The Reality of Reality-Based Interaction: Understanding the Impact of a Framework as a Research Tool

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Frameworks such as Direct Manipulation or Instrumental Interaction have been an important force in HCI research. Evaluating the impact of frameworks can identify whether and how a framework was used, how it has evolved, and what trends have developed over time. However, studying the impact of such theoretical contributions requires consideration of various perspectives and level of impact. As a case study for investigating the impact of theoretical work in HCI, we present our evaluation of the impact of the Reality Based Interaction (RBI) framework, introduced by the authors in 2008. We provide our findings about the impact of the framework both on contemporary research, through content-based citation analysis, and in HCI education, through a survey we conducted on emerging interaction frameworks. The paper contributes a comprehensive methodology for evaluating the impact of frameworks through our twofold approach: content-based citation analysis, including the design of a new citation typology; and a survey on the use of frameworks in education using a taxonomy of learning goals. We also consider the role of frameworks in HCI as well as the future of the RBI framework.

CCS Concepts: • **Human-centered computing** → **HCI theory, concepts and models**; • **Information systems** → *Link and co-citation analysis*; • **Social and professional topics** → *Computing education*;

Additional Key Words and Phrases: framework, citation analysis, education, reality-based interactions, emerging interactions, tangible user interaction

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1 INTRODUCTION

Frameworks are the foundation of strong research, tying together seemingly disparate topics, showing a complete picture of a research subfield, helping researchers to identify open areas for generating new research and design ideas, and helping to explain and contextualize results. Within the field of human computer interaction (HCI), there are hundreds of frameworks, from direct manipulation [72] and resource model [89] to natural user interfaces [86], tangible interaction [34] or instrumental interaction [5]. We note 690 articles in the ACM Digital Library that include the word *HCI* and that also have the word *framework* in the title[1]. We observe a steep increase in articles focusing on frameworks in the last 10 years, with 460 articles compared with 162 in the decade prior. This trend corresponds to the emergence of novel interaction styles that diverge from existing paradigms, as well as to a general increase in HCI publications, with frameworks representing approximately 1.4% of papers since 2000.

While new frameworks typically reflect on ones that came before, expanding them [5, 44, 82], and comparing them [54], researchers have rarely investigated the impact of a particular framework and the role it might have had in shaping a field. We argue the importance of evaluating the impact of frameworks and other theoretical research in HCI. Doing so can identify whether and how a framework is used [19], and the way it has evolved since it was created [83].

In this paper, we focus on the Reality Based Interaction (RBI) framework, which was introduced by the authors about ten years ago [42]. It proposed a unified view of a large subset of emerging interaction styles at the time. We seek both to study its impact and to present a case study on the evaluation of the impact of a framework. In particular, acknowledging the synergistic relationship between research and education and their shared role in shaping the field of HCI, we consider impact in terms of both influence on published research and on HCI education. We do this through two methods: 1) investigating RBI's impact on contemporary research through citation patterns, and 2) analyzing its use in education to inform and shape new generations of researchers.

First, we present a content-based citation analysis of over 650 citations of the RBI framework. We introduce a comprehensive methodology to the HCI research field and describe the citation type classification we created, specific to investigating frameworks, to understand how and where the work has influence. Second, we report on our survey of HCI instructors to shed light on the role of emerging interaction frameworks, including RBI, in their teaching. Finally, we identify gaps and propose extensions for the RBI framework in the future. This work is an opportunity to reflect on the design and use of frameworks and their impact on the community.

This paper offers four main contributions:

(1) We propose and use a methodology for evaluating the impact of frameworks through a content-based citation analysis, including the design of a new citation typology;
(2) We assess the role of frameworks on HCI education by presenting findings from a survey of HCI instructors that provide insight on the use of emerging interaction frameworks in educational settings, focusing on post-Windows-Icon-Menus-Pointer (WIMP) interaction paradigms and techniques;
(3) We evaluate the research impact of RBI, a highly cited framework, by evaluating an existing space, and contextualizing work with respect to the design space;
(4) We discuss the future of the RBI framework.

2 RELATED WORK

To frame the context of this article, we start by looking at the role of frameworks in HCI research and report on authors who have reflected on past theoretical work. We then describe citation

[1] ACM Digital Library accessed on December 10, 2018

analyses, specifically detailing the established content-based citation analysis methodologies and various citation typologies.

2.1 Frameworks in HCI research

Frameworks are theoretical contributions, which can also include definitions, theories, models, or principles [88]. Frameworks on their own are not a clearly defined entity—they blend with theories and other concepts. Authors are the first to characterize their work as a framework, but at times, others interpret them as theories. For instance, the Trajectories Conceptual Framework was positioned as a framework by its authors [8], yet as a theory by others, as reported by Velt, Benford, & Reeves [83]. For the purpose of this current analysis, a strict definition for frameworks is not necessary. We aim to analyze the impact of a theoretical piece of research that was originally labeled a framework by its authors. Hence, we focus on frameworks, though our work may be applied to other types of theoretical works.

As theoretical contributions, frameworks are meant to "inform what we do, why we do it, and what we expect from it" [88]. Rogers [68] defines a framework as "a set of interrelated concepts and/or a set of specific questions that is intended to inform a particular domain area." Frameworks outline the basic structure of concepts, systems, ideas, with descriptive or predictive power. Lundgren et al. [49] categorized frameworks as *relational maps* combined with a set of design properties.

Frameworks serve various roles. Mazalek and van den Hoven [54] identified categories of frameworks, in the context of tangible user interfaces, and we can use these as a starting point for our study of broader HCI frameworks. Their three framework types are abstracting, designing and building. *Abstracting* frameworks focus on categorizing and analyzing past systems; *Designing* frameworks help designers and researchers to conceptualize concepts by "outlining problem spaces"; *Building* frameworks help implement new systems. The former categories are supported by Lundgren et al. (2015) who identify two main purposes of frameworks: "as a *design tool* for ideating and (re)-designing through selection and adaptation of the framework's properties; as an *analytic tool* for systematically describing interactive systems for collocated mobile experiences". These categories are also in line with Bederson and Shneiderman's five kinds of theories in HCI: descriptive, explanatory, predictive, prescriptive, generative [6].

2.2 Evaluating the impact of theoretical HCI publications

While theoretical contributions are validated primarily through empirical work [88], there are instances where HCI researchers have aggregated these validations, through citations, to evaluate the contributions of frameworks [19, 46, 83].

Clemmensen, Kaptelinin and Nardi looked at the use of activity theory in HCI over a 25 year period [19]. They looked at 109 English, peer-reviewed journal and conference papers that used activity theory, beyond simply citing it. They identified five ways papers related to activity theory: they used it; they referenced a classic text; they identified which specific concept was used; they used it alone or in combination with other theories; and they comment and reflect on their use. After that, the authors proposed five purposes for using activity theory: 1) as an object of analysis, 2) as a meta tool, to inform the design of additional tools; 3) as a tool for conceptual analysis; 4) as a tool for empirical analysis and 5) as a framework for design. The investigation yielded an overview of the use and adoption of activity theory in HCI: two thirds of the cited papers used it for analysis, 15% to inform new tools, and the rest (16%) to inform their design.

Velt, Benford and Reeves [83] performed a similar exercise with Trajectories Conceptual Framework, undertaking an analytic literature review of works citing three original academic sources for the framework. They selected a set of 60 papers engaged with the framework. They looked at the purpose the framework served in the citing paper and which concepts were applied. Classifications

include situating the work, analyzing and describing an experience, designing experiences, and discussing and building concepts. The paper provides examples to paint a picture of the use of the framework by contemporary works.

Reflections can also help to get a higher level view on debates within a community. Following a decade of discussion sparked by their 2004 paper, Kjeldskov and Skov [46] performed a meta-analysis of discussions on lab and field evaluation in the mobile HCI research field. By looking at the 142 papers that cited their original publication, they found about 44% used lab or field evaluations, 11% compared lab and field evaluation and 45% engaged in a discussion of field and lab evaluations. Their overall discussion of their findings included a status update of the state of mobile HCI evaluation research.

Conferences, such as CHI [4], OzCHI [58], IndiaHCI [31], and HRI [3] have also looked at their impact over time, for instance by looking at keywords, citations, or author affiliations. This enables the identification of trends and directions of research focus, the general influence of the conference as well as collaborations among authors. This exercise revealed the growing importance of the themes of Design, Health and Well-being, and Education at the OzCHI conference [58], a low repeat authorship in IndiaHCI [31], and that best papers are not cited more than a random sample of papers from the same year [4].

2.3 Citation Analysis and Content-based Citation Analysis

Citations are the tool researchers use to demonstrate the originality of their contribution to the field by allowing them to identify prior work and publications that have had a major influence on their work [74]. To evaluate the impact of theoretical contributions, a citation list provides a starting point, based on the premise that a citation indicates that the citing author was influenced by the cited author [91]. While citations do not capture all sources of influence of an article [51], they do provide an explicit, trackable source of the formal influence of the scientific work. Citation analysis is characterized by looking at the frequency of citations. Traditional bibliometric approach for this counts each reference as one, independently of the number of times it is cited within an article. Many HCI researchers such as Clemmensen et al. [19], Velt et al. [83], Kjeldskov & Skov [46], Bartneck & Hu [4] have used this technique.

2.3.1 Citing behaviors and citation typologies. Authors cite for a variety of reasons, such as giving credit to related work, providing background reading, substantiating claims, criticizing previous work, to name a few of the 15 reasons first elaborated by Garfield [27], and that there are no absolutes as to when to cite. More recently, Bornmann & Daniel [10] summarized the eight most important types of citations from a meta-review of 40 empirical studies about citing behaviors (Table 1). They noted the general proportion of each type of citation, some of which vary greatly (e.g. affirmational citation type).

In investigating the types of citations made by CHI2016 authors, Marshall et al. [53] describe three main types of citations: cursory, descriptive and critical. A *cursory* citation is one that is given without additional comment. The authors qualify them as shallow or throwaway citations. Cursory citations can be part of a list or as an indication that the work exists on this particular topic. *Descriptive* citations can be conceptual, when authors are looking to present a concept, a definition, or a theory; while they can be methodological when the citation is there to justify the use of a certain methodology (procedure, material, etc.). Descriptive citations can support a fact to justify a factual statement. The work cited can also be described, including any of its justifications, methods and findings. Finally, *critique* citations describe the original work in more details, to affirm, contrast or compare the current work, to critique the original manuscript, or when the citation strongly influenced the work. The authors analyzed over 3000 citations from 13% of the CHI2016

Table 1. Bornmann and Daniel [10] meta-review of empirical studies about citing behaviors.

Citation Type	Description	Range of proportions for this type across studies
Affirmational	"citing work confirms cited work; citing work is supported by cited work; citing work depends on cited work; citing work agrees with ideas or findings of cited work; citing work is strongly influenced by cited work"	10-90%
Assumptive	"citing work refers to assumed knowledge that is general/specific background; citing work refers to assumed knowledge in an historical account; citing work acknowledges cited work pioneers"	5-50%
Conceptual	"use of definitions, concepts, or theories of cited work"	1-50%
Contrastive	"citing work contrasts between the current work and cited work; citing work contrasts other works with each other; citing work is an alternative to cited work"	5-40%
Methodological	"use of materials, equipment, practical techniques, or tools of cited work; use of analysis methods, procedures, and design of cited work"	5-45%
Negational	"citing work disputes some aspects of cited work; citing work corrects/questions cited work; citing work negatively evaluates cited work"	1-15%
Perfunctory	"citing work makes a perfunctory reference to cited work; cited work is cited without additional comment; citing work makes a redundant reference to cited work; cited work is not apparently strictly relevant to the author's immediate concerns"	10-50%
Persuasive	"cited work is cited in a "ceremonial fashion"; the cited work is authored by a recognized authority in the field"	5-40%

papers. Overall, they found 29% of the citations were cursory, 64% descriptive and less than 5% of the citations were critiques or analyses of previous work. The authors note that this is a failure of our discipline, as the lack of critical analysis may lead to poor-quality research.

Taskin and Al [79] created five citation purposes: literature, definition, data, method, and data validation. The large majority of citations (84%) were listed as prior literature, following with 9% of citations used as definitions in a review of over 400 peer-reviewed open-access papers from two Turkish journals. Their analysis also identified that 97.2% of citations had a neutral meaning, 2% qualified as positive, and 0.8% as negative.

Combining these three examples of typologies with those discussed in the previous section, we note that various citation typologies may depend on the level of analysis, the type of articles analyzed and the goal of the researchers. We adapted those categories in our own citation typology as applied to a theoretical framework in HCI.

2.3.2 Content-based citation analysis. Content-based citation analysis takes into account the content and the context of in-text citations, called citation mentions. Two levels characterize the content-based citation analysis [22]: the semantic and the syntactic level.

Citations can be examined at the *semantic level* by analyzing their intended meaning, by characterizing their contribution to the cited work. For that, in-text citations are classified individually based on a chosen citation typology. By allowing the analysis to distinguish the citation type, we can understand more clearly the contribution and influence of the cited articles on the current work [48].

We can also look at the *syntactic level*, by identifying their location in the cited work. Ding et al. [22] divided articles from the *Journal of the American Society for Information Science and Technology* into the following sections: Abstract, Introduction, Literature Review, Methodology (includes Design), Results (includes Discussion), Conclusion. They found, for instance, that citations tend to appear in the Introduction and Literature Review sections. When applying this methodology to a single article (Hirsch's 2005 article introducing the "h-index" as a method of quantifying a scientist research output), Lu, Ding & Zhang [48] found more than 40% of citation mentions occur in the Introduction. These citations tend to be perfunctory and provide a definition of the h-index and its function. The authors also observed how types uses vary in time: they identified three phases of citation data collected: first, Discussion, where citing articles discuss the features and argue for variations of the index in the discussion section; then, Reputation, where most mentions, perfunctory, appear in the introduction; and finally, Adoption, where citations mentions are used in the methodology section of the citing articles.

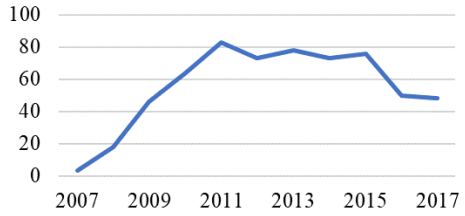
2.3.3 Problems with citation analysis. We must also acknowledge that citation analyses do not capture the entire portrait of an article's influence. In listing problems with citation analysis, MacRoberts and MacRoberts [51] include that not all influences, formal and informal, are cited, that there is bias in citing, including due to disciplines, nationality, time period, and size, that secondary sources are often preferred, that the citing author motivation is not well captured, and authors are sometimes ignorant of the literature. In a more recent article, they took the concept further and propose to investigate both types of influence, those that are cited, and those that are not cited [50]. They investigate uncited influence by reading the text to determine what the influences on scientific work actually are.

Given this, our work not only focuses on assessing the direct, formal influence of a work through its cited work: we must find ways to include informal influences, beyond those in publications. As a step toward this, we focus on understanding the role of frameworks in formal education of future researchers and practitioners as an important area of uncited influence. In particular, we report on a survey we conducted to gauge the use of emerging HCI frameworks in courses and to understand their role in fostering learning. Other areas of influence (e.g. industry practice) are out of the scope of this article, but would be valuable to study in future work.

3 REALITY-BASED INTERACTION

For this paper, we focused our investigation on the Reality Based Interaction (RBI) framework by Jacob, Girouard, Hirshfield, Horn, Shaer, Solovey and Zigelbaum. Initially briefly introduced in a CHI2006 workshop entitled *What Is the Next Generation of Human-Computer Interaction?* [39], with a mention in a follow up *Interactions* article [40], the framework appeared as a work-in-progress at CHI2007 [41], then as a full paper at CHI2008 [42]. The RBI framework proposed a common language to unify a large subset of seemingly divergent research, understand, compare and relate new interaction styles and bridge gaps between research areas. Through four themes, naïve physics, body awareness and skills, environment awareness and skills, and social awareness and skills, the RBI framework provided a lens to analyze, compare alternative designs and evaluate design tradeoffs. The RBI framework paper proposed implications for design, mainly addressing how simply mimicking reality alone is not sufficient—researchers must make tradeoffs, giving up reality

Fig. 1. Citation per year according to Google Scholar for the CHI2008 RBI paper (Dec 1, 2017).



only in return for other desired qualities such as efficiency, expressive power, versatility, ergonomics, accessibility or practicality. This tradeoff should be made explicitly. RBI was proposed to allow a community of HCI researchers to think explicitly about connecting their research to others in next generation HCI.

The RBI framework has been widely used by the HCI research community, evidenced by a relatively steady stream of citations from 2007-2017 (over 600 citations total, ~ 75 a year, as illustrated by Figure 1). It seems that the topic of the framework is still relevant ten years later, as the framework did not focus on specific, potentially now outdated, technologies.

4 CONTENT-BASED CITATION ANALYSIS

To analyse the impact of the framework on the community, we first look at how it may have directly influenced contemporary publications through citations. We started our investigation with a citation analysis, observing general patterns of the metadata from citing articles. Following this general analysis, we performed a content-based citation analysis to go beyond mere citation counts and provide a first in-depth measure of the impact of a framework paper. Our content-based citation analysis looks at both the *syntax* (where in the citing article are the citations located) and *semantics* of the citations (what is the context and intent for each citation) [22].

4.1 Methodology

For our analysis, we focused on all documents that cite the 2008 RBI paper. We used the citations taken from Google Scholar as it has a larger citation index than other databases such as ResearchGate, Scopus, or Web of Science [55, 57, 80] and it is freely available. Specifically, we found that Google Scholar yields the most complete picture of the citations for human computer interaction papers and produces a more nuanced ranking, as it indexes not only journals and conferences (like Scopus and Web of Science) but also books, book chapters, dissertations, reports, workshop submissions [4, 55]. In addition, Moed, Bar-Ilan and Halevi [57] found that double citations due to duplicate documents occurred in less than 2% of cases in Google Scholar. Google Scholar found 656 citations to the 2008 CHI paper on December 2, 2017 [30]. In comparison, the ACM Digital Library indicated 205 citations for this paper on the same date.

Using Publish or Perish [32], we extracted the citations of this paper as identified by Google Scholar, including the title, authors, year of publication, number of citations, source, publisher and article URL. We used Google Sheets as our qualitative data analysis software due to its flexibility in coding, low cost, and efficient collaborative features [52]. We manually downloaded, with help from research assistants, 506 manuscripts (available publicly or through subscriptions from our institutions). We found the correct publisher for each entry, as the source and publisher information are often domain names (e.g. "dl.acm.org"), incomplete (e.g. containing an ellipsis), or not from the actual publisher (e.g. extracted from researchgate.net, or from the author's website). We also

identified the language of the publications and determined the type (journal, book, conference, report, workshop, thesis, other type) of all English publications. Other type included items such as book chapters, preprints, magazines, webpages, and articles from other languages than English. We manually fixed a few additional entries (e.g. missing year). Finally, we extracted the author keywords from all English manuscripts retrieved. We gathered 433 sets of keywords. We focused on English works as it is the common publication language in our field.

For the content-based citation analysis, we focused on the subset of citations published by the Association for Computer Machinery (ACM). They represent the largest single source of citing works (25%); their standard format provides more trackable impact; and they cover mainly peer-reviewed or juried publications. ACM is also the largest publisher of HCI work, which includes the premier conference in the field, the CHI conference. We had access to all publications through the ACM Digital Library subscription from our institutions. This subset contained 166 papers from conferences, journals and magazines.

For each of those 166 papers, we studied all citation instances of the RBI paper. To extract those citations, one undergraduate and one author manually identified each reference number to the 2008 RBI paper, searched for this reference number within the text, and noted the sentence that cited it directly. When context was relevant, we also noted the surrounding paragraph. We also searched for the keywords "reality", "reality-based" and "Jacob" to identify any additional relevant citations.

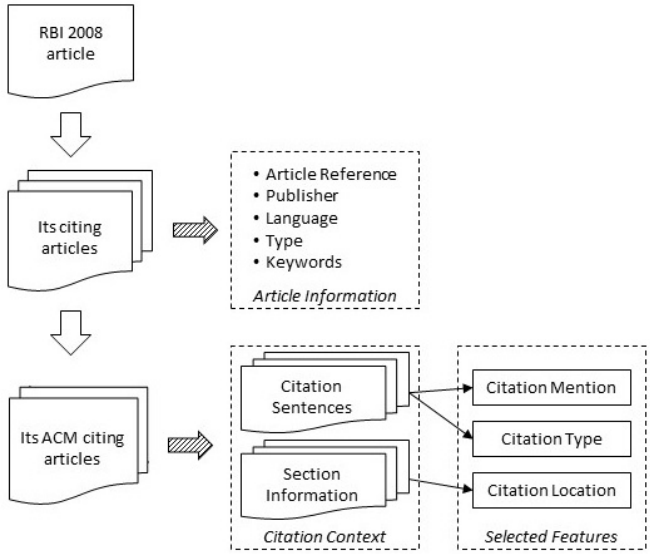
For the syntactic level analysis, we noted the location of the citation within the citing work, grouping them into the following nine section types: Abstract, Introduction, Related work, Design, Methodology, Analysis & Results, Discussion, Conclusion, Other [14]. For citations in subsections, we looked up the master section title. We first classified sections that include the type verbatum, then proceeded to classify ones that used a direct synonym (e.g. *Literature review* as a synonym for *Related work*). Finally, we read the entire section of the rest citation to classify into the nine main section types. For our purposes, Design includes interaction techniques, application scenarios, prototype systems, or the design section of frameworks; Analysis & Results includes case studies; and Other includes citations that do not fit obviously into other categories, such as citations in more theoretical or survey papers or workshop and studio details.

For the semantic level analysis, we proceeded to classify the citation types manually. Starting from a typology based on prior work discussed above, we jointly classified 12 randomly selected papers (containing 23 citations) and discussed the preliminary classification of an additional dozen citations by one of the authors. The goal of this initial stage was to refine the description of the types and ensure a common understanding of the typology terms. We divided the rest of the papers so that two authors classified each citation. We iteratively updated the citation typology as we read more citations. When there were divergent classifications for a citation, a third author reviewed it. All authors discussed unresolved typology selections to select a final citation type. This iterative methodology prevents us from reporting an agreement score, as many citations are the result of a group decision.

We illustrate our methodology in Figure 2, inspired by that of Lu, Ding & Zhang [48]. To summarize, for each citation, we noted the following features for our citation content analysis coding:

- **Citation mention:** the number of mentions within a paper (instances);
- **Citation type:** the function of the citation in the citing work;
- **Citation location:** where the citation content is located.

Fig. 2. Overview of the data collection and selected features.



4.2 Citation Typology

Our final citation classification includes eight types: cursory, descriptive, term, supportive, justification, analysis, critique and generative. Our typology is based on, and extended from, the approaches of Bornmann et al. [10], Marshall et al. [53], and Clemmerson et al. [19]. We refined the classification in extensive discussions while classifying citations. Table 2 details the typology, including a description of each of the eight types, with two to four examples of RBI citations to illustrate the type.

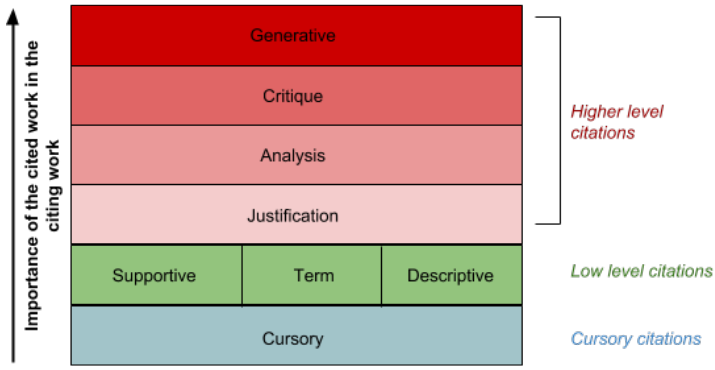
Type	Examples from Citing Articles
A **cursory** citation is one that mentions the citation in passing, without any context, details, or information. It sometimes lists the authors, sometimes the name of the work, though it can also be part of a list of citations and contain no details.	• "Frameworks for interaction between users and physical objects, and between physical objects and related software entities, have been a focus of both the pervasive gaming and tangible interaction communities, though comprehensive standards for physical interaction are still more aspiration than reality [RBI + 4 other citations][2]." [11] • "At the other end of the scale, in the second approach, a number of authors have introduced design-orientated frameworks that aim to guide the creation of novel interactive systems [e.g. RBI + 2 citations]." [24] • "As ubiquitous computing continues to spread, researchers have looked to the features of the world in which computation takes place in order to inform the creation of new interfaces [RBI]." [92]

[2]For clarity when reporting examples (in this table and in the rest of the document), we replaced the citation numbers in square brackets by either "RBI" (when they were citing the CHI 2008 RBI paper), or by "citation" (for any other external citation), or both.

Type	Examples from Citing Articles
A **descriptive** citation contains details about the cited work (RBI), such as describing its methodology, or explaining the claims made by the cited work (RBI).	• "Using one's own body awareness and skills is part of Jacob's Reality-Based Interaction (RBI) Framework [RBI]. RBI's stance is that users engage in these environments by leveraging their pre-existing knowledge of the everyday world, their own bodies (naïve physics), as well the surrounding environment and social context (Fig. 3)." [15] • "Jacob et al. highlight that reality-based interaction principles should at times be traded off against other goals, such as efficiency computational power, versatility, accessibility, technical feasibility and physical ergonomics [RBI]." [34]
A **term** citation demonstrates the adoption of a framework as common and understood term and concept in the field. This citation type occurs when authors write *reality-based interaction* with a citation without detailing it. It can also define a grouping or a category.	• "Third, research in shape-changing interfaces rarely focuses on interaction and does not relate shape change to models of interaction (e.g., on reality-based interaction [RBI] or tangible user interfaces [2 citations])." [66] • "In that sense, the interaction paradigm does not have to be only a reality based interaction [RBI], but an interaction paradigm that gives digital applications a real life interaction." [13] • "A number of systems illustrate the potential of supporting science education through reality-based interaction [RBI]." [71]
A **supportive** citation supports a statement, a simple fact, without necessarily detailing the cited work.	• "These systems can sense physical movement of the participants to create reality-based interactions that are easily understandable to even the novice participant [RBI]." [9] • "Finally, several emerging interaction styles, including touch-based interaction, ubiquitous computing, embodied interaction, and mixed reality, share salient commonalities with TUIs [RBI]." [70]
A **justification** citation contributes to an argument, when the citation strengthened a line of reasoning, such as to justify a methodological choice, or a data pattern observed.	• "Embedded inertial sensors, which capture displacement and orientation, provide rich opportunities for interaction design including direct physical manipulation, and symbolic and metaphorical gestures. This novel combination of sensing and actuation capabilities goes beyond simple changes of (virtual) states (e.g. by the use of buttons) offering significantly more potential of expressive interactions [RBI]." [63] • "The direct control of the projection device creates an immediate link between the device and the projected object. Physical movement and angling of the device draws upon our understanding of 'naïve physics' and our 'body awareness and skills' [RBI]." [87] • "Mobile Game Interfaces are a suitable application domain for applying reality-based interaction techniques in a creative setting." [67]

Type	Examples from Citing Articles
An **analysis** citation is used to evaluate, compare or contrast the author's current work.	• **Evaluate:** "Based on the procedures of interaction analysis [RBI] and qualitative content analysis, separate categories within the four themes of RBI were inductively developed for coding the videos." [29] • **Compare**: "Jacob et al. [RBI] asserted that our iCon is a post-WIMP interface [citation], and can be categorized as belonging to Naïve Physics." [16] • **Contrast:** "Having said that the burgeoning numbers of pen-based interfaces such as [citation] are now pushing digital pens to provides variety of interface manipulations that are semantically incoherent with our understanding of a 'pen' such as the ability to lasso, grab and flick objects. But such an approach stands in contravention to the suggested push towards reality-based interfaces (one of the supposed advantages of tangible systems) discussed in [RBI]." [45]
A **critique** citation discusses the strength and limitations of, or provides support for the cited work (RBI).	• **Strength**: "At this point trade off considerations as proposed by Jacob et al. [RBI] provide a helpful guideline." [61] • **Limitations**: "First, the ephemeral (i.e., transient) is a natural phenomenon that yields potential for application in HCI but that has not yet been thought of as part of reality-based interaction [RBI]." [23] • **Limitations**: "None of the tradeoffs and conflicting objectives presented by Jacob et al. [RBI] quite captures the issue focused on in this paper, that apparent realism may mislead users to expect the system to behave 'like the real thing'." [34] • **Evidence:** "This focus on representations of familiar interactions and motor responses also serves as an additional grounding for the description of RBI [RBI], explicitly relating the themes of familiarity and skill with body, environment, etc, to a cognitive theory and brain function." [75]

Fig. 3. Visual representation of the importance of citation types.



Type	Examples from Citing Articles
A **generative** citation occurs when the authors use the cited work to inspire or inform the design of their own work, for instance when design choices are inspired or explained using the framework	• "Our approach leans on Jacob et al.'s framework which describes the contextual factors arising from users' interactions with the environment as well as "social others" to explain bodily interaction with non-keyboard controlled devices [RBI]. Jacob et al. suggest that a "four lens view" provides sufficient detail and abstraction to analyse new systems that feature the human body. As such, our perspective of the human body is similarly structured using four lenses: the Responding Body; the Moving Body; the Sensing Body; and the Relating Body." [59] • "The Stomp system can be considered in terms of bodily interaction [citation] and as an example of reality-based interaction [RBI]. The system is designed so that stomping, stepping, and sliding in Stomp are like stomping, stepping and sliding in the real world. Kicking a soccer ball in Stomp is closely related to kicking a soccer ball on the soccer pitch." [90] • "Our approach is grounded in a reality-based methodology which argues for building upon the knowledge and experiences of people in the "real world" [RBI]. Thereby, we respect that people's natural behavior such as physical, social and bodily interactions are highly practiced and robust and thus require little effort to learn and perform. Due to the particular challenging characteristics of creative group work, we believe that a sensitive and subtle deployment of technology is required. We therefore consider "power vs. reality tradeoffs" , with the goal "to give up reality only explicitly and only in return for other desired qualities" [RBI]. In our design we strive for a balance between the power of the interface and its level of reality." [28]

Table 2. Citation Classification.

Our classification can be viewed as distinguishing three main groups of citations: higher level citations (generative, critique, analysis and justification citations), which presumably use the cited work as a direct influence, low level citations (supportive, term, descriptive), which help lay a foundation of the work, but their omission would not be critical to the manuscript, and cursory citations, which are shallow, "throw-away" citations [53]. Figure 3 illustrates the hierarchy of importance of the citation typologies.

Table 3. Mapping of citations classification proposed with prior work.

Our Types	**Bornmann & Daniel** [10]	**Marshall et al.** [53]	**Clemmensen et al.** [19]	**Velt et al.** [83]
Cursory	Perfunctory Assumptive Persuasive	List Work exists		Situating the work
Descriptive	Methodological	Described		
Term	Conceptual	Work exists		
Supportive	Affirmational	Supports a fact		Situating the work
Justification	Affirmational			
Analysis	Contrastive	Critique	Conceptual analysis Empirical analysis	Analyzing and describing an experience Discussing and building concepts
Critique	Negational	Critique	Meta-tools Object of analysis	Discussing and building concepts
Generative			Design	Designing experiences

Our classification is designed to identify citations suggesting that the cited work had an influence on the new work and to categorize the type of influence. While the classification is general enough to be applied to any article, it is designed to evaluate the impact of a specific theoretical work or framework. For example, the *term* citation type likely applies mainly to theories or frameworks.

Table 3 compares our citation typology to prior typologies. Contrary to Clemmensen et al. [19] or Velt et al. [83], we consider the impact the work may have had as a whole on the community by analyzing articles that may only cite the framework in a cursory manner, or supporting a simple fact. However, our typology does not distinguish between various types of *cursory* citations (such as Bornmann et al. [10] and Marshall et al. [53], which distinguish between a list, or an acknowledgment that the work exists) as this is not a necessary level of detail for our analysis.

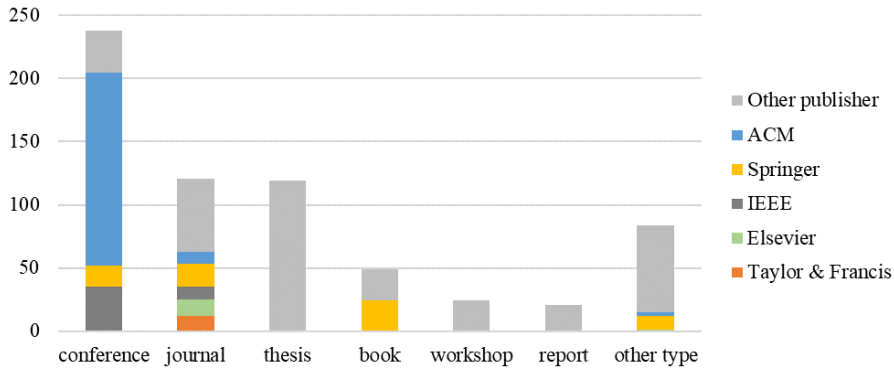
In contrast, we provide a more comprehensive list of types of "higher level" citations than some of the prior work. Bundled as *critique* by Marshall et al. [53], we distinguish between *analysis* and *critique* citations to show various integration of the cited work in the development and analysis of the citing work. Finally, the *generative* citations go beyond Bornmann et al. [10] and Marshall et al. by borrowing an element from Clemmensen et al. [19], which describes citations used to help generate or design the citing work.

Finally, it is worth noting that the two categories *supportive* and *justification* can be seen as very similar. However, we found that there is an important distinction between articles that use a citation to support a fact and those that contribute to an argument. In *supportive* citations, we see statements of facts that relate to and are supported by similar statements in the RBI paper. We acknowledge that at times, the line between the two may be thin or blurry, as the authors' intent it not always clear.

4.3 Results

We first look at the citation analysis conducted to situate the work generally with regards to the type of publications that cite the reality-based interaction framework, before diving into our content-based citations analysis.

Fig. 4. Count of publications type for publications citing RBI, grouped by Publisher.



4.3.1 General citation analysis. We found 656 citations for the RBI paper on Google Scholar as of December 2nd, 2017. Most publications were in English (86.7%). Among works published in other languages, 46 are in German, 10 in Chinese, 9 in French, 6 in Portuguese, 4 each in Spanish, Greek and Italian, 3 in Korean, and one in Czech.

Publication type & Publisher. For publications where we could identify the type, most were conferences (238), followed by journals (121), theses (119), and books (49). Most publications were from ACM (166), followed by Springer (70) and IEEE (45). Figure 4 illustrates the publication type frequencies, organized by publisher. *Other publisher* includes any publisher of fewer than 10 publications citing RBI, or publications without a clear publisher. *Other type* includes documents without a clear publication type and those that fall under grey literature (bulletins, patents, preprints, etc.).

Diving into ACM, the largest publisher of publications citing RBI, most ACM publications are from conferences (153), with 10 additional publications from ACM journals, and 3 from Interactions Magazine. This ratio is expected as conferences are preferred in this field [21]. The conference papers that cite the RBI paper are overwhelmingly coming from CHI (34 as regular papers and 25 from the extended abstract (EA) category) and TEI (26). Other conferences include ITS (7), BSC-HCI (7), NordiCHI (6). We also find 23 additional conferences that have four papers or fewer citing RBI. Figure 5 displays the number of papers in each ACM publication venue.

Keywords. To observe the general topics and research areas of the publications that cite the RBI paper, we extracted the keywords of all English manuscripts retrieved, as well as for the ACM papers subset, cleaned them to standardize their spelling (capitalization, singular/plural form). Figure 6 displays the keywords with a relative frequency higher than 0.5% in the larger dataset (20 keywords). The top keywords include tangible, design, virtual and augmented reality. We also produced a word cloud where the frequency of the keyword is represented by font size (Figure 7).

RBI in title/keywords. We found 20 publications that used "reality-based interaction" or "reality-based interface" in the paper title. Of the 433 works where we extracted keywords, we found an additional 36 publications that used the terms above as keywords. Of those 56 publications that refer directly to RBI in title and/or keywords, six were authored by the RBI paper authors (10.7%). We notice that publications used RBI as a keywords mainly during 2009-2014 (Figure 8).

Fig. 5. Count of publications citing RBI by ACM venues. For graph clarity, we removed venues that contained a single citing publication.

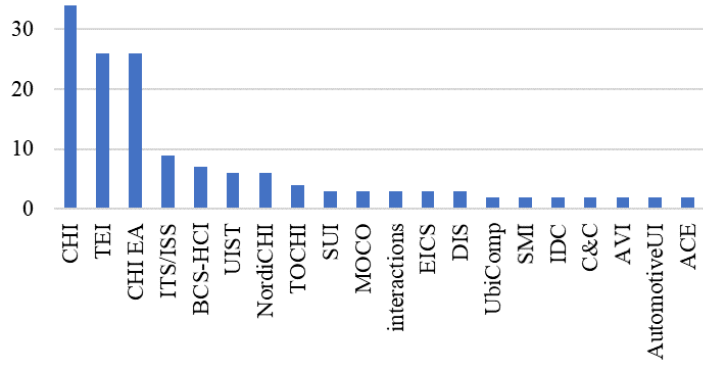
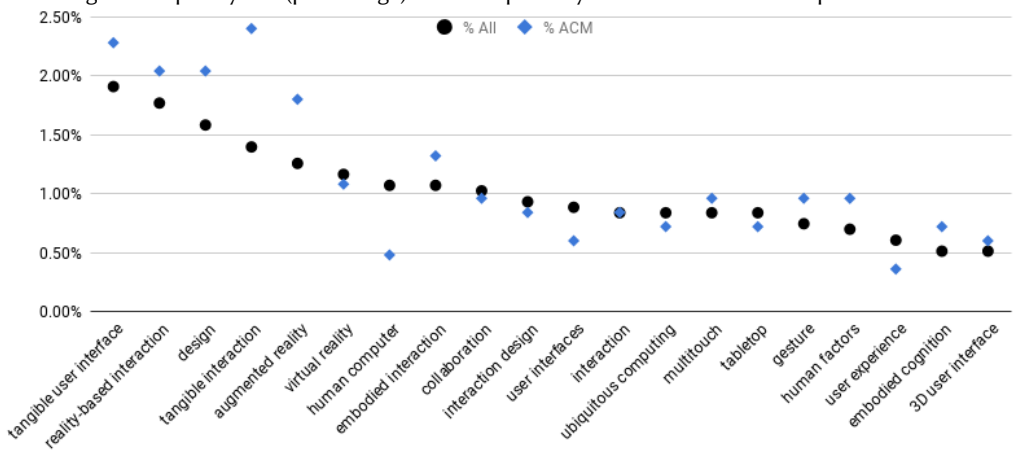


Fig. 6. Frequency use (percentage) for the top 20 keywords from both set of publications.



Self-citations. 27 publications citing the 2008 article are authored by one or more of the 2008 RBI paper authors (4.1%). Most were published between 2008 and 2011 (median of 4.5/year).

4.3.2 *Content-based Citation Analysis.*

Citation Mentions. There are 164 papers with the 2008 RBI paper in the reference list, as two papers did not actually cite RBI from the original lot from Google Scholar. Within those 164 papers, we extracted 322 instances of in-text citations. Table 4 reports the number of citing papers and mentions per year. 59% of papers (n=94) had a single in-text citation (Figure 9). One publication in this set included RBI in their bibliography, but did not cite it within the text. We omit it from our analysis.

Citation types. We further analyzed the citations according to the citation types introduced in Citation Typology section above to investigate the impact of RBI on the papers we examined. Most citations are justification, followed by generative and supportive (Figure 10).

Fig. 7. Word clouds of author keywords citing RBI. On the left, keywords from all publications (frequency of 3 and more), on the right, keywords from ACM publications (frequency of 2 and more). This is based on the same data as Fig. 6, with frequency mapped to font size.

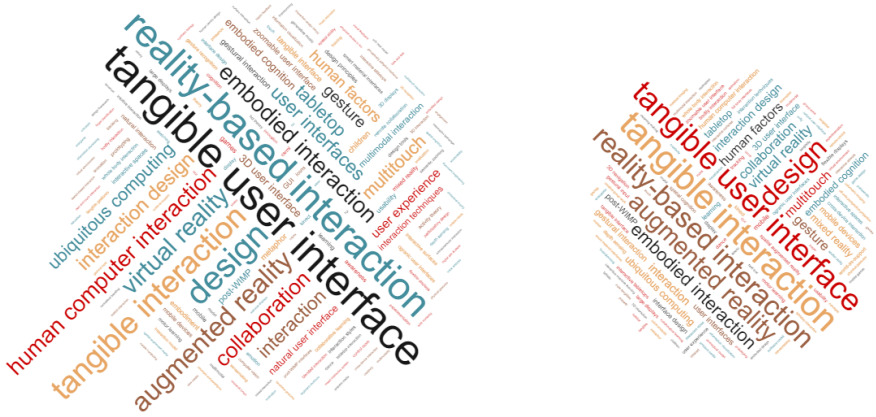


Fig. 8. Count of publications using RBI (in short or long form) as a keyword, by publisher and year.

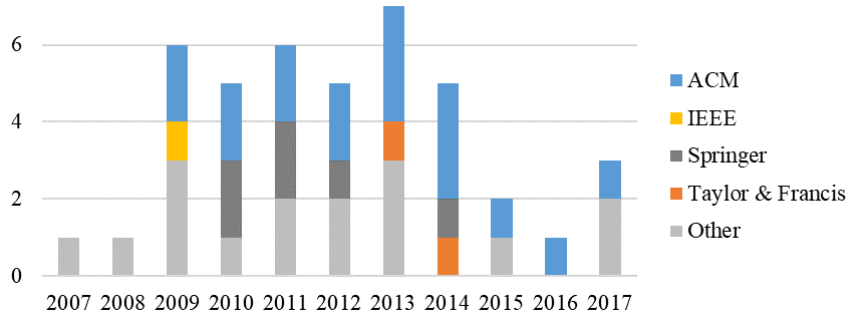


Fig. 9. Ratio of in-text citation mentions per ACM paper

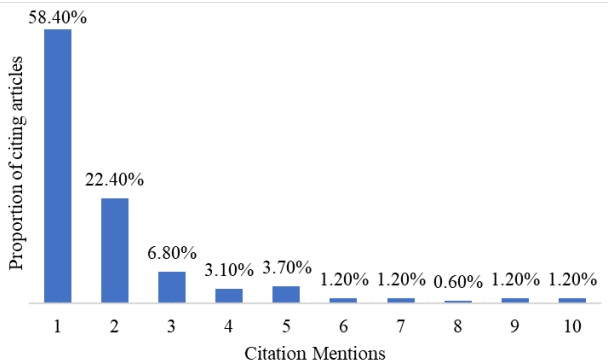
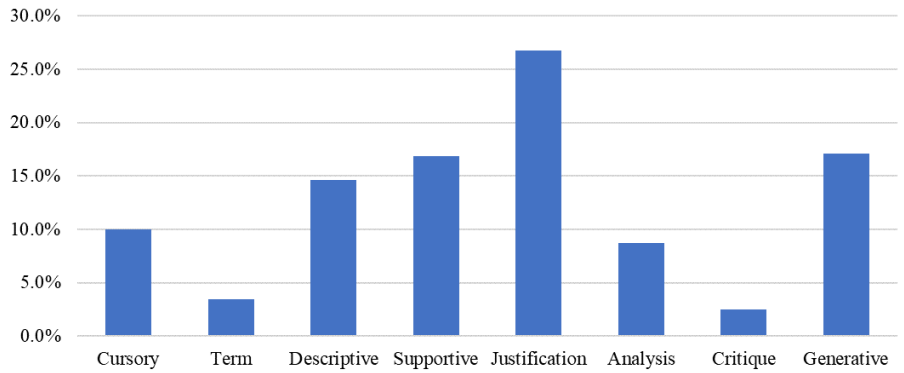


Table 4. Numbers of citing ACM articles and mentions collected each year

Year	# of citing articles	# of citation mentions	Citation mentions per article
2008	4	6	*1.50*
2009	12	32	*2.67*
2010	23	52	*2.26*
2011	23	42	*1.83*
2012	16	30	*1.88*
2013	19	37	*1.95*
2014	23	48	*2.09*
2015	14	22	*1.57*
2016	10	25	*2.50*
2017	17	27	*1.59*
Total	**161**	**321**	***1.99***

Fig. 10. Frequency of citations per types



Citation Locations. When observing where the citations are within a paper, we observe without surprise that the core of them are located within the introduction and related work (Figure 11). A more interesting series of observations occurs when we break down each location by the type of citation occurring. There, we notice that while a majority of citations in the introduction are of lower importance, there are still a significant number used to support the authors' argument in their work, as well as to generate new ideas. 45% of the design sections' citations are of the generative type.

Conversely, it is relevant to look at where each type of citation is found in a paper. Lower level citation types (cursory, term, descriptions, supportive, see Table 2 in the Citation Typology section) are in a large majority cited at the beginning of the paper (between 73% and 82% of those citations occur in the Introduction or Related work). Only 55% of citations that justify an argument are located in these sections. The rest are mainly located in the Discussion section (14%) and the Design section (13%). Analysis citations are distributed in all sections (between 1 and 7 citations each). We find Critique citations in five sections, not simply at the end. Finally, while the design section contains the largest amount of generative citations (35%), it is interesting to note that they show up in all sections.

Fig. 11. Frequency of citations type per location

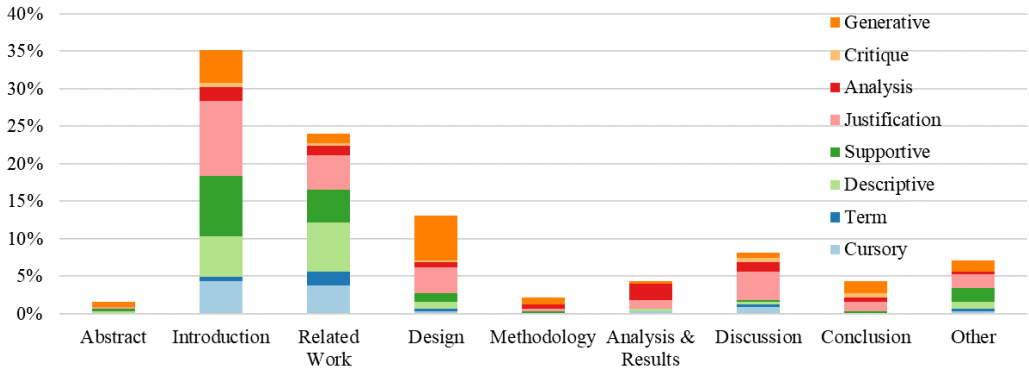
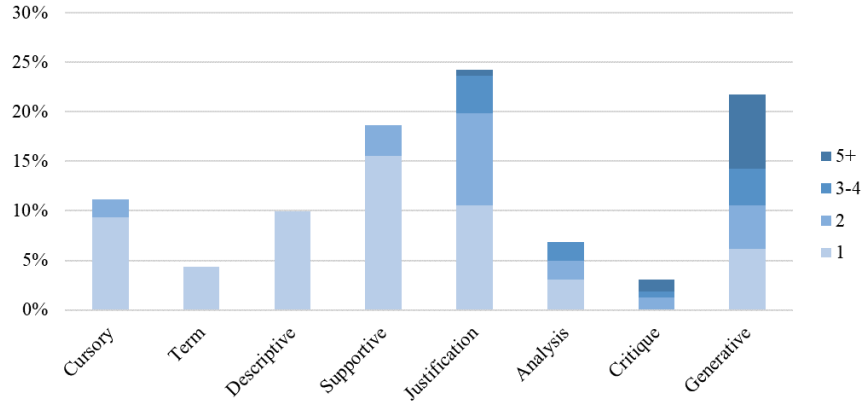


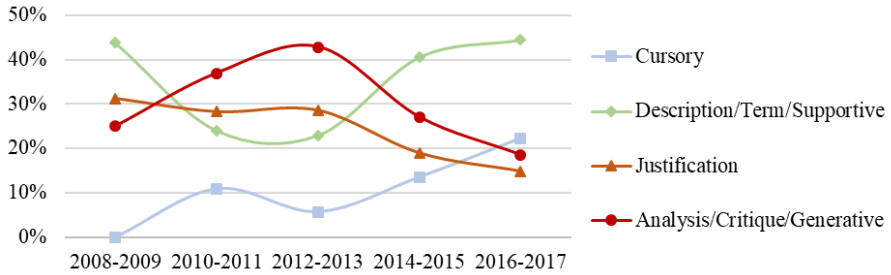
Fig. 12. Highest citation type in our taxonomy per paper, grouped by types (x-axis), and grouped by the number of citations in the paper.



Citation type based on the number of citations in a paper. Based on the hierarchy of the classification types (see Figure 3 in the Citation Typology section), we selected the highest citation type among all citations in a paper, to represent the paper, as we postulate that those represent the best ultimate use of the RBI citation in the cited work (Figure 12). This exercises illustrates that two thirds of papers with a single RBI citation have a low level citation type (cursory, term, descriptive, support a fact). We also note that papers with more citations (5+) have higher-level citations (generative).

Citations in time. When looking at a temporal trend of use of the different types of citations, we notice a shift in use (Table 13). We notice that low level citations (term, descriptive, and supportive) count for more than 40% of citations for last 4 years. In recent years, authors do not use RBI as much to justify or in a higher level way than previously. We also note that cursory citations slowly increasing.

Fig. 13. Proportion of the highest citation type per paper, per year (grouped in pairs of years to avoid individual year variability)



4.4 Discussion

4.4.1 Justifications: contributing towards an argument. As seen in Figure 10, citations that justify an argument are the most common, and this is often done in the introduction though they are also found throughout the other sections of the paper (Figure 11). For instance, Seyed et al. [69] said *"The goal of our work is to improve interaction with 3D volumetric medical images for medical imaging specialists. Our approach is to leverage tangible objects as an interaction mechanism, taking advantage of existing spatial and physical reasoning skills [RBI]."* We consider justifications to be in the higher level category of citations, as they imply a use of the prior work to contribute towards an argument. This requires an integration of the concepts, as opposed to cursory or basic referencing.

4.4.2 RBI, a generative framework. Over 17% of papers citing the RBI framework did so in a generative way (Figure 10), making it the second highest category of citations. Generative citations most often appeared in the Design section, followed by the Introduction. Generative frameworks are important as they inspire researchers to come up with new ideas, new interaction techniques, and new systems, enabling practitioners to create or invent or discover something new [6].

In addition to the examples listed in Table 2, we provide three examples of generative mentions. Zigelbaum et al. based their work in RBI: *"We wanted to base g-stalt as much upon real-world phenomena as possible following the guidelines of Reality- Based Interaction [RBI]. By rooting the interaction design in conventional phenomena such as inertia, persistence in space, and solid geometry we designed the actions in g-stalt to mimic the real world."*, while Takala [78] explicitly mentions being inspired and influenced by RBI: *"The name of RUIS and the philosophy behind it is inspired by a paper from Jacob et al. [RBI], who introduced "Reality-Based Interaction" (RBI), which is a conceptual framework for non-traditional interfaces involving the following themes: naïve physics, body awareness, environment awareness, and social awareness. The RBI themes influenced us to strive for a VR toolkit that enables developers to utilize a physics engine and full-body tracking in their VR applications."*. Finally, Widgor et al. [85] based their work on the concept of naïve physics: *"These shapes were selected by roughly matching physical properties to their perceived effect to a user's understanding of naïve-physics, as advocated by Jacob et al. [RBI]."*

An open question is what features of the framework make it generative. The current work does not provide an answer to this. However, one potential factor is that the framework is not tied to a particular technology or interaction style, which could quickly become outdated. Instead, it is defined by human properties.

4.4.3 Established as a term. This analysis showed that reality-based interaction has become an established term in the HCI community. Authors cite it without adding details, similarly to other

general, established concepts and terms such as tangible user interactions, post-WIMP, direct manipulation or organic user interfaces. For example, Kwon, Javed, Elmvist and Yi [18] wrote: "*The influences of direct manipulation are not limited to traditional WIMP (windows, icons, menus, pointer) interfaces, but are widely applied to other types of interface—often known as post-WIMP [citation] or reality-based interaction [RBI]—such as information visualization (e.g., [citation]), augmented/virtual reality (e.g., [citation]) and direct touch interfaces (e.g., [citation])*". In this example, and those in Table 2, the quoted text is the only citation mention of RBI.

RBI is also used to refer simply to one of the concepts of the framework, e.g. "*interaction gestures based on reality-based [RBI] metaphors such as grouping cubes to tag them with a common element; shaking to express yes or no; and "sugar pack snap" to clear cube contents.*" [81]. We also found examples of the term used to identify groups of works, e.g. with the heading title "*Reality-Based Interfaces for Science Education*" [71].

While these might be similar to a cursory citation as their authors omit details, these citations demonstrate the adoption of the term by the community. The adoption of a framework's name as a term allows researchers to reason about and refer to it in a compact way. In this case, the name itself becomes a description.

The presence of reality-based interaction as a keyword in 44 publications also support that RBI has become a well-established term. For example, the following list of keywords appeared in a paper: "*design tools, collaborative design, affinity diagramming, reality-based interaction, digital pen & paper, hybrid interactive surfaces*" [25]). By the nature of keywords, they need to be words that people understand without citation.

4.4.4 Low proportion of cursory citations. The proportion of cursory citations for the RBI framework (10%) is relatively lower than that reported by Bornmann and Daniel [10], which range from 5 to 50 percent for types perfunctory, assumptive and persuasive (Table 1), and by Marshall et al. [53], who found 29% of CHI 2017 citations to be cursory. It indicates that authors citing RBI do it not in a "ceremonial," but in a relevant, fashion. Perhaps this low number of cursory citations is also influenced by the fact that RBI has become an established term.

4.4.5 Strong Link between Tangible User Interaction and RBI. The keyword analysis of the complete set of citations revealed an adoption of the reality-based interaction framework by the tangible interaction community, with the most common author keywords being *tangible user interfaces*, *tangible interaction* (4.8% of all keywords include the word *tangible*). We also notice other common keywords common to the tangible interaction field such as *design*, *embodied interaction*, *interaction design*. The Tangible, Embedded and Embodied Interactions (TEI) conference is also the second preferred venue to publish works that cite RBI, after CHI. If we take into account the relative size of the conferences (in 2018, TEI published 37 papers while CHI published 666), we find that RBI is cited disproportionally high by TEI conference authors.

However, it is unclear if the link between tangible user interfaces and RBI is due to a particularly strong connection in topics, to the adoption of the framework by the TEI community, or because the original authors are prominent members of the TEI community (e.g. three RBI authors are on the TEI conference steering committee following their participation in creating or chairing the conference). In addition, there is a relatively high amount of framework papers published at TEI (1-2 a year, representing approximately 4% of papers, which is more than double the general trend in HCI). Perhaps this indicates that the TEI community appreciates and uses frameworks in their work, which helps explain the adoption of the RBI framework by the community.

Beyond the fact that RBI was mostly adopted by TEI authors, the keywords word cloud and top 20 list indicate that RBI framework is applied to a range of subfields. The fields of augmented

reality and virtual reality (combined with 3DUI) represent 3.8% of the keywords, demonstrating adoption of RBI in these communities as well.

4.4.6 Self-citations. In reflecting on the impact of the use of a framework, it is critical to qualify the use of it by the original authors, to indicate if it has been adopted largely by others. The overall impact may be diminished if the work is mainly cited by its creators, as each self-citation yields an additional 3.65 citations from others over a ten-year period [26]. In this case, we found just over 4% of citations from the authors of the original RBI paper, which is much less than the 11% found over a similar 10-year period by Fowler and Asknes [26]. Hence, we do not expect that those self-citations had a strong impact on indirect citations and assume that the works has been independently accepted in the community.

4.4.7 Critiques. We examined the citations categorized as "critiques" further, to see whether they could identify areas for improvement or updating of the RBI framework. There were seven such citations. Several mentioned that RBI taken at its face is too simple—emulating reality perfectly is not the ultimate goal. Hornecker [34] illustrates this well: *"None of the tradeoffs and conflicting objectives presented by Jacob et al. [RBI] quite captures the issue focused on in this paper, that apparent realism may mislead users to expect the system to behave 'like the real thing'."* This needs clarification in the future, because the goal was not to match reality perfectly, but to make conscious and intelligent tradeoffs at each point where a system diverges from reality. Another point was to connect more closely with embodied interaction and perhaps cognitive linguistics: *"However, RBI alone is not sufficient. To understand the relation between our experience of the physical and social environment and our cognition, we must consider theories from embodied cognition and cognitive linguistics."* [43] And yet another was to cover ephemeral or transient natural phenomena.

Nevertheless, it is worth considering whether reality ought to be the standard against which the tradeoffs are made. The original RBI formulation specifically excluded computer artifacts from the "real world", arguing that they are less deeply embedded in the brain than the physical world. However, with an emerging generation of digital natives, this could be revisited.

4.4.8 Contemporary Use of RBI. Over the course of the past decade, as new and innovative interactive technologies have emerged, the broad scope of the RBI framework has continued to evolve and influence other frameworks and concepts of interaction. We noticed specific works that iterate on RBI concepts as being ones that cite the RBI frameworks numerous times.

RBI has been used as the foundation to update earlier, yet influential, user-centered models such as the 1986 Norman Model [36]. In Poor et al. [64], the authors used RBI to provide an updated view of post-WIMP interaction to evaluate whether the Norman model, more specifically the interplay between the UI and the mental representation of the UI described within, could be applied to more current interaction. They found that these post-WIMP interactions led to enhancements of mental representation of both the UI and the task. By understanding these enhancements and the details of human cognitive structures involved in these new interaction through the lens of RBI, Poor et al. were better equipped to explain observed differences in user performance, thereby extending the original Norman model.

Other authors took a different approach to the application of RBI. Both Jetter et al. [44] and Geyer et al. [29] used RBI as the foundation for their more focused frameworks. Jetter et al. considered RBI's "four themes of reality and their considerations about power versus reality tradeoffs as an important basis for Blended Interaction." However, Jetter et al. not only embraced the concepts outlined in RBI, but they also extended them to say that "...some concepts from the digital world have been adopted and deeply internalized by the user population and are applied almost as effortlessly as if it were basic-level sensorimotor experiences." This extension of the RBI framework

into what the authors called "Blended Interaction" combined the notions of reality with those experiences that users bring from digital technologies. As for Geyer et al., they considered RBI to be the theoretical framework for their work and used the four themes outlined within to identify "crucial characteristics of embodied design practice." It was these characteristics that served as the basis for their evaluation of reality-based interactive systems for creative group work.

Given the two works above, it is worth noting that Reiterer's lab embraced the notion of tradeoffs and the recommendation from the RBI framework to explicitly identify them. In seven publications [12, 28, 29, 47, 60, 61, 65], they address the tradeoff between power (expressive or computational) against reality to analyze their work. We find interesting that Müller et al. [61] called them "design tradeoffs".

Finally numerous authors used specific portions of RBI to help shape their arguments or advance concepts within their areas. Hornecker [34] focused on the concept of tradeoffs in order to explore the issue of "apparent realism" and how this effect can lead to incorrect actions taken by users who are misled by an interaction that does not behave the way the user would expect. Hornecker criticizes the RBI tradeoffs as they do not capture the idea of apparent realism, which "may mislead users to expect the system to behave 'like the real thing'." Other authors, such as Neale et al. [62], shaped their prototypes such that the users actions would more closely correlate to real, non-digital world actions.

4.4.9 Limitations. Citation analyses inherently are limited to the quality of the citation list foraged. Researchers have shown that Google Scholar provides the largest citation index [55, 57, 80], but it still may have omitted some works. With regards to our content-based citation analysis performed, we looked systematically, but solely, at individual citations and their surrounding paragraph: we did not consider the greater paper as a whole. It is possible that we misinterpreted the context or intention of authors by proceeding this way. This also means that we may have missed other use of the RBI framework within a paper. We believe that the influence of both of these are likely limited. In performing the syntactic analysis of citations, we used location categories of typical scientific papers. However, HCI manuscripts do not always conform to the standard outline. We foresee that these limitations have had at most a minor impact on the overall analysis, as the wealth of citations collected allowed for a robust analysis.

We also reiterate some of the problem with citation analyses described in Section 2.3.3. This analysis is based on the premise that a citation indicates that the citing authors was influenced by the cited author [91], as stated in Section 2.3. However, we recognize that citing a paper is not proof that one has read it. As such, authors may cite the RBI paper because the term "reality-based interface" can be interpreted and used without knowledge of the underlying framework. We also recognize that a citation may not indicate influence, as perhaps the citation was added post hoc. These exemplifies problems with citation analyses, where the citing author motivation is not well captured [51]. Our current citation typology is unable to distinguish the motivation behind the citations.

5 EMERGING INTERACTION FRAMEWORKS IN EDUCATION

Frameworks often have an important impact on a field beyond published works. In particular, frameworks have a role in informing and inspiring future practice and research through education. We view research and teaching as connected and synergistic - the inclusion of frameworks in the training of students in the field provides them with lenses to scope, study, and analyze a design space, as well as guidance for new design and research projects.

To evaluate the influence of frameworks on the field through education, we complement our citation analysis, with findings from an online survey of HCI instructors, which inquires whether, and how, frameworks are used by instructors in the classroom.

While impact of theoretical work on future researchers and practitioners in the field may happen through discussions between advisors and advisees, our survey focuses on the inclusion and use of frameworks in HCI courses. We were particularly interested in how such frameworks are integrated into a course, and what learning goals are related to them.

While our citation analysis is focused on the RBI framework, we expanded the focus of our educational impact inquiry to *emerging interactions frameworks*, as it provides a reasonable medium between inquiring about all frameworks in HCI, a topic too large (it contains several hundreds of frameworks) and potentially vague for respondents, or inquiring only about the RBI framework, which would limit the depth and usefulness of the answers with such a narrow topic. Emerging interactions encompass the post-Windows-Icons-Menus-Pointers (WIMP) interaction techniques and technologies discussed by the reality-based interaction framework as well as by numerous of other frameworks.

In the survey, we included theoretical works that could be classified as *paradigms* - overarching approaches that provide a set of novel or accepted practices and describe a phenomena to observe and inquire, as well as *frameworks* - a set of core concepts, principles, or questions to consider when analyzing, critiquing, or designing in a particular domain [68]. We acknowledge that these definitions are not mutually exclusive and might overlap in their purpose or level of abstraction. We included works from tangible interaction frameworks [2, 35, 38] and augmented and virtual reality [56], to ubiquitous computing [84], instrumental interactions [5] and natural user interfaces [86]. These emerging post-WIMP interactions, encompass the main research areas that have adopted RBI based on the keyword analysis conducted in the previous section (see Figure 7): tangible interaction, augmented and virtual reality, ubiquitous computing, embodied interaction, tabletop.

5.1 Blooms' Taxonomy

To frame our educational investigation around learning goals, we use the revised Bloom's taxonomy introduced in 2001 by Anderson and Krathwohl [1]. The revised cognitive taxonomy emphasizes different types and levels of knowledge—factual, conceptual, procedural and metacognitive. The taxonomy uses verbs rather than nouns to highlight progression from simple to more advanced types of thinking and learning. More specifically, the revised taxonomy includes the following types of learning:

(1) **Remembering**: retrieving or reciting definitions, facts, or lists, from previously learned information.
(2) **Understanding**: constructing meaning as demonstrated by activities such explaining, interpreting, classifying, summarizing, and comparing.
(3) **Applying**: using or implementing the learned materials in new situations.
(4) **Analyzing**: distinguishing between components, instances, or parts; organizing and relating elements based on common attributes.
(5) **Evaluating**: Assessing and comparing based on pre-defined criteria and standards.
(6) **Creating**: combining elements in a new coherent structure or pattern through a design process to generate a novel conceptual, aesthetic, or functional product.

We used these types of learning to query instructors about the expected learning goals related to integrating frameworks in a particular course. While we chose to use a learning-centered terminology in the survey, the terms are related to those we used in our citation analysis (see Table 3): Remembering mirrors *cursory* citation; Understanding relates to *descriptive* and *term* citations;

Table 5. Frameworks suggested in the emerging interactions survey.

Framework	Year	Theme	Citation Count[3]
The Computer for the 21st Century [84]	1991	Ubiquitous Computing	15254
Tangible Bits: Towards Seamless Interfaces Between People, Bits, and Atoms [38]	1997	Tangible User Interactions	4474
Augmented Reality: a Class of Displays on the Reality-Virtuality Continuum [56]	1995	Augmented Reality & Virtual Reality	1729
Getting a Grip on Tangible Interaction: a Framework on Physical Space and Social Interaction [35]	2006	Tangible User Interactions	748
Reality-Based Interaction: A Framework for Post-WIMP Interfaces [42]	2008	Post-WIMP	669
Instrumental Interaction: An Interaction Model for Designing Post-WIMP User Interfaces [5]	2000	Post-WIMP	553
Brave NUI World: Designing Natural User Interfaces for Touch and Gesture [86]	2011	Natural User Interfaces	541
The CTI Framework: Informing the Design of Tangible Systems for Children [2]	2007	Tangible User Interactions & Children	142

Applying relates to *justification* and *supportive* use of citations; Analyzing and Evaluating maps to *analysis* and *critique*; and Creating is equivalent to *generative*. More generally, learning goals that requires higher levels of knowledge integration relate to higher level citations - both indicating direct influence on learners or works.

5.2 Methodology

The survey was composed of four sections: course content presentation, learning goals, courses taught and demographic questions.

In the **course content presentation** section, we were interested in investigating the use of emerging interactions frameworks in the classroom. We presented an initial list of eight frameworks to participants, but indicated that list is not exhaustive and participants could list additional frameworks. We selected the initial list of frameworks to cover a variety of emerging interactions. We also ensured that each framework had enough citations to show some adoption by the research community (Table 5).

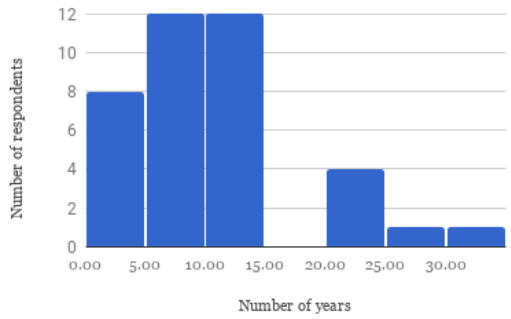
For each framework, participants indicated if they integrate the framework as part of their teaching and in what capacity (presented in a lecture, discussed in class, assigned as a reading, or not part of their teaching). The survey randomized the order of presentation of the frameworks. Participants could expand on how they teach frameworks. We then asked why they chose to include, discuss, or assign these framework papers their teaching, or, alternatively, to indicate why they do not include framework papers in their teaching.

The **learning goals** section relates to Bloom's revised taxonomy [1]. For participants not familiar with it, we provided a link to a summary of the taxonomy[4]. We listed the six cognitive process dimensions of the taxonomy, worded to relate to the use of HCI frameworks:

[3]Feb 19, 2018, Google Scholar

[4] http://www.celt.iastate.edu/teaching/effective-teaching-practices/revised-blooms-taxonomy

Fig. 14. Distribution of years teaching HCI among the survey participants



- *Remembering:* recall, lists the paper, remembering they read the paper and it's related to the field
- *Understanding*: comprehends, summarize & explain core ideas of the paper, give an example for an interface and explain how it related to the core ideas of the framework.
- *Applying*: use the framework to analyse an existing work, to describe their own work.
- *Analysing:* deconstructs the framework core ideas to illustrate
- *Evaluating:* criticize the framework.
- *Creating:* inspire students' new designs.

For each taxonomy listed in the first section, we asked participants what their learning goals are when integrating the framework in their teaching. In addition to the six goals, the option to indicate that a framework is not part of their teaching was available. As in the other section, the survey listed the frameworks in a random order (not necessarily in the same order in the previous section). We then asked participants to provide examples of how their students integrate the frameworks in their learning. They could also provide additional comments relating to learning goals.

We designed the **courses** section to learn more about the classes participants teach. We asked in what type of teaching do they integrate emerging interaction styles (undergraduate course(s), graduate course(s), other, or that they are not part of their courses). Optionally, they could provide the title and/or course outlines of the classes where they use framework papers. **Demographic** questions included the country they teach in, their role (e.g. faculty member, instructor, post-doctoral fellow, graduate student), and how long they have been teaching HCI courses.

We sought participants that teach the topic of HCI, with a specific interest for instructors who discuss the topic of emerging interaction styles. While the survey was in English, participants could discuss classes taught in another language. We advertised the survey on social media, via mailing lists that serve the greater HCI community, and at the CHI conference. The authors also emailed the survey invitation to over a hundred HCI colleagues directly. The survey was open for two months, between March and May 2018. We received clearance from the research ethics board of Carleton University for this study.

5.3 Participants

The survey was advertised and administered non-anonymously by the authors. We recruited 38 participants (1 doctoral student, 1 postdoc, 36 faculty members) with an average of 9.8 years teaching HCI (SD=7.0). Figure 14 shows the distribution of years teaching HCI as reported by participants. Table 6 show the geographical distribution of our participants.

Table 6. Geographic distribution of survey participants

List of Countries	Number of participants
Australia	1
Austria	1
Belgium	3
Canada	7
Denmark	2
Finland	2
France	2
Germany	7
Israel	1
Japan	1
New Zealand	1
Sweden	1
Switzerland	1
United Kingdom	1
United States	7

5.4 Survey Results

5.4.1 Course Content. Most participants (33/38) reported integrating the suggested frameworks into their teaching, in both undergraduate and graduate courses. Table 7 shows the type of courses reported by participants. Five participants reported not integrating any of the proposed frameworks in their teaching, two of these do not use any frameworks in their teaching.

On average, participants reported using 3.6 of the proposed frameworks in their teaching (SD=2.0). Presentation formats vary and include presentation in lecture, discussion in class, and assigned readings. Table 8 summarizes the presentation format for each of the suggested frameworks. In addition to the proposed frameworks, participants listed 42 other emerging interactions frameworks. We list here the five surveys cited more than once by participants. See Appendix A.2 for the complete list.

- Holman and Vertegaal. *Organic user interfaces: designing computers in any way, shape, or form.* Commununication of the ACM, 2008. [33]
- 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.* CHI, 2002. [7]
- Hiroshi Ishii, Dávid Lakatos, Leonardo Bonanni, and Jean-Baptiste Labrune. 2012. *Radical atoms: beyond tangible bits, toward transformable materials.* interactions, 2012. [37]
- Marcelo Coelho and Jamie Zigelbaum. 2011. *Shape-changing interfaces.* Personal Ubiquitous Computing, 2011. [20]
- Scott S. Snibbe and Hayes S. Raffle. 2009. *Social immersive media: pursuing best practices for multi-user interactive camera/projector exhibits.* CHI, 2009. [76]

5.4.2 Learning Goals. Table 9 shows the learning goals expected by instructors for each framework. Note that instructors could select any number of learning goals for each framework. While Bloom's taxonomy is a scale, where Remembering represents a shallower integration of knowledge and Creating indicates the strongest integration, participants could interpret this question as they pleased. Some selected only a single option (e.g. Understanding only), a combination of options

Table 7. Types of HCI courses integrating emerging UI frameworks (participants could select more than one option)

In what type of teaching do you integrate emerging UI framework papers?	Number of Answers
Undergraduate course(s)	24
Graduate course(s)	34
Other	2
Frameworks are not part of my courses	5

Table 8. In-course presentation formats used by instructors when including the suggested frameworks in their teaching. Participants could select multiple options independently using check boxes.

Frameworks	Presented in a lecture	Discussed in class	Assigned as a reading
Ubiquitous Computing [84]	24	11	9
Tangible Bits [38]	23	12	9
Tangible User Interactions [35]	15	9	5
Reality Based Interactions [42]	13	10	4
Tangible User Interaction and Children [2]	4	4	1
Instrumental interaction [5]	6	4	1
Natural User Interface [86]	11	5	4
Augmented and Virtual Reality [56]	20	9	3

(e.g. Understanding and Creating), or all options until their designated higher level goal (e.g. Remembering, Understanding, Applying, Analyzing and Evaluating). The results indicate that for all frameworks, instructors assigned not only shallow learning goals but also the learning goal of Creating - informing the design process of novel systems, which requires the highest-level of knowledge integration.

Figure 15, shows an aggregation of assigned learning goals for frameworks. The figure highlights the various goals of integrating frameworks to teaching and the expectation that frameworks will have analytical (Evaluating) as well as generative role (Creating).

Responses to the question "Can you give examples in how your students integrate the frameworks in their learning?" consistently highlight both analytic and generative applications. For example, one participant wrote "Student use and create exemplar devices based on the frameworks. Applying them to new problem domains." Another participant shared, "Mostly in using frameworks (not necessarily those [listed]) to critique their own work / reflect on it. Also considering the limitations of the framework and to what extent it might apply / not apply." An additional example highlighted the importance of integrating frameworks, "understanding the whole picture; providing a lens to look through for their design and evaluations; they tend to miss things and lose focus in their work if the work with frameworks is reduced/avoided."

5.4.3 RBI results. 18 participants reported using the RBI framework in their teaching, presenting it in class (13), discussing it in class (10), and assigning it as readings (4). Figure 16 shows the distribution of learning goals for integrating RBI in teaching.

One participant reached out to the authors and shared an unsolicited personal communication: *"I use [RBI] all the time — it appears in my undergrad HCI courses, and I find myself constantly thinking about and citing it in my own research. I feel like it describes everything that is "new hotness" in HCI*

Table 9. Count of learning goals of participants when integrating frameworks in their teaching. Options could be selected independently.

Frameworks	Remembering	Understanding	Applying	Analyzing	Evaluating	Creating
Ubiquitous Computing [84]	17	20	13	6	7	11
Tangible Bits [38]	21	22	13	7	7	14
Tangible User Interactions [35]	13	13	10	6	5	10
Reality Based Interactions [42]	14	14	8	7	4	4
Tangible User Interaction and Children [2]	6	7	5	3	2	6
Instrumental Interaction [5]	6	7	4	4	2	2
Natural User Interface [86]	13	12	6	3	3	9
Augmented and Virtual Reality [56]	18	19	11	8	5	12

Fig. 15. Percentage of total learning goals when integrating frameworks in teaching.

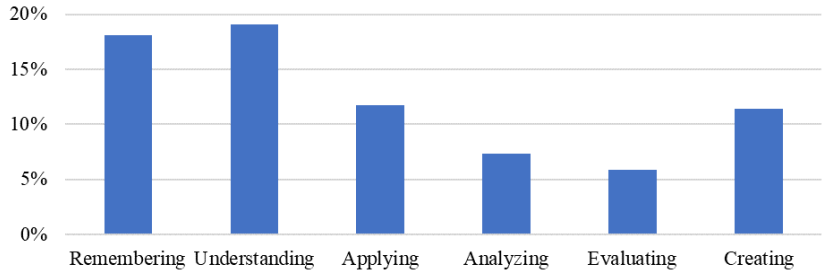
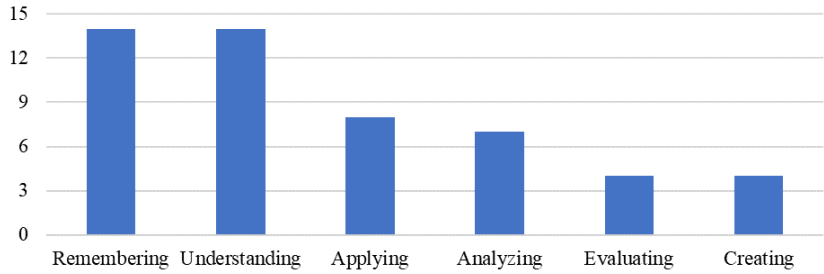


Fig. 16. Distribution of learning goals for integrating RBI in teaching



and interaction. I think the tightness of the concepts, and the clarity in the ideas are what I like best about it. It's just so easy to explain, and _it_just_makes_sense_. "

5.5 Discussion

Our study of the role of emerging HCI frameworks in education was aimed to investigate the uncited influence of RBI and other frameworks. In particular, we sought to evaluate the role of frameworks in informing and inspiring future practice and research through their integration in formal education. Results indicate at least 38 instructors, who are distributed geographically across 15 different countries, integrate one of the 8 frameworks listed in the survey to their courses. The RBI framework is included in at least 13 different undergraduate and graduate courses. This indicates that the 8 frameworks, including RBI, do have an important uncited influence—impacting HCI practitioners and researchers through their training and education. In addition to evaluating the impact of these 8 frameworks, the survey contributed a table (see Appendix A.2) that could serve as a living document of emerging HCI frameworks used in education. Our use of the revised Bloom's taxonomy for classifying the uncited influence of RBI, reflects the classification we applied for studying the cited influence of RBI. Using both Bloom's taxonomy and the citation classification, we can differentiate between higher level citations (generative, critique, analysis and justification citations) or learning goals (applying, analyzing, evaluating, creating), which use frameworks as a direct influence; and low level citations or low level learning goals which help lay a foundation for a specific work or area of study. Our findings indicate that emerging frameworks are used to impact learners through both analytical (evaluating) and generative (creating) high-level learning goals. For example, 10/38 participants reported that they used RBI in their courses to help student *create* new projects. This echoes our finding that over 17% of papers citing the RBI framework did so in a generative way. This supports that both cited and uncited influences of RBI may have direct impact on new work.

5.5.1 Limitations. Our selection of 8 framework papers for the survey might have introduced bias due to area of studies, nationality, time period, and motivation. Also our non-anonymous advertising and administration of the study may introduce a self selection bias. Instructors who do not use any of the 8 frameworks may have decided not to answer the survey, so the number of respondents who are not using frameworks might not be large enough to reflect the reality of using frameworks in education.

6 FUTURE OF THE RBI FRAMEWORK

We take the occasion of this ten-year retrospective analysis to step back and identify gaps and consider extensions or future applications for the RBI framework.

We developed the notion of Reality-Based Interfaces as a way to characterize and understand new interaction styles around the same time as developments such as virtual reality, tangible interfaces, computer vision-based interfaces, and more "natural" pen and touch-based interfaces were rapidly emerging into practice from the HCI research world; and it was inspired by these trends. Ten years later, this raises the question of how strongly our notion was tied to a particular technological era and whether it will be viable in the future. It is a good time to ask whether there is a new emerging generation requiring new explication, or perhaps a broader theory or framework that spans generations – or whether RBI can still be a helpful way to view further generations of interface styles or should be extended to accommodate them.

The core concepts of RBI were built around the properties, skills, and knowledge possessed by the human users, rather than around technological developments. The former are less changeable and thus provide a more solid foundation on which to continue into the future. In fact, the most basic notion underlying RBI could apply to nearly any skilled human work. For any system or tool, one can enumerate the pieces of skill or knowledge needed to use it. One then considers which of these the user already knows vs. which must be learned for the new system. The former might

have come from the "real world" as with RBI (which is defined much more precisely for RBI as the union of naïve physics, body awareness and skills, environment awareness and skills, and social awareness and skills) or, more broadly, might simply have been learned previously from any source. This provides the basis for a simple relative indication of the difficulty of using any new system [17].

On the other hand, new trends are emerging in interaction styles, which may push beyond the boundaries of reality-based interaction. For example, conversational user interfaces, voice-based personal assistants, and chatbots are being deployed widely. Human-robot interaction is similarly growing, and now includes social robotics and robot companions. Self-driving cars raise user interface questions as well as moral issues. Interfaces using brain measurement and other passive real-time physiological sensing are also emerging. Some of these, such as conversational personal assistants, seem quite straightforwardly based on the kind of "real world" conversations that people already know how to conduct with other people and thus fit nicely. What about an implicit or passive brain-computer interface that measures its user's mental workload and adjusts itself in real time to accommodate the user [77]. Such mind-reading does not seem to happen literally in the real world. However, people can be quite good at detecting the mental state of others through subtle cues and responding appropriately, so perhaps this type of interface can be viewed as approximating reality by emulating an interaction with a real-world partner with an almost superhuman degree of empathy.

One issue for both RBI and the trend in interaction styles that it most closely describes is the extent to which "reality" becomes a limitation. As stated in the original RBI paper, "a useful interface will rarely entirely mimic the real world, but will necessarily include some unrealistic or artificial features and commands. In fact, much of the power of using computers comes from this multiplier effect–the ability to go beyond a precise imitation of the real world." [42]. Shneiderman argues similarly that anthropomorphic user interfaces that strive to mimic humans are ultimately restricted by the powers and abilities of humans [73]. RBI described a trend toward greater emulation of the real world in HCI which had begun ten years ago and seems to be continuing unabated; the framework can help evaluate and discuss where a given interface falls along this direction; whether it is a good direction in the long run is a question for the future.

7 CONCLUSION

Frameworks such as Direct Manipulation or Instrumental Interaction have been an important force in HCI research. Frameworks contribute to HCI research through reflection and analysis of a wide selection of prior work in an area to extract common overarching principles and concepts. They often provide a foundation for study and their influence may emerge over time as they are adopted in research, education and beyond. Evaluating the impact of frameworks can identify whether and how a framework was used, how it has evolved, and what trends have developed over time. However, studying the impact of such theoretical contributions requires consideration of various perspectives and levels of impact. Analyzing and understanding the impact of a framework beyond the superficial level of raw citation counts is challenging and there are few examples of approaches for doing so effectively.

As a case study for investigating the impact of theoretical work in HCI, we present our evaluation of the impact of the Reality Based Interaction (RBI) framework, introduced by the authors in 2008. Through the two studies, we consider the influence of the RBI framework in both research and education perspectives. Together, we hope they shed light on the use of frameworks in general, the RBI framework in particular, and introduce new analysis approaches for understanding such frameworks.

Our citation study revealed that RBI is used directly by contemporary authors to justify arguments and significantly to generate new designs; and the education study provided support towards a measure of the intangible impact of the framework on future researchers and practitioners. Reflecting on existing frameworks, as we have done here, can identify new insights and potential refinements, particularly once enough time has passed for a framework to experience measurable adoption. Further, by exploring trends and potential factors contributing to the impact of the framework, we pave the way for effective development and evaluation of future HCI frameworks. Future work could include a further comparison of citation analyses of various frameworks, examining how the application of RBI has changed over time, as well as evaluating the impact of frameworks on industry practice through the reviews of patent or trade references.

Beyond the methodological approach introduced, we did also find that, overall, the RBI framework seems to remain relevant and in use despite the advancement of new technologies that the original paper could not have foreseen; it seems to have thrived within these new areas of interaction; and has evolved to inspire new emerging lines of research.

A SUPPLEMENTARY MATERIALS

A.1 Content-based citation analysis

See *RBI citations.xlsx*

A.2 Additional frameworks named in the survey

See *Education Survey Results.xlsx*

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REFERENCES

[1] L W Anderson and David Krathwohl. 2001. *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Vol. 6.

[2] Alissa N. Antle. 2007. The CTI framework: informing the design of tangible systems for children. In *Proceedings of the 1st international conference on Tangible and embedded interaction - TEI '07*. ACM Press, New York, New York, USA, 195. https://doi.org/10.1145/1226969.1227010

[3] Christoph Bartneck. 2011. The end of the beginning: A reflection on the first five years of the HRI conference. *Scientometrics* 86, 2 (2011), 487–504. https://doi.org/10.1007/s11192-010-0281-x

[4] Christoph Bartneck and Jun Hu. 2009. Scientometric analysis of the CHI proceedings. *Proceedings of the 27th international conference on Human factors in computing systems - CHI 09* (2009), 699. https://doi.org/10.1145/1518701.1518810

[5] Michel Beaudouin-Lafon. 2000. Instrumental interaction: An Interaction Model for Designing Post-WIMP User Interfaces. *Proceedings of the 18th international conference on Human factors in computing systems - CHI '00* 2, 1 (2000), 446–453. https://doi.org/10.1145/332040.332473

[6] Benjamin B. Bederson and Ben Shneiderman. 2003. *The Craft of Information Visualization: Readings and Reflections*. 1–410 pages. https://doi.org/10.1016/B978-1-55860-915-0.X5000-8

[7] 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 *CHI*. https://doi.org/10.1145/503376.503450

[8] Steve Benford and Gabriella Giannachi. 2008. Temporal trajectories in shared interactive narratives. In *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems - CHI '08*. 73. https://doi.org/10.1145/1357054.1357067

[9] Andrew Bluff. 2015. Remote Control of Complex Interactive art installations. *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition* (2015), 197–200. https://doi.org/10.1145/2757226.2764553

[10] Lutz Bornmann and Hans-Dieter Daniel. 2008. What do citation counts measure? A review of studies on citing behavior. *Journal of Documentation* 64, 1 (2008), 45–80. https://doi.org/10.1108/00220410810844150

[11] Chris Branton, Doris Carver, and Brygg Ullmer. 2011. Interoperability standards for pervasive games. *Proceeding of the 1st international workshop on Games and software engineering - GAS '11* (2011), 40. https://doi.org/10.1145/1984674.1984689

[12] Simon Butscher, Harald Reiterer, and Maximilian Dürr. 2017. InformationSense: Trade-offs for the Design and the Implementation of a Large Highly Deformable Cloth Display. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol* 1, 28 (2017), 1–28. https://doi.org/10.1145/3090053

[13] Eduardo H. Calvillo-Gãmez, Ana I. Grimaldo-Martínez, Víctor M. Gonzãlez, and Rafael Llamas Contreras. 2011. Pamphlet vs. Mobile: Sensemaking of Health Information. In *Proceedings of the 10th Brazilian Symposium on Human Factors in Computing Systems and the 5th Latin American Conference on Human-Computer Interaction (IHC+CLIHC '11)*. Brazilian Computer Society, Porto Alegre, Brazil, Brazil, 157–161. http://dl.acm.org/citation.cfm?id=2254436.2254464

[14] L. U. Ch'ao, Chengzhi Zhang, and M. A. Shutian. 2015. How does citing behavior for a scientific article change over time? A preliminary study. *Proceedings of the Association for Information Science and Technology* 52, 1 (2015), 1–4. https://doi.org/10.1002/pra2.2015.145052010097

[15] Debaleena Chattopadhyay and Davide Bolchini. 2013. Laid-Back , Touchless Collaboration around Wall-size Displays : Visual Feedback and Affordances. (2013).

[16] Kai-Yin Cheng, Rong-Hao Liang, Bing-Yu Chen, Rung-Huei Laing, and Sy-Yen Kuo. 2010. iCon: Utilizing Everyday Objects as Additional, Auxiliary and Instant Tabletop Controllers. *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10* (2010), 1155. https://doi.org/10.1145/1753326.1753499

[17] Georgios Christou, Frank E. Ritter, and Robert J.K. Jacob. 2012. Codein-A New Notation for GOMS to Handle Evaluations of Reality-Based Interaction Style Interfaces. *International Journal of Human-Computer Interaction* 28, 3 (2012), 189–201. https://doi.org/10.1080/10447318.2011.581893

[18] Bum chul Kwon, Waqas Javed, Niklas Elmqvist, and Ji Soo Yi. 2011. Direct Manipulation Through Surrogate Objects. *Proceedings of the International Conference on Human Factors in Computing Systems (CHI'11)* (2011), 627–636. https://doi.org/10.1145/1978942.1979033

[19] Torkil Clemmensen, Victor Kaptelinin, and Bonnie Nardi. 2016. Making HCI theory work: an analysis of the use of activity theory in HCI research. *Behaviour & Information Technology* 35, 8 (2016), 608–627. https://doi.org/10.1080/0144929X.2016.1175507

[20] Marcelo Coelho and Jamie Zigelbaum. 2011. Shape-changing interfaces. *Personal and Ubiquitous Computing* 15, 2 (jul 2011), 161–173. https://doi.org/10.1007/s00779-010-0311-y

[21] Computing Research Association. 1999. Evaluating computer scientists and engineers for promotion and tenure. *Computing Research News* September (1999), A–B. http://www.cra.org/uploads/documents/resources/bpmemos/tenure{_}review.pdf

[22] Ying Ding, Xiaozhong Liu, Chun Guo, and Blaise Cronin. 2013. The distribution of references across texts: Some implications for citation analysis. *Journal of Informetrics* 7, 3 (jul 2013), 583–592. https://doi.org/10.1016/j.joi.2013.03.003

[23] Tanja Döring, Axel Sylvester, and Albrecht Schmidt. 2013. Ephemeral User Interfaces: Valuing the Aesthetics of Enterface Components That Do Not Last. *Interactions* 20, 4 (2013), 32. https://doi.org/10.1145/2486227.2486235

[24] Augusto Esteves, Saskia Bakker, Alissa N. Antle, Aaron May, Jillian Warren, and Ian Oakley. 2014. Classifying physical strategies in tangible tasks. *Proceedings of the extended abstracts of the 32nd annual ACM conference on Human factors in computing systems - CHI EA '14* (2014), 1843–1848. https://doi.org/10.1145/2559206.2581185

[25] Ylva Fernaeus, Jakob Tholander, and Martin Jonsson. 2008. Beyond representations: towards an action-centric perspective on tangible interaction. *Int. J. Arts and Technology* 14, 34 (2008), 249–267. https://doi.org/10.1504/IJART.2008.022362

[26] James H. Fowler and Dag W. Aksnes. 2007. Does self-citation pay? *Scientometrics* 72, 3 (sep 2007), 427–437. https://doi.org/10.1007/s11192-007-1777-2

[27] Eugene Garfield. 1964. Can Citation Indexing be Automated? *Statistical Assoc . Methods for Mechanized Documentation* 269 (1964), 84–90. https://doi.org/10.1093/ije/dyl190

[28] Florian Geyer, Jochen Budzinski, and Harald Reiterer. 2012. IdeaVis: A Hybrid Workspace and Interactive Visualization for Paper-based Collaborative Sketching Sessions. *Proceedings of the 7th Nordic Conference on Human-Computer Interaction Making Sense Through Design - NordiCHI '12* (2012), 331. https://doi.org/10.1145/2399016.2399069

[29] Florian Geyer, Ulrike Pfeil, Anita Höchtl, Jochen Budzinski, and Harald Reiterer. 2011. Designing reality-based interfaces for creative group work. *Proceedings of the 8th ACM conference on Creativity and cognition - C&C '11* (2011), 165. https://doi.org/10.1145/2069618.2069647

[30] Google Scholar. [n. d.]. Jacob: Reality-based interaction: a framework for post-WIMP interfaces. https://scholar.google.ca/scholar?oi=bibs{&}hl=en{&}cites=209617002667207170

[31] Aakar Gupta. 2015. Five years of IndiaHCI. *Proceedings of the 7th International Conference on HCI, IndiaHCI 2015 - IndiaHCI'15* (2015), 56–61. https://doi.org/10.1145/2835966.2835973

[32] Anne-Wil Harzing. 2007. Publish or Perish. http://www.harzing.com/pop.htm

[33] David Holman and Roel Vertegaal. 2008. Organic user interfaces: Designing computers in any way, shape, or form. *Commun. ACM* 51, 6 (2008), 48–55. https://doi.org/10.1145/1349026.1349037

[34] Eva Hornecker. 2012. Beyond Affordance: Tangibles ' Hybrid Nature. *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction* (2012), 175–182. https://doi.org/10.1145/2148131.2148168

[35] Eva Hornecker and Jacob Buur. 2006. Getting a grip on tangible interaction: a framework on physical space and social interaction. In *Proceedings of the SIGCHI conference on Human Factors in computing systems*. 437–446. https://doi.org/10.1145/1124772.1124838

[36] Edwin L. Hutchins, James D. Hollan, and Donald A. Norman. 1985. Direct Manipulation Interfaces. *HumanâĂŞComputer Interaction* 1, 4 (dec 1985), 311–338. https://doi.org/10.1207/s15327051hci0104_2

[37] Hiroshi Ishii, Dávid Lakatos, Leonardo Bonanni, and Jean-Baptiste Jb Labrune. 2012. Radical Atoms : Beyond Tangible Bits, Toward Transformable Materials. *Interactions* XIX, February (2012), 38–51. https://doi.org/10.1145/2065327.2065337

[38] Hiroshi Ishii and Brygg Ullmer. 1997. Tangible bits: towards seamless interfaces between people, bits, and atoms. In *Proceedings of the 8th international conference on Intelligent user interfaces*. 3–3. https://doi.org/10.1145/604045.604048

[39] Robert J. K. Jacob. 2006. What is the next generation of human-computer interaction?. In *CHI '06 extended abstracts on Human factors in computing systems - CHI EA '06*. ACM Press, New York, New York, USA, 1707. https://doi.org/10.1145/1125451.1125768

[40] Robert J. K. Jacob, Audrey Girouard, Leanne M. Hirshfield, Michael S. Horn, Orit Shaer, Erin Treacy Solovey, and Jamie Zigelbaum. 2007. CHI2006: what is the next generation of human-computer interaction? *interactions* 14, 3 (2007), 53–58. http://portal.acm.org/citation.cfm?id=1242459

[41] Robert J. K. Jacob, Audrey Girouard, Leanne M. Hirshfield, Michael S. Horn, Erin Treacy Solovey, Orit Shaer, and Jamie Zigelbaum. 2007. Reality-based interaction: unifying the new generation of interaction styles. In *Proceeding of CHI'07 extended abstracts on Human factors in computing systems*. ACM, New York, New York, USA, 2465–2470. https://doi.org/10.1145/1240866.1241025

[42] Robert J. K. Jacob, Orit Shaer, Audrey Girouard, Leanne M. Hirshfield, Michael S. Horn, Orit Shaer, Erin Treacy Solovey, and Jamie Zigelbaum. 2008. Reality-Based interaction: A framework for post-WIMP interfaces. In *Proceeding of the twenty-sixth annual CHI conference on Human factors in computing systems - CHI '08*. ACM, New York, New York, USA, 201. https://doi.org/10.1145/1357054.1357089

[43] Hans-Christian Jetter, Raimund Dachselt, Harald Reiterer, Aaron Quigley, David Benyon, and Michael Haller. 2013. Blended interaction: Envisioning Future Collaborative Interactive Spaces. *CHI '13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA '13* (2013), 3271. https://doi.org/10.1145/2468356.2479664

[44] Hans-Christian Jetter, Harald Reiterer, and Florian Geyer. 2014. Blended Interaction: understanding natural humanâĂŞcomputer interaction in post-WIMP interactive spaces. *Personal and Ubiquitous Computing* 18, 5 (jun 2014), 1139–1158. https://doi.org/10.1007/s00779-013-0725-4

[45] David Kirk, Abigail Sellen, Stuart Taylor, and Nicolas Villar. 2009. Putting the physical into the digital: issues in designing hybrid interactive surfaces. *Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology* (2009), 35–44. https://doi.org/10.1145/1671011.1671016

[46] Jesper Kjeldskov and Mikael B. Skov. 2014. Was it Worth the Hassle? Ten Years of Mobile HCI Research Discussions on Lab and Field Evaluations. In *Proceedings of the 16th international conference on Human-computer interaction with mobile devices & services - MobileHCI '14*. ACM Press, New York, New York, USA, 43–52. https://doi.org/10.1145/2628363.2628398

[47] Eike Kleiner, Roman Rädle, and Harald Reiterer. 2013. Blended Shelf: Reality-based Presentation and Exploration of Library Collections. *CHI '13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA '13* (2013), 577. https://doi.org/10.1145/2468356.2468458

[48] Chao Lu, Ying Ding, and Chengzhi Zhang. 2017. Understanding the impact change of a highly cited article: a content-based citation analysis. *Scientometrics* 112, 2 (aug 2017), 927–945. https://doi.org/10.1007/s11192-017-2398-7

[49] Sus Lundgren, Joel E. Fischer, Stuart Reeves, and Olof Torgersson. 2015. Designing Mobile Experiences for Collocated Interaction. *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing - CSCW '15* (2015), 496–507. https://doi.org/10.1145/2675133.2675171

[50] M.H. MacRoberts and B.R. MacRoberts. 2010. Problems of citation analysis: A study of uncited and seldom-cited influences. *Journal of the American Society for Information Science and Technology* 61, 1 (jan 2010), 1–12. https://doi.org/10.1002/asi.21228 arXiv:0803.1716

[51] M. H. MacRoberts and Barbara R. MacRoberts. 1996. Problems of citation analysis. *Scientometrics* 36, 3 (1996), 435–444. https://doi.org/10.1007/BF02129604 arXiv:0521865719 9780521865715

[52] Megh Marathe and Kentaro Toyama. 2018. Semi-Automated Coding for Qualitative Research. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (2018), 1–12. https://doi.org/10.1145/3173574.3173922

[53] Joe Marshall, Conor Linehan, Jocelyn Spence, and Stefan Rennick Egglestone. 2017. Throwaway Citation of Prior Work Creates Risk of Bad HCI Research. *ACM CHI extended abstracts - alt.chi 2017* (2017), 827–836. https://doi.org/10.1145/3027063.3052751

[54] Ali Mazalek and Elise van den Hoven. 2009. Framing tangible interaction frameworks. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 23, 03 (2009), 225–235. https://doi.org/10.1017/S0890060409000201

[55] Lokman I. Meho and Yvonne Rogers. 2008. Citation counting, citation ranking, and h-index of human-computer interaction researchers: A comparison of scopus and web of science. *Journal of the American Society for Information Science and Technology* 59, 11 (2008), 1711–1726. https://doi.org/10.1002/asi.20874 arXiv:0803.1716

[56] Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino. 1995. Augmented reality: a class of displays on the reality-virtuality continuum. In *Proc. SPIE 2351, Telemanipulator and Telepresence Technologies*, Hari Das (Ed.), Vol. 2351. 282–292. https://doi.org/10.1117/12.197321 arXiv:NIHMS150003

[57] Henk F. Moed, Judit Bar-Ilan, and Gali Halevi. 2016. A new methodology for comparing Google Scholar and Scopus. *Journal of Informetrics* 10, 2 (may 2016), 533–551. https://doi.org/10.1016/j.joi.2016.04.017 arXiv:1512.05741

[58] Omar Mubin, Abdullah Al Mahmud, and Muneeb Ahmad. 2017. HCI down under: reflecting on a decade of the OzCHI conference. *Scientometrics* 112, 1 (2017), 367–382. https://doi.org/10.1007/s11192-017-2293-2

[59] Florian 'Floyd' Mueller, Darren Edge, Frank Vetere, Martin R Gibbs, Stefan Agamanolis, Bert Bongers, and Jennifer G Sheridan. 2011. Designing sports: a framework for exertion games. *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11* (2011), 2651–2660. https://doi.org/10.1145/1978942.1979330

[60] Jens Müller. 2014. Exploiting Spatian Memoty and Navigation Performance in Dynamic Peephole Environments. *ITS '14 ACM International Conference on Interactive Tabletops and Surfaces Adjunct* (2014), 485–490. https://doi.org/10.1145/2669485.2669492

[61] Jens Müller, Tobias Schwarz, Simon Butscher, and Harald Reiterer. 2014. Back to tangibility: A Post-WIMP Perspective on Control Room Design. *Proceedings of the 2014 International Working Conference on Advanced Visual Interfaces - AVI '14* (2014), 57–64. https://doi.org/10.1145/2598153.2598161

[62] Steven Neale, Winyu Chinthammit, Christopher Lueg, and Paddy Nixon. 2014. Facilitating Learning Through Hands-on Engagement With Virtual Museum Artefacts. *Proceedings of the 28th International BCS Human Computer Interaction Conference on HCI 2014 - Sand, Sea and Sky - Holiday HCI* (2014), 222–227. https://doi.org/10.14236/ewic/hci2014.27

[63] D Nowacka, K Ladha, N Hammerla, D Jackson, C Ladha, E Rukzio, and P Olivier. 2013. Touchbugs: actuated tangibles on multi-touch tables. *Proceedings of CHI 2013* (2013), 759–762. https://doi.org/10.1145/2470654.2470761

[64] G Michael Poor, Samuel D Jaffee, Laura Marie Leventhal, Jordan Ringenberg, Dale S Klopfer, Guy Zimmerman, and Brandi A. Klein. 2016. Applying the Norman 1986 User-Centered Model to Post-WIMP UIs. *ACM Transactions on Computer-Human Interaction* 23, 5 (2016), 1–33. https://doi.org/10.1145/2983531

[65] Roman Rädle. 2013. Design and evaluation of proxemics-aware environments to support navigation in large information spaces. *CHI '13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA '13* (2013), 1957. https://doi.org/10.1145/2468356.2468710

[66] Majken K. Rasmussen, Esben W. Pedersen, Marianne G. Petersen, and Kasper Hornbæk. 2012. Shape-changing interfaces. *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12* August (2012), 735. https://doi.org/10.1145/2207676.2207781

[67] Thomas Reufer, Martin Panknin, and Christian Geiger. 2010. SensoDroid - Multimodal Interaction Controlled Mobile Gaming. *Proceedings of the 13th International Conference on Humans and Computers* (2010), 32–36. https://dl.acm.org/citation.cfm?id=1994486.1994497

[68] Yvonne Rogers. 2012. HCI Theory: Classical, Modern, and Contemporary. *Synthesis Lectures on Human-Centered Informatics* 5, 2 (2012), 1–129. https://doi.org/10.2200/S00418ED1V01Y201205HCI014

[69] T. Seyed, F. Maurer, F.M. Rodrigues, and A. Tang. 2014. Medical imaging specialists and 3D: A domain perspective on mobile 3D interactions. *Conference on Human Factors in Computing Systems - Proceedings* (2014), 2341–2346. https://doi.org/10.1145/2559206.2581301

[70] Orit Shaer and Robert J.K. Jacob. 2009. A specification paradigm for the design and implementation of tangible user interfaces. *ACM Transactions on Computer-Human Interaction* 16, 4 (2009), 1–39. https://doi.org/10.1145/1614390.1614395

[71] Orit Shaer, Megan Strait, Consuelo Valdes, Taili Feng, Michael Lintz, and Heidi Wang. 2011. Enhancing genomic learning through tabletop interaction. *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11* (2011), 2817. https://doi.org/10.1145/1978942.1979361

[72] Ben Shneiderman. 1983. Direct Manipulation: A Step Beyond Programming Languages. *IEEE Computer* 16, 8 (aug 1983), 57–69. https://doi.org/10.1109/MC.1983.1654471

[73] Ben Shneiderman. 1992. *Designing the User Interface (2Nd Ed.): Strategies for Effective Human-computer Interaction.* Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA.

[74] ACM SIGCHI. 2018. CHI 2018 Guide to a successful submission. https://chi2018.acm.org/guide-to-a-successful-submission/

[75] Daniel Sjölie, Kenneth Bodin, Eva Elgh, Johan Eriksson, Lars-Erik Janlert, and Lars Nyberg. 2010. Effects of interactivity and 3D-motion on mental rotation brain activity in an immersive virtual environment. *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10* (2010), 869. https://doi.org/10.1145/1753326.1753454

[76] Scott S Snibbe and Hayes S. Raffle. 2009. Social Immersive Media: Pursuing Best Practices for Multi-user Interactive Carmera/Projector Exhibits. *Proc. CHI* (2009).

[77] Erin Treacy Solovey, Daniel Afergan, Evan M. Peck, Samuel W. Hincks, and Robert J. K. Jacob. 2015. Designing Implicit Interfaces for Physiological Computing: Guidelines and Lessons Learned Using fNIRS. *ACM Trans. Comput.-Hum. Interact.* 21, 6, Article 35 (Jan. 2015), 27 pages. https://doi.org/10.1145/2687926

[78] Tuukka M. Takala. 2014. RUIS - A toolkit for developing virtual reality applications with spatial interaction. *Proceedings of the 2nd ACM symposium on Spatial user interaction - SUI '14* (2014), 94–103. https://doi.org/10.1145/2659766.2659774

[79] Zehra Taşkın and Umut Al. 2018. A content-based citation analysis study based on text categorization. *Scientometrics* 114, 1 (2018), 335–357. https://doi.org/10.1007/s11192-017-2560-2

[80] Mike Thelwall and Kayvan Kousha. 2017. ResearchGate versus Google Scholar: Which finds more early citations? *Scientometrics* 112, 2 (aug 2017), 1125–1131. https://doi.org/10.1007/s11192-017-2400-4

[81] Consuelo Valdes, Diana Eastman, Casey Grote, Shantanu Thatte, Orit Shaer, Ali Mazalek, Brygg Ullmer, and Miriam K. Konkel. 2014. Exploring the design space of gestural interaction with active tokens through user-defined gestures. *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14* (2014), 4107–4116. https://doi.org/10.1145/2556288.2557373

[82] Elise van den Hoven and Berry Eggen. 2004. Tangible Computing in Everyday Life: Extending Current Frameworks for Tangible User Interfaces with Personal Objects. In *Ambient Intelligence. EUSAI 2004. Lecture Notes in Computer Science, vol 3295*, Crowley J.L. Markopoulos P., Eggen B., Aarts E. (Ed.). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-30473-9_22

[83] Raphael Velt, Steve Benford, and Stuart Reeves. 2017. A Survey of the Trajectories Conceptual Framework: Investigating Theory Use in HCI. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (2017), 2091–2105. https://doi.org/10.1145/3025453.3026022

[84] Mark Weiser. 1991. The Computer for the 21st Century. *Scientific American* 265, 3 (1991), 94–104. https://doi.org/10.1038/scientificamerican0991-94 arXiv:arXiv:1011.1669v3

[85] Daniel Wigdor, Hrvoje Benko, John Pella, Jarrod Lombardo, and Sarah Williams. 2011. Rock & rails: extending multi-touch interactions with shape gestures to enable precise spatial manipulations. In *Proc. CHI*. 1581–1590. http://portal.acm.org/citation.cfm?id=1979173

[86] Daniel Wigdor and Dennis Wixon. 2011. *Brave NUI World : designing natural user interfaces for touch and gesture.* Morgan Kaufmann. 264 pages. http://www.amazon.com/Brave-NUI-World-Designing-Interfaces/dp/0123822319

[87] Kdd Willis, Ivan Poupyrev, and T Shiratori. 2011. Motionbeam: a metaphor for character interaction with handheld projectors. *Proceedings of the SIGCHI ...* (2011), 10. https://doi.org/10.1145/1978942.1979096

[88] Jacob O. Wobbrock and Julie A. Kientz. 2016. Research Contributions in Human-Computer Interaction. *Interactions* 23, 3 (2016), 38–44. https://doi.org/10.1145/2907069

[89] Peter C. Wright, Robert E. Fields, and Michael D. Harrison. 2000. Analyzing Human-Computer Interaction as Distributed Cognition: The Resources Model. *Human-Computer Interaction* 15, 1 (2000), 1–41. https://doi.org/10.1207/S15327051HCI1501_01

[90] Peta Wyeth, Jennifer Summerville, and Barbara Adkins. 2011. Stomp: An Interactive Platform for People with Intellectual Disabilities. *Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology - ACE '11* (2011), 1. https://doi.org/10.1145/2071423.2071487

[91] Guo Zhang, Ying Ding, and Staša Milojević. 2013. Citation content analysis (CCA): A framework for syntactic and semantic analysis of citation content. *Journal of the American Society for Information Science and Technology* 64, 7 (jul 2013), 1490–1503. https://doi.org/10.1002/asi.22850 arXiv:0803.1716

[92] Jamie Zigelbaum, Adam Kumpf, Alejandro Vazquez, and Hiroshi Ishii. 2008. Slurp: Tangibility, Spatiality, and an Eyedropper. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI EA '08)* (2008), 2565–2574. https://doi.org/10.1145/1358628.1358713

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