, 13 pages. <https://doi.org/10.1145/3491102.3501954>
- [91] Andreea Muresan, Jess McIntosh, and Kasper Hornbæk. 2023. Using Feedforward to Reveal Interaction Possibilities in Virtual Reality. *ACM Trans. Comput.-Hum. Interact.* (jun 2023). <https://doi.org/10.1145/3603623> Just Accepted.
- [92] Jaye Nias. 2015. Guessability as an Ethnographic Study of Mobile Technology Usage in Kenya. In *Proceedings of the Seventh International Conference on Information and Communication Technologies and Development* (Singapore, Singapore) (ICTD '15). Association for Computing Machinery, New York, NY, USA, Article 53, 4 pages. <https://doi.org/10.1145/2737856.2737898>
- [93] Don Norman. 2004. Affordances and design. *Unpublished article, available online at: http://www.jnd.org/dn.mss/affordances-and-design.html* (2004).
- [94] Donald A. Norman. 2013. *The design of everyday things: Revised and expanded edition*. Basic books.
- [95] Arfika Nurhudatiana and Alixia Shafira Caesarion. 2020. Exploring User Experience of Massive Open Online Courses (MOOCs): A Case Study of Millennial Learners in Jakarta, Indonesia. In *Proceedings of the 2020 9th International Conference on Educational and Information Technology* (Oxford, United Kingdom) (ICEIT 2020). Association for Computing Machinery, New York, NY, USA, 44–49. <https://doi.org/10.1145/3383923.3383968>
- [96] Timo Ojala, Vassilis Kostakos, Hannu Kukka, Tommi Heikkinen, Tomas Linden, Marko Jurmu, Simo Hosio, Fabio Kruger, and Daniele Zanni. 2012. Multipurpose interactive public displays in the wild: Three years later. *Computer* 45, 5 (2012), 42–49.
- [97] Alex Olwal, Jon Moeller, Greg Priest-Dorman, Thad Starner, and Ben Carroll. 2018. I/O Braid: Scalable Touch-Sensitive Lighted Cords Using Spiraling, Repeating Sensing Textiles and Fiber Optics. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (Berlin, Germany) (UIST '18). Association for Computing Machinery, New York, NY, USA, 485–497. <https://doi.org/10.1145/3242587.3242638>
- [98] Annuska Perkins and Tira Cohene. 2006. The Impact of User Research on Product Design Case Study: Accessibility Ecosystem for Windows Vista. In *Proceedings of the 8th International ACM SIGACCESS Conference on Computers and Accessibility* (Portland, Oregon, USA) (Assets '06). Association for Computing Machinery, New York, NY, USA, 281–282. <https://doi.org/10.1145/1168987.1169055>
- [99] Nicole Ke Cheng Pong. 2020. *Interacting with signifier-less designs - the case of swidgets*. Theses. Université de Lille (2018-....). <https://hal.inria.fr/tel-03133122>
- [100] Nicole Ke Chen Pong and Sylvain Malacria. 2019. Awareness, Usage and Discovery of Swipe-Revealed Hidden Widgets in IOS. In *Proceedings of the 2019 ACM International Conference on Interactive Surfaces and Spaces* (Daejeon, Republic of Korea) (ISS '19). Association for Computing Machinery, New York, NY, USA, 193–204. <https://doi.org/10.1145/3343055.3359713>
- [101] Venkatesh Potluri, Priyan Vaithilingam, Suresh Iyengar, Y. Vidya, Manohar Swaminathan, and Gopal Srinivasa. 2018. CodeTalk: Improving Programming Environment Accessibility for Visually Impaired Developers. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) (CHI '18). Association for Computing Machinery, New York, NY, USA, 1–11. <https://doi.org/10.1145/3173574.3174192>
- [102] Janet T. Powell and Mark J. W. Koelemay. 2022. Systematic Reviews of the Literature Are Not Always Either Useful or the Best Way To Add To Science. *EJVES Vascular Forum* 54 (2022), 2–6. <https://doi.org/10.1016/j.ejvsf.2021.10.021>
- [103] Alisha Pradhan, Kanika Mehta, and Leah Findlater. 2018. "Accessibility Came by Accident": Use of Voice-Controlled Intelligent Personal Assistants by People with Disabilities. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) (CHI '18). Association for Computing Machinery, New York, NY, USA, 1–13. <https://doi.org/10.1145/3173574.3174033>
- [104] Raquel O Prates, Simone DJ Barbosa, and Clarisse S de Souza. 2000. A case study for evaluating interface design through communicability. In *Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques*. 308–316.
- [105] Jennifer Preece, Helen Sharp, and Yvonne Rogers. 2019. *Interaction design: beyond human-computer interaction*. John Wiley & Sons.
- [106] Silvia Ramis, Francisco J Perales, Cristina Manresa-Yee, and Antoni Bibiloni. 2014. Usability study of gestures to control a smart-tv. In *Iberoamerican Conference on Applications and Usability of Interactive TV*. Springer, 135–146.
- [107] Christian Rendl, Patrick Greindl, Kathrin Probst, Martin Behrens, and Michael Haller. 2014. Presstures: Exploring Pressure-Sensitive Multi-Touch Gestures on Trackpads. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) (CHI '14). Association for Computing Machinery, New York, NY, USA, 431–434. <https://doi.org/10.1145/2556288.2557146>
- [108] Anne Roudaut, Eric Lecolinet, and Yves Guiard. 2009. MicroRolls: Expanding Touch-Screen Input Vocabulary by Distinguishing Rolls vs. Slides of the Thumb. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 927–936. <https://doi.org/10.1145/1518701.1518843>
- [109] Paulo J Santos and Albert Badre. 1995. *Discount learnability evaluation*. Technical Report. Georgia Institute of Technology.
- [110] Marcos Serrano, Eric Lecolinet, and Yves Guiard. 2013. Bezel-Tap gestures: quick activation of commands from sleep mode on tablets. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) (CHI '13). Association for Computing Machinery, New York, NY, USA, 3027–3036. <https://doi.org/10.1145/2470654.2481421>
- [111] Mindy Seto, Stacey Scott, and Mark Hancock. 2012. Investigating Menu Discoverability on a Digital Tabletop in a Public Setting. In *Proceedings of the 2012 ACM International Conference on Interactive Tabletops and Surfaces* (Cambridge, Massachusetts, USA) (ITS '12). Association for Computing Machinery, New York, NY, USA, 71–80. <https://doi.org/10.1145/2396636.2396647>
- [112] Ross Shannon, Aaron Quigley, and Paddy Nixon. 2006. Software considerations for automotive pervasive systems. *Workshop on Software Engineering Challenges for Ubiquitous Computing* (01 2006).
- [113] Adish Singla and Ingmar Weber. 2010. Tagging and Navigability. In *Proceedings of the 19th International Conference on World Wide Web* (Raleigh, North Carolina, USA) (WWW '10). Association for Computing Machinery, New York, NY, USA, 1185–1186. <https://doi.org/10.1145/1772690.1772866>
- [114] Arjun Srinivasan, Mira Dontcheva, Eytan Adar, and Seth Walker. 2019. Discovering Natural Language Commands in Multimodal Interfaces. In *Proceedings of the 24th International Conference on Intelligent User Interfaces* (Marina del Rey, California) (IUI '19). Association for Computing Machinery, New York, NY, USA, 661–672. <https://doi.org/10.1145/3301275.3302292>
- [115] Hironobu Takagi, Shin Saito, Kentarou Fukuda, and Chieko Asakawa. 2007. Analysis of Navigability of Web Applications for Improving Blind Usability. *ACM Trans. Comput.-Hum. Interact.* 14, 3 (sep 2007), 13–es. <https://doi.org/10.1145/1279700.1279703>
- [116] Suja Thomas. 2019. 2019 Feature Adoption Report.
- [117] user&i. 2021. Do you consider Discoverability when designing? Retrieved January 27th, 2022 from <http://www.userand.com/do-you-consider-discoverability-when-designing/>.
- [118] Priyan Vaithilingam and Philip J. Guo. 2019. Bespoke: Interactively Synthesizing Custom GUIs from Command-Line Applications By Demonstration. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New Orleans, LA, USA) (UIST '19). Association for Computing Machinery, New York, NY, USA, 563–576. <https://doi.org/10.1145/3332165.3347944>
- [119] Jo Vermeulen, Kris Luyten, Elise van den Hoven, and Karin Coninx. 2013. Crossing the Bridge over Norman's Gulf of Execution: Revealing Feedforward's True Identity. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) (CHI '13). Association for Computing Machinery, New York, NY, USA, 1931–1940. <https://doi.org/10.1145/2470654.2466255>
- [120] J Vieira, Rosane Sampaio, Rafael Nascimento, João Pedro Ferreira, Sara Machado, Nuno Ribeiro, Estevão Silva, and S Mouta. 2016. Gestures while driving: A guessability approach for a surface gestures taxonomy for in-vehicle indirect interaction. *Proceedings of the Human Factors and Ergonomics Society Europe*, 249–263.
- [121] Daniel Vogel and Ravin Balakrishnan. 2004. Interactive Public Ambient Displays: Transitioning from Implicit to Explicit, Public to Personal, Interaction with Multiple Users. In *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology* (Santa Fe, NM, USA) (UIST '04). Association for Computing Machinery, New York, NY, USA, 137–146. <https://doi.org/10.1145/1029632.1029656>
- [122] I. Wagner, M. Kompast, and R. Lainer. 2002. Visualization Strategies for the Design of Interactive Navigable 3-D Worlds. *Interactions* 9, 5 (sep 2002), 25–34. <https://doi.org/10.1145/566981.566994>
- [123] Robert Walter, Gilles Bailly, and Jörg Müller. 2013. StrikeAPose: Revealing Mid-Air Gestures on Public Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 841–850. <https://doi.org/10.1145/2470654.2470774>
- [124] Hongling Wang and Joseph K. Kearney. 2006. A Parametric Model for Oriented, Navigable Surfaces in Virtual Environments. In *Proceedings of the 2006 ACM International Conference on Virtual Reality Continuum and Its Applications* (Hong Kong, China) (VRCLIA '06). Association for Computing Machinery, New York, NY, USA, 51–57. <https://doi.org/10.1145/1128923.1128933>
- [125] Daniel Wigdor and Dennis Wixon. 2011. *Brave NUI world: designing natural user interfaces for touch and gesture*. Elsevier.
- [126] Darren Wilson. 2019. The A to Z of UX — D is for Discoverability: 15 tips to ensuring users find what they need. Retrieved January 27th, 2022 from <https://uxdesign.cc/the-a-to-z-of-ux-d-is-for-discoverability-a-15-point-list-to-ensuring-users-find-what-they-need-8659416ee41>.
- [127] Jacob O. Wobbrock, Htet Htet Aung, Brandon Rothrock, and Brad A. Myers. 2005. Maximizing the Guessability of Symbolic Input. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1869–1872. <https://doi.org/10.1145/1056808.1057043>
- [128] Jacob O. Wobbrock, Meredith Ringel Morris, and Andrew D. Wilson. 2009. User-Defined Gestures for Surface Computing. In *Proceedings of the SIGCHI Conference*

on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, 1083–1092. <https://doi.org/10.1145/1518701.1518866>

[129] Te-Yen Wu, Lu Tan, Yuji Zhang, Teddy Seyed, and Xing-Dong Yang. 2020. Capacitivo: Contact-Based Object Recognition on Interactive Fabrics Using

Capacitive Sensing. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology (Virtual Event, USA) (UIST '20)*. Association for Computing Machinery, New York, NY, USA, 649–661. <https://doi.org/10.1145/3379337.3415829>