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Escaping the Trough: Towards Real-World Impact of Tabletop Research

Anders Bruun, Kenneth Eberhardt Jensen, Dianna Hjorth Kristensen, and Jesper Kjeldskov

Department of Computer Science, Aalborg University, Aalborg Oest, Denmark

ABSTRACT

In the past decade, there has been increasing interest in studying tabletop technologies in HCI. Using the Gartners Hype Cycle as an analytical framework, this article presents developments in tabletop research within the last decade. The objective is to determine the level of maturity of tabletop technologies with respect to the research foci and the extent to which tabletops have shown their worth in real world settings. We identify less studied topics in the current body of literature with the primary aim of evoking further discussions of the current and future research challenges. We analyzed 542 research publications and categorized these according to eight types of research foci. Findings show that only 3% of all studies are conducted in natural settings, i.e. there is a clear tendency to emphasize laboratory evaluations of tabletop technology. Also, very few studies demonstrate relative benefits of tabletops over other technologies in collaborative settings (1%). We argue for a need to increase emphasis on understanding real-world use and impact rather than developing new tabletop technologies.

1. Introduction

In the 1990s, one of the focal areas within computer science research was "The Disappearing Computer" where researchers envisioned the integration of technology into the existing furniture such as tables (Müller-Tomfelde & Fjeld, 2012). Weiser was one of the first presenting an article on interacting with large horizontally oriented "boards" (Weiser, 1991) and several technologies have since then lived up to the guiding principle of ubiquity, including the large horizontal interfaces we now denote "tabletops".

The subject of research in this study is tabletop technologies. In this article, we define tabletops based on Müller-Tomfelde (2010) and related literature:

> The term tabletop stands in the tradition of earlier terms, such as desktop and laptop, highlighting the location of the computer or display. Tabletops distinguish themselves by being suitable as group interfaces and by the fact that their horizontal display is the interface where the user directly interacts with digital information rather than using the keyboard and mouse. (Müller-Tomfelde, 2010, p. 2)

This definition is also reflected throughout the literature where the technology is presented in diverse ways, e.g. "Large horizontal collaborative surfaces" (Tuddenham, Davies, & Robinson, 2009), "Direct-touch digital tabletop display" (Hancock, Vernier, Wigdor, Carpendale, & Shen, 2006), "Direct multi-touch, multi-user tabletop" (Ryall, Morris, Everitt, Forlines, & Shen, 2006) and "Interactive tabletop" (Ajaj, Vernier, & Jacquemin, 2009). The word used for the device itself has multiple variations, e.g. *tabletop, surface, interface, system, display, table*, and *screen*. Interaction techniques are also used in the descriptions of tabletop devices, e.g. *multi-touch, direct touch*, and the hybrid of *direct multi-touch*. Surface alignment is another property employed when referring to interactive surfaces in general. Although tabletops per definition are *horizontally* aligned, this is often mentioned explicitly.

Although the underlying idea of tabletops stems from the early 1990's, researchers disagree on its level of maturity. Morris et al. claimed that tabletops are still an emerging technology (Morris, Fisher, & Wigdor, 2010) while Müller-Tomfelde and Fjeld stated that this has reached a high level of maturity (Müller-Tomfelde & Fjeld, 2012). The latter, however seems to stand in contrast to recent research efforts as we will discuss below.

In this article, we follow the evolution of tabletops in order to *determine their level of maturity* and to *discuss how we should move forward* to further nurture this. Toward this, we analyzed 542 research publications, most of which originate from the last decade. We will discuss the number of publications over time and trends based on the research foci within articles. Our primary aim is to *evoke further discussions of current and future research challenges* related to tabletop technologies. We do this by 1) providing a snapshot of the current research practices within the field of tabletops and 2) identifying and discussing shortcomings in the current state-of-the-art.

In the past decade, there has been varying interest in tabletop technology within HCI research. This is reflected in the number of publications within the topic, which is shown in Figure 1. This figure is a result from one of our studies outlined in Section 4. From 2005 to 2006, there was a sudden rapid increase in the amount of research reported, reaching an

CONTACT Anders Bruun bruun@cs.aau.dk Department of Computer Science, Aalborg University, Selma Lagerlöfs Vej 300, Aalborg Oest, DK-9220, Denmark.
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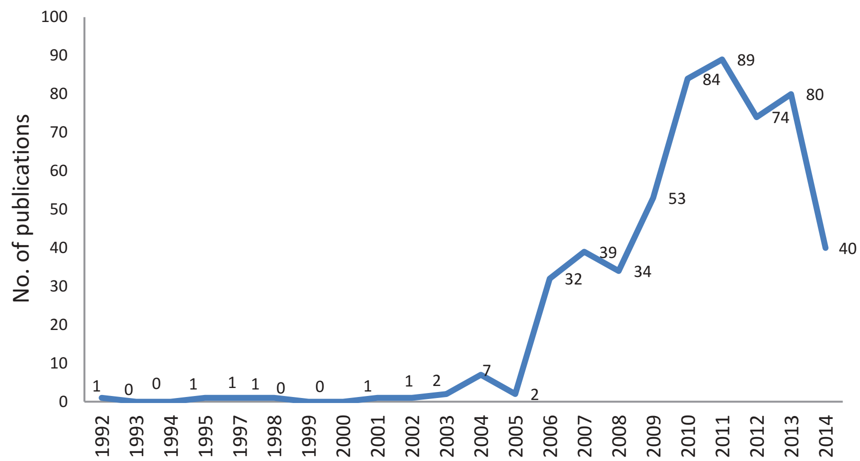

Figure 1. Number of publications in key conferences, which include the topic of tabletops (see Section 3.2 for details).

all-time high in 2011. After 2013, however, there was a steep drop in the amount of reported research on the subject.

The peak of research illustrated in Figure 1 prompts the questions if the challenges for human–computer interaction with tabletops have been largely resolved, and if tabletop technologies can now be considered so mature that further research is no longer relevant. In this article, we argue that this is not the case. We will argue that the recent drop in research is not caused by *lack* of challenges, but in a *shift* in challenges toward real world use and impact of tabletop technology. Learning from other emerging technologies, we will argue that "escaping the trough" for tabletop technologies require research that focuses not so much on technical issues but more on issues of real world use and utility.

The current research efforts emphasize development of new tabletop technologies and pushing these to the limit rather than proving their applicability in real-world settings, which is a necessary step in determining the maturity of technologies (Fenn & Raskino, 2008; O'Leary, 2008). An example of research emphasis is studying tangible user interfaces where e.g. Lepreux, Kubicki, Kolski, and Caelen (2012) use Radio-Frequency Identification (RFID) technology to enable tabletop interaction using physical objects. Pedersen and Hornbæk developed active motorized tangibles to reflect changes in the digital model to provide haptic feedback (Pedersen & Hornbæk, 2011). Another example is the article by Spindler et al. which studies the use of 3D layers above a horizontal surface (Spindler, Martsch, & Dachselt, 2012). That article reports from a laboratory experiment investigating issues such as the optimal number of layers and their thickness. The study described by Wolfe, Graham, and Pape (2010) takes up the challenge of increasing touch accuracy on tabletops. Wolfe et al. derived a new algorithm that increases accuracy without the cost of higher computational power. These are examples of the technology development emphasis.

It seems to be contradictory that there is a continuing emphasis on developing new tabletop technologies while we see a decreasing number of tabletop publications. This observation can be explained through the Gartners Hype Cycle (Fenn & Raskino, 2008), see Figure 2 below.

1.1. The Hype Cycle

The Hype Cycle describes a pattern of positive and negative hype of technology spanning over a certain period of time.

Triggered by early adopters of such technology, we typically see increasing interest in news media, research, and a broader audience hoping to experience the success (Fenn & Raskino, 2008). However, often the new technology does not live up to its initial promises, which causes it to be abandoned by those who adopted it. This pattern of hope and disappointment is observed all the time with technologies and is denoted the Hype Cycle.

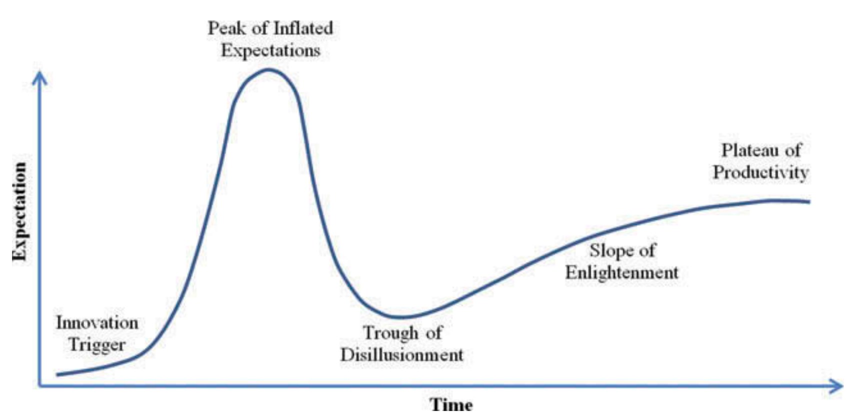

Figure 2. General hype cycle graph and the five phases.

The Innovation Trigger is the phase starting the Hype Cycle and embarks from the point of a breakthrough of an innovation, which leads to increased interest from media and industry. At this point, the innovation extends beyond its inventors and hype is starting to spread. At this point, an initial positive hype is set in motion, leading to the effect where "a wave of buzz quickly builds." An example of an innovation trigger is Weiser's work in which large horizontally oriented "boards" were introduced as an alternative to PC's (Weiser, 1991). Based on the development in number of publications (Figure 1), this trigger phase continued until 2007 where there was a strong increase in the number of articles. This increase can be partly attributed to Jefferson Han's research and TED talk on concepts related to low-cost and scalable interactive surfaces, see e.g. Han (2005).

The Peak of Inflated Expectations marks the end of the trigger phase and the buzz-effect leads to this second phase. This peak represents a phase where e.g. companies seek to harvest the benefits of the innovation before their competitors. As the hype builds more parties join in and a "bandwagon effect" emerges as the innovation is pushed to its limits. Media coverage further increases followed by a rhetoric of "ignore at your peril". At this point, an innovation may seem to take off due to the initial positive hype and increasing interest in the technology. Historically, however, new innovations also go through a period of negative hype as an innovation does not live up to its initial promises, i.e. it is premature. According to the number of publications in Figure 1, we reached the peak of inflated expectations in 2011, which coincided with two large IT companies introducing an updated version of a commercially available tabletop. We here refer to Microsoft's and Samsung's partnership in creating the Surface 2.0, which included a new set of features such as updated camera technology, thinner layout etc.

The Trough of Disillusionment sets in when adopters realize that the innovation does not live up to its promises, i.e. expectations were inflated. Innovations often need considerable experimentation and development before the real value is found, so even if the innovation does possess benefits, it may take a while for these to emerge. Thus, when benefits are slow to arrive, hard to measure or the innovation costs are high it leads to missed expectations in real-world settings. This is followed by negative hype. Looking at the state-of-the-art in tabletop technology, we argue that this area of research is currently in the trough due to a continuing emphasis on technology development with little evidence of its benefits materializing in real-world settings. We base this on the striking similarity between the trend of research produced on the topic and the development of inflated expectations within the general Hype Cycle graph (Figure 2). Based on this observation, we believe there is a need to evoke further discussion on extending the research agenda to include more real-world studies, which would mature tabletop technologies and move out of the trough.

The Slope of Enlightenment denotes the point where adopters start to experience sought-after benefits and efforts are recommitted in order to move forward. During this phase the innovation matures and developers improve this based on feedback from previous phases. In this phase, we also begin to see methods prescribing how to apply the innovation successfully and these are also socialized.

The Plateau of Productivity is the final phase in which "real-world" benefits are proven and these have reached a stage of acceptance among adopters. This is followed by the uptake of the innovation which is rapidly accelerated due to demonstrated productive values. Although the Hype Cycle is not used that often in relation to research, the latter phases are fully in line with sought-after needs in research literature. The influential work in Kjeldskov and Graham (2003) and Wixon (2003) also points toward the importance of unveiling real-world benefits of technologies or methods.

In the remainder of this article, we present the Hype Cycle followed by an overview of related work. After this we present the two studies conducted to uncover the number of publications and research trends within articles. Finally, we discuss and conclude on our findings in relation to the Hype Cycle and related work.

2. Related Work

In this section, we take a further look at similar review articles based on the Hype Cycle and from the area of tabletop research. The Hype Cycle was originally developed for marketing purposes and for industry professionals to make business decisions and its use in research is still novel. However, O'Leary investigated the use of the hype cycle for categorizing and analyzing technology to understand research issues in the area of information systems (O'Leary, 2008). O'Leary studied the development and application of stock price and accounting technologies for the financial sector. By studying previous publications, he found that the location of a technology on the Hype Cycle impacted the type of research questions addressed. Research emphasis at the *Technology Trigger* stage dealt with implementing technology distant from real-world settings. This is because few organizations had adopted the technologies in question. At the *Peak of Inflated Expectations* researchers started to anticipate how technology could impact real-world settings, e.g. within companies. At this stage, there were only a few case studies describing use of the technology within real-world settings and success stories were scarce. The *Trough of Disillusionment* was characterized by studies of "things gone wrong," which lead researchers to turn away from studying the technologies. For a technology to be successful it must move beyond the *Trough of Disillusionment*, and the only viable option at that point is to conduct case studies within the few organizations that have an interest in adopting these (O'Leary, 2008).

There are very few review articles describing trends within tabletop research. Grossman and Wigdor are the first to present such an overview (Grossman & Wigdor, 2007). They determine categories emphasizing 3D in conjunction with tabletop technologies and generate a taxonomy on the subject. The taxonomy is divided into three main areas; Display properties, input properties and physical properties. The *display properties* are the technical underpinnings of the display, e.g. if it is based on stereoscopic 3D or if it is using 3D graphics as visualization for the user. *Input properties* refer to how users interact with the tabletop. This can be in the interaction space, where the z-axis is considered and as such creates the opportunity to use interaction gestures in mid-air. Finally the *physical properties* relate to form-factor and the size of the table. Grossman and Wigdor emphasize a relevant niche area within tabletops and for that reason do not provide an overview of the general research area.

In contrast, Müller-Tomfelde (2010) focussed on providing a general overview at a high level of abstraction and categorizes the area based on recent research. Müller-Tomfelde presents three overall categories of *Under, On and Above* and *Around and Beyond*. These categories refer to three different focus areas of research in tabletops. *Under* represents hardware specification and considerations that is needed in order to create a successful tabletop technology. This includes specifications on height of the table to specific dimensions on the size of the tabletop. The second category, *On and Above*, concerns the aspect of interaction specifically discussing tangibility and different interaction styles and ends with a taxonomy of the 3D tabletop systems, which is based on findings in Grossman & Wigdor (2007). The final part of Müllers overview relates to *Around and Beyond* the tabletop. This part discusses contextual aspects such as collaboration and social interaction around the tabletop device.

More recently Müller-Tomfelde and Fjeld also wrote an article in which they discuss when usage of tabletop technology will accelerate (Müller-Tomfelde & Fjeld, 2012). This discussion is based on Gartners Hype Cycle and they propose the graph illustrated in Figure 3. In that article, it is claimed that we reached the *Peak of Inflated Expectations* back in 2005 after which we moved down the *Trough of Disillusionment*. Furthermore, it is stated that the climb up the *Slope of Enlightenment* began in 2011 when new technologies like Microsoft Surface 2.0 reached the market. The reason given for moving out of the trough is that these technologies "closely integrate display pixels and multitouch sensors and could allow very small form factors" (p. 81). Müller-Tomfelde and Fjeld also emphasize another technology, which could potentially accelerate tabletop adoption over the next decade: "… emerging technologies could accelerate current trends, including integration of organic light-emitting displays (OLEDs) with multitouch technology and a new unobtrusive way to detect and distinguish input from users concurrently to better support group collaboration" (p. 81). Thus, in Müller-Tomfelde and Fjeld (2012), it is emphasized that mere advancement in technology will be the catalyst accelerating our move toward the *Plateau of Productivity*. This stands in contrast to the need of proving real-world benefits of the technology as suggested in Fenn and Raskino (2008) and O'Leary (2008).

We have been inspired from these previous review articles and build on those by considering a broader area than 3D, which was the focus in Grossman and Wigdor (2007). We aim to extend the overview provided in Müller-Tomfelde (2010) as that is based on 18 articles. Also, we seek to extend the three categories of *Under, On and Above*, and *Around and Beyond* in order to represent the current body of literature with a finer level of granularity. As an example of this, our second study (outlined in section 5) led to the identification of eight categories of research foci within the 542 articles. Each of these categories can be mapped onto the three categories in Müller-Tomfelde (2010), e.g. our category of *Implementation* corresponds to *Under* from Müller-Tomfelde (2010), our three categories of *Interaction, Individuality* and *Visualization* correspond to Müller-Tomfelde's *On and Above* etc.

Looking at our eight categories, we find one category (*Implementation)* corresponding to *Under* while three (*Interaction, Individuality* and *Visualization*) correspond to *On and Above*. The final four (*Collaboration, Design, Cross-Device* and *User*) correspond to *Around and Beyond*.

Furthermore, we have been inspired by the work described in Müller-Tomfelde and Fjeld (2012) and aim to build on that by conducting a systematic and comprehensive literature review and to discuss our findings in relation to that study and the Hype Cycle.

3. Study 1: Number of Publications

The development in number of publications over time is critical for positioning tabletop technologies on the Hype Cycle graph. Considering Figure 2, the *y*-axis (expectations) on the graph is expressed through the level of visibility of an innovation in, e.g. news, conversations and conferences where high visibility leads to a high expectations (Fenn & Raskino, 2008). A central metric to which such expectations can be measured is the number of article references to a technology (Fenn & Raskino, 2008). In the following we describe how we identified the number of tabletop publications and our findings in relation to this.

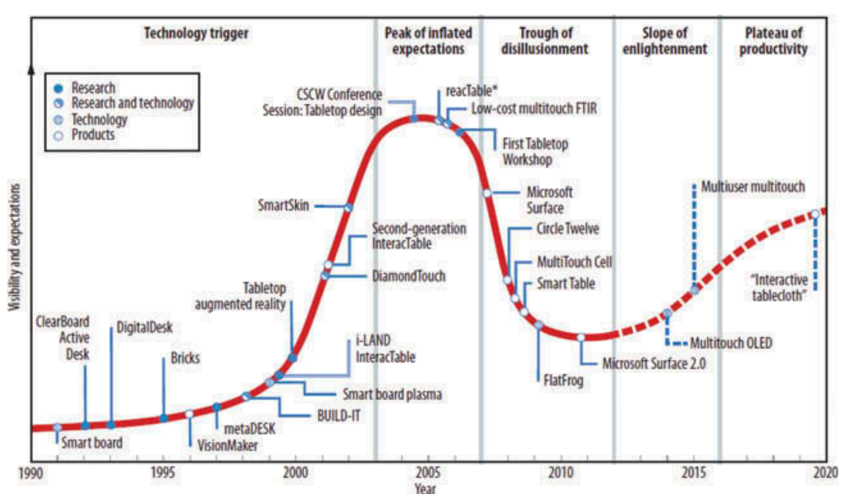

Figure 3. Hype cycle graph of tabletop technologies. Suggested in (Müller-Tomfelde & Fjeld, 2012). Permission to reuse the image has been given by the publisher under the license no. 3910061321803. © IEEE. Reproduced by permission of IEEE. Permission to reuse must be obtained from the rightsholder.

3.1. Method

We traversed abstract, introduction and conclusions in all articles from the conference proceedings of IEEE Tabletop from years 2006 to 2008 and ACM ITS from 2009 to 2014. We excluded demo videos and focused on text documents as the source of information and identified a total of 456 articles including full articles, notes/short articles and posters. We also applied the Scopus database to search for relevant publications as this covers a broad range of HCI journals and conference proceedings. We applied the following search string:

> (tabletop OR surface OR interface OR system OR display OR table OR screen) AND (touch OR multi-touch)
>
> AND horizontal

This string was obtained through the terms, which were typically applied to describe tabletop technologies in ITS and IEEE Tabletop articles, which we traversed before the Scopus search. The search string is built on the basis of device naming conventions (e.g. tabletop, surface etc.), interaction methods (e.g. multi-touch) and surface alignment (horizontal), which is also in line with the definition given in Müller-Tomfelde (2010).

The search covered word-matching in the entirety of documents, i.e. we did not limit the words to be included in the title or abstract only. The search was performed 11 May 2015 and resulted in 2972 hits which we then filtered in the following order:

(1) Limit research areas to engineering and computer science (1319 hits)
(2) Limit to journals and conference proceedings (1144 hits)
(3) Limit to HCI conferences and journals (289 hits)

Thus, through our IEEE Tabletop, ACM ITS, and Scopus search we analyzed a total of 456 + 292 = 748 articles. We found 206 of these to be irrelevant for our study as they emphasized surface technologies different from horizontally oriented tabletops, e.g. studies based on bodily interactions such as Vega and Fuks (2013), which is based on RFID nails and conductive makeup. Other examples of dismissed studies emphasize the use of e.g. public vertical displays (Ten Koppel, Bailly, Müller, & Walter, 2012) or mobile phones and tablets (Kajastila & Lokki, 2009). The remainder of this article deals with the 542 relevant publications, i.e. articles emphasizing horizontal displays.

3.2. Findings

Table 1 shows the distribution of articles according to outlets and the online supplemental appendix provides references for all 542 relevant articles. Out of the 542 articles we found 520 to be published in conference proceedings of which 287 are full articles and 233 are notes, short articles or posters. ITS is the main outlet for publishing articles on tabletop research followed by IEEE Tabletop (the ITS predecessor) and CHI. We additionally found 22 journal articles, all of which seem to be equally (less) popular for publishing tabletop research.

Table 1. Distribution of relevant articles according to outlets.

Outlet type	Outlet name	#
Conference proceedings	ITS	265
	IEEE Tabletop	86
	CHI	87
	UIST	14
	CSCW	13
	INTERACT	10
	AVI	6
	Miscellaneous (≤5 publications per outlet)	39
	Total	520
Journals	Int. J. Hum.–Comp. Stud. (IJHCS)	4
	Pers. Ubi. Comp. (PUC)	4
	Trans. Vis. Graph. Compt. (TVGC)	4
	Adv. Hum.–Comp. Interact. (AHCI)	3
	Comp. Graph. Appl. (CGA)	3
	Trans. Hum.–Comp. Interact. (TOCHI)	2
	Ergonomics	1
	Int. J. Hum.–Comp. Int. (IJHCI)	1
	Total	22

Figure 1 in the introduction section shows the development in number of articles published per year. From 1992 to 2003 we found 8 articles studying tabletop technologies. Similarly, we found very few publications in years 2004 and 2005. In 2006, there was a considerable increase to 32 articles. With an exception of the minor drop in 2008 there was a continuing increase from 2006 to the all-time high of 89 publications in 2011. After that we see a slight decrease in years 2012 and 2013 followed by a considerable drop to 40 publications in 2014.

4. Study 2: Trends in Research Objectives

If a technology is to reach the *Plateau of Productivity* there needs to be evidence of its benefits in real-world settings (Fenn & Raskino, 2008; O'Leary, 2008). In this study we identify research objectives over time showing where tabletop research has been and where it is heading in terms of the Hype Cycle. In particular, we find it relevant to examine the extent of natural setting studies conducted in environments outside experimental control. It is critical to reveal qualitative details which the tell stories of success, failure or both in such settings.

Additionally, we are interested in going in-depth with studies emphasizing *collaboration around tabletops*. Since its inception it has been argued that this technology has the potential to support collaboration more efficiently than the existing technologies (Basheri, Burd, & Baghaei, 2012; Fleck et al., 2009; Marshall, Morris, Rogers, Kreitmayer, & Davies, 2011; Martinez, Collins, Kay, & Yacef, 2011; Pauchet et al., 2007; Weiser, 1991). Thus, findings in articles that emphasize collaboration aspects could reveal the underlying benefits of this technology, which also serves as an indication of how close (or far) we are from reaching the *Plateau of Productivity*.

4.1. Method

Three of the authors applied grounded theory (Strauss & Corbin, 1990) to categorize research objectives in all 542 relevant articles. Grounded theory is a qualitative research method in which meta information is created about the contents within a text, i.e. it is a way of abstracting a text to form a theory describing its contents. In essence, we did this by reading a passage of text describing the research objective after which a code was provided to describe this specific passage. Initially this was done using open coding, i.e. no codes existed in the beginning (the first 200 articles). Eventually the open coding led to a set of codes denoting research objectives such as "implementation." Based on the established set of codes, we could then continue to code the remainder of articles using closed coding, i.e. passages of text denoting research objectives could be classified using one of the existing codes. This was done following a three-step process (steps 1 and 2 were done during the open and closed coding phases while the third step was conducted in the closed coding phase only):

(1) **Individual coding (open and closed coding phases)**: To uncover research objectives three of the authors read the abstract, introduction and conclusion of each article individually. Codes were given to specific segments in the article related to the research objectives.
(2) **Merging codes (open and closed coding phases)**: After completing the individual analysis, authors compared codes one article at a time. This included discussions and negotiations of what codes to apply in describing objectives in each article. Individually coded segments of text and arguments were presented to each other and continued until an agreement or disagreement was decided. We calculated the Fleiss kappa interrater reliability to be 0.73 indicating substantial agreement in the closed coding phase (Landis & Koch, 1977). Disagreements were handled by returning to the article in question at a later point in time where we discussed it again until agreement was reached. After the open coding process based on 200 articles we abstracted a set of eight categories (the grounded theory) denoting the following research objectives: *Collaboration, Interaction, Design, Cross-Device, Implementation, Individuality, User* and *Visualization* (elaborated in the following section). These categories were then used in the closed coding phase to categorized the remaining set of articles.
(3) **Validating codes (closed coding phase only)**: The eight categories were compared with the categories identified in Müller-Tomfelde (2010). This was also done by three of the authors. The 18 articles presented in Müller-Tomfelde (2010) are divided in the following categories: *Under, On and Above* and *Around and Beyond*. Looking at our eight categories, we found one category (*Implementation)* corresponding to *Under* while three (*Interaction, Individuality* and *Visualization*) corresponded to *On and Above*. The final four (*Collaboration, Design, Cross-Device* and *User*) corresponded to *Around and Beyond*.

Note that we found several articles belonging to more than one category, e.g. an article emphasizing the implementation of a new tabletop device could also be emphasizing a specific type of user. Based on this observation, we decided to allow articles to be positioned in multiple categories. As an example, if an article deals with developing a tabletop device to support the use of tangibles for novel interaction techniques, then it will be positioned under the categories of "Implementation" and "Interaction." Appendix A provides traceability on how the 542 relevant articles are located according to identified categories.

4.2. Research Objectives in Tabletop Studies

Through the grounded theory approach we identified the eight research objectives in Table 2.

Figure 4 shows the number of articles distributed according to the research objectives. Note that the total number of articles in this (762) and following figures is higher than the 542 relevant articles. This is an expression of some articles falling into more than one category. A total of 273 of the 542 articles were categorized as *Implementation* and 183 as *Interaction*. We found 86 of the articles were related to the *Design* category while 62 were positioned in the *User* category. Additionally we found that 56 of the articles emphasized

Table 2. Categories of research objectives.

Collaboration	Interaction
Emphasis on aspects of multiple persons working together and explore use of tabletop devices in co-work settings. This category includes studies that focus on co-located collaboration, distributed collaboration or both.	Focus on proposing and/or evaluating specific interaction techniques, e.g. techniques supporting manipulation of data through digital pens or different gestures. Another example is interaction techniques related to feedback like e.g. tactile, auditory or visual feedback mechanisms.
Design	**Cross-Device**
Development of principles, recommendations and/or guidelines for tabletop software, hardware or application areas. The guidelines can be aimed at a specific area such as 3D applications, hand-gesture interaction or aim at contributing general guidelines such as the size of objects etc.	Emphasis on the devices used within the same setting as the tabletop device. Examples of devices used include mobile phones, tablets and laptops. Such devices are independent from the tabletop device but are applied to communicate and interact with it.
Implementation	**Visualization**
Focus on technical aspects regarding realization of tabletop technologies. Includes articles describing the development of a physical tabletop device or implementation of a software application.	Articles in this category emphasize aspects of e.g. 3D graphics and how to support visual overviews of complex data on tabletops.
User	**Individuality**
Emphasis on the needs for a particular target group of users. Research articles categorized here analyze the users and/or their behavior around a tabletop device, which gives insights in the needs by this target group.	Focus on the personal space around a tabletop device. Articles in this category study e.g. privacy issues in protecting individual data, personalization with individually customizable settings, personal workspace that cannot be accessed by others and view dependency issues like available viewing angles.

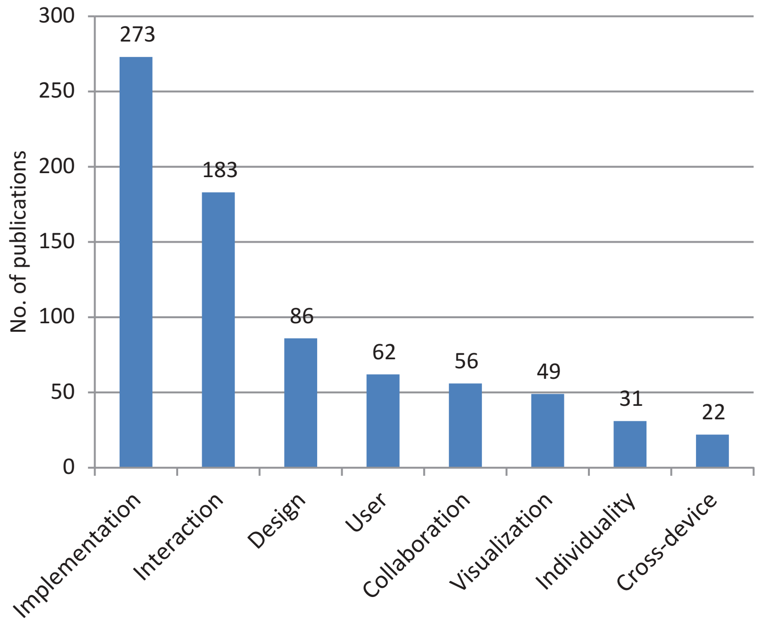

Figure 4. Number of articles distributed according to the eight identified categories of research foci. Note that several articles are positioned in multiple categories (sum = 762).

Collaboration while 49 focused on *Visualization*. Finally, 31 of the articles concern *Individuality* and 22 are positioned in the *Cross-Device* category. Thus, the main emphasis in tabletop research over the past 10 years has been to implement new tabletop devices and software. Another main focus area has been on developing and evaluating specific interaction techniques to support e.g. user input, navigation and feedback. These two top areas are followed, at a considerable distance, by the remaining six categories.

4.3. Research Objectives over Time

Figure 5 shows the distribution of identified research categories each year in the period <2003 (1992–2003) to 2014 and Table 3 provides the underlying numbers. From these we see that the main trend of implementation is a consistently popular research topic throughout most of the years, especially in years 2007 and onwards, which indicates that a considerable amount of new tabletop devices and software are being developed each year. The same pattern is found for studies

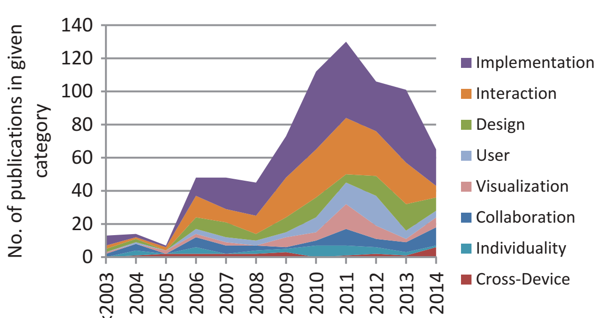

Figure 5. No. of articles distributed on categories each year (see Table 2 for actual numbers). Note that the column <2003 includes articles from 1992 to 2003.

evaluating specific interaction techniques, which is the second most emphasized topic over all these years.

The third most popular category, *Design*, is also relatively popular across the 10 year period. Two exceptions are years 2011 and 2012 where more articles emphasized tabletop technology for particular groups of users such as children with autism spectrum disorders (Giusti, Zancanaro, Gal, & Weiss, 2011; Zarin & Fallman, 2011) and school children learning mathematics (Tyng, Zaman, & Ahmad, 2011). Articles emphasizing particular users took off in 2010 and continued to increase slightly in 2011 and 2012 after which we see a drop.

Additionally, we found that articles started emphasizing visualization aspects of tabletops in 2003 but became more popular in 2009 with a peak in 2011 after which popularity has decreased. Individuality and collaboration categories are equally (less) popular overall and are scattered across most of the years. They are relatively stable; however, in 2011 we see an increase in articles emphasizing collaboration, but have yet to gain momentum. The category of Cross-Device is the least popular with publications scarcely spread over the whole period with its highest point in 2014. This latter finding may seem to be surprising given that the field of multi-device surface computing is currently very popular. However, we emphasize that our work relates to horizontally oriented tabletops, and there are relatively few studies describing multi-device interactions in conjunction with tabletops.

4.4. Natural Setting Studies

In this section, we highlight articles based on studies in natural uncontrolled settings. Reaching the *Plateau of Productivity* requires real-world benefits to be demonstrated and accepted by adopters of a technology (Fenn & Raskino, 2008). This is in line with O'Leary (2008) where studies within information systems research emphasized real-world case studies of

Table 3. Number of articles distributed on categories.

Year	<2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Implementation	6	2	1	11	19	20	26	48	47	30	45	22
Interaction	2	1	2	13	8	11	25	30	34	27	25	7
Design	2	2	0	7	9	4	9	12	5	12	17	8
User	0	1	0	4	4	4	3	10	14	18	6	4
Visualization	1	0	2	2	2	0	6	5	15	7	2	6
Collaboration	2	4	0	6	5	3	1	3	10	5	6	11
Individuality	0	3	0	4	0	2	2	7	6	4	1	1
Cross-device	0	1	2	2	2	2	3	0	1	2	1	6

Note. The column <2003 includes articles from 1992–2003.

technologies located in the later stages of the hype cycle. We have identified 16 articles presenting such studies. As an example, Ryall et al. (2006) present a study evaluating the use of tabletops in public and workplace settings. The outcome is a set of design considerations related to e.g. simultaneous touching, ambiguous input, crowding, clutter etc. The following articles focus on either public, home or workplace settings.

4.5. In Public

Hornecker presents a tabletop system for a museum which asked visitors questions about natural history (Hornecker, 2008). The results showed that visitors found the tabletop engaging but it did not encourage social interactions. Other studies have also emphasized tabletops in museum and exhibition settings (Hakvoort, 2013; Hinrichs & Carpendale, 2011; Patsoule, 2014).

In Cao, Lindley, Helmes, and Sellen (2010) a tabletop for constructing narratives was installed in a school library for a period of 2 weeks. Children interacted with it in breaks and also during some lectures. Authors report how the tabletop fitted into the existing school culture. We also identified three other natural setting studies emphasizing tabletops in student/teacher contexts (Fleck et al., 2009; Ioannou, Zenios, & Stylianou, 2014; Prieto, Sharma, Wen, Dillenbourg, & Caballero, 2014).

Also in a public setting, O'Hara (2010) presented a tabletop system installed in a café over a 2-week period. Findings in that article primarily relate to what is denoted as non-interactive aspects, e.g. artifact placement which blocked other interactions made with the tabletop.

In Marshall et al. (2011), it is presented how a shared planning tabletop was applied in a field setting in front of a tourist office. The study was conducted over a 5-week period and qualitative data on how users approached and interacted with the tabletop was collected. Findings show a need for rethinking the designs of such multi-user information kiosks.

4.6. At Home

The article by Kirk et al. describes a study where a table-top device was installed in three homes over a period of 1 month (Kirk et al., 2010). Family members could scan and archive artifacts and memorabilia with the system. Observations showed how the device interfered with family roles and everyday practices. Additionally, it was found that the tabletop was used asynchronously.

In Mazalek, Reynolds, and Davenport (2007), a table is presented which allows several users to interact with a range of media applications in relation to viewing TV, playing games etc. Interactions are based on tangible objects. A preliminary study was conducted in one home over a period of 1 month and findings relate to form factor considerations, e.g. fitness of size and height in relation to other furniture. Authors also conclude that robustness is of the essence when positioning tabletops in the home due to food and beverage spills.

Gaver and colleagues introduced their Drift Table into a private apartment shared by three roommates over a period of 6 weeks (Gaver et al., 2007). The Drift Table displays a map at the center of the device and users can move the map around by positioning weights at the edges. The purpose of the study was to gain an understanding of the playfulness introduced by the tabletop in non-work settings. One of the findings showed that, although the tabletop was designed for individual use, it became an object of conversations and led to social interactions.

4.7. At the Workplace

The longitudinal study described in Wigdor, Penn, Ryall, Esenther, and Shen (2007) spanned a 13-month period. One participant took part in the study and was asked to primarily use a tabletop device for all his everyday office tasks. Findings in relation to physical use showed that the table functioned as a computing device and as a regular piece of furniture on which coffee cups etc. was placed. Also, authors present findings in relation to managing interaction space, touch precision and gestures. Another longitudinal study is presented in Augstein, Neumayr, and Schacherl-Hofer (2014), which spanned a 5 month period. Fourteen neuro-rehabilitation therapists participated by using two tabletop applications together with their patients. The focus on that article is on the experienced usability from the perspective of the therapists, who reported a number of usability problems with the systems.

The study described in Morris, Brush, and Meyers (2008) was conducted over a period of 1 month in an office environment. Eight participants took part in the study and worked with the tabletops together with their normal computer setups. Findings resulted in a set of design recommendations related to, e.g. cursor positioning when switching between displays, physical robustness when placing objects on the table etc.

Tabard and colleagues describes a study of the eLabBench, which is designed to support work tasks in biology lab settings (Tabard, Hincapié Ramos, & Bardram, 2012). The device was deployed in natural settings (a biology lab) and used by seven molecular biologists over a period of 16 weeks. Participants used the tabletop individually while working on their everyday tasks, i.e. no tasks were predefined. Findings showed that particularly one participant used the tabletop device extensively, and that the biologists used the device in an open-ended way, which was not anticipated.

4.8. Collaboration Studies

In the following provide further details on the findings presented in the 56 articles emphasizing collaboration. In relation to the Hype Cycle, Fenn and Raskino argued that benefits of an innovation must be demonstrated in order for this to move beyond the *Trough of Disillusionment* (Fenn & Raskino, 2008). Tabletops have the potential to support collaboration and to facilitate collaborative learning more efficiently than the existing technologies. Throughout literature, this is the main argument of why we should consider tabletops, see e.g. (Basheri et al., 2012; Fleck et al., 2009; Marshall et al., 2011; Martinez et al., 2011; Pauchet et al., 2007). Additionally, group work is crucial in several types of information work as well as in education (Morris, Fisher, & Wigdor, 2010).

As mentioned earlier we allowed articles to be positioned in multiple categories, i.e. articles presented in this subsection belong to the Collaboration category, but also the categories of Implementation, Interaction, Visualization and Design. The main trend within collaboration articles is to implement new hardware to support co-work environments. As an example Pauchet et al. (2007) proposed a tabletop platform for co-located and distributed collaboration. It presents a controlled experiment with 30 participants where the tabletop platform is applied in six different conditions, e.g. remote face-to-face and local side-by-side. Findings show that the platform improves efficiency of a collaborative task in distributed conditions compared to co-located conditions.

4.9. Tabletops vs. Established Technologies

Seven articles in the Collaboration category are particularly interesting as they demonstrate the benefits of tabletops over other established technologies in co-work settings. Koburov et al. presented a study comparing 1) a classical single mouse and monitor setup; 2) shared-monitor with multiple-mice; and 3) a tabletop device to perform collaborative tasks (Kobourov et al., 2005). A controlled experiment with seven pairs of participants was conducted and findings reveal that the tabletop condition is superior to the other conditions in terms of task completion time. A very similar study is presented in Matsuda, Matsushita, Yamada, and Namemura (2006), which empirically compares two conditions; Shared tabletop and individual LCD screens. Four participants were asked to play a collaborative game. Findings show that the tabletop condition enhances the fluidity of communication between participants compared to the individual screen condition. Authors attribute this finding to the higher level of eye contact and facial expressions. Such information channels are limited when participants have to focus on their own screen and caused participants to communicate using a more formalized language.

This latter finding contrasts results in Heilig et al. (2011). That study emphasizes the impact of a Tangible User Interface (TUI). In a controlled experiment a TUI setup is compared to a condition with three synchronized PCs, which showed the same interface updated in real time. The PCs were controlled with mice and keyboards. Seventy-five participants (divided in groups of three) were asked to collaborate on a search task using either of two setups. Findings show that participants in the tabletop condition applied a wider array of search strategies compared to the PC condition. However, they did not find any noticeable differences in verbal communication between the two conditions.

In Basheri et al. (2012), a controlled experiment is presented in which a tabletop and a PC setting were compared. Eighteen participants were asked to create UML diagrams in groups of two. Findings reveal that the tabletop increased equity of participation as well as encouraging parallel-participative design. These results are in line with those found in Marshall, Hornecker, Morris, Dalton, and Rogers (2008) described in the previous subsection regarding interaction.

The aim of the study presented in Buisine, Besacier, Najm, Aoussa, & Vernier (2007) is to examine the usability of tabletop technology to support group creativity. A tabletop interface was implemented which enabled collaborators to create mind-maps. A controlled experiment based on 24 participants was conducted to compare usability of the tabletop interface to a traditional pen and article setting. Findings showed no differences in idea production, however, the tabletop interface lead to a higher balance in contributions between group members. Thus, in terms of supporting equal participation, findings are in line with those found in Basheri et al. (2012) and Marshall et al. (2008). Similarly, Schubert, George, and Serna (2012) presented a pilot study on how tabletops can encourage collaborative learning in brainstorming activities. They compare a tabletop setting to traditional pen and article. Findings show that collaborative learning might be increased using tabletops, but it is also noted that: "We are not in favor of solely transposing a paper-version onto the tabletops" (Schubert et al., 2012, p. 632).

The study presented in Perron and Laborie (2006) investigates the use of tabletop technology as information sharing during remote work sessions compared to vertical shared displays. This was conducted as a longitudinal study over a period of 25 weeks and the tabletop showed "promising" advantages over vertically oriented boards. However, these advantages were mainly related to the physical setup. As an example, when using the vertical boards, the other party could not observe non-verbal communication due to camera placement. This was not an issue with the tabletop.

5. Discussion

In this section, we synthesize our observations on the development in number of tabletop publications and research foci over the past decade. We discuss these observations in relation to the Hype Cycle and related research areas within HCI. Most notably we argue that several indicators point toward the *Trough of Disillusionment* and we discuss how to prepare for moving out of this and onto the *Plateau of Productivity*.

5.1. Dropping Number of Publications

The interest in tabletop technology research increased considerably from 2006 coming to an all-time high in 2011. However, the number of publications dropped considerably in 2014. This shows that we are on the other side of a peak. This observed pattern is very similar to a Hype Cycle graph and Figure 6 shows the graph suggested in Müller-Tomfelde and Fjeld (2012) (red color with peak at 2005) with our graph (blue color with peak at 2011) as an overlay.

The two graphs in Figure 6 are skewed by 6 years as Müller-Tomfelde and Fjeld suggested a peak in 2005. Thus, according to Müller-Tomfelde and Fjeld (2012), we should by now have reached the *Slope of Enlightenment*. However, based on the number of publications, our study indicates that the peak was reached in 2011 and that we are now on our way down the *Trough of Disillusionment*. In Müller-Tomfelde and Fjeld (2012), the graph is primarily based on specific tabletop products and the time these were introduced. Thus, the observed difference in prognosis can partly be explained by a publication lag from the time until a product was introduced and until research studies were published. Yet, a publication lag of 6 years seems too high. Also, it is unclear how metrics on the *y*-axis are derived in Müller-Tomfelde and Fjeld (2012), though it is mentioned that the cycle reflects research and technology. In terms of research, we do not find that the number of publications reflects what is found in Müller-Tomfelde and Fjeld (2012).

We also found that the most popular research trend throughout the past decade has been on implementing new tabletop devices and software. Thus, technology is also embedded in our metrics and this trend has remained relatively stable from 2006 and onwards. This indicates that tabletop technology is still an immature field of research where many technical possibilities are still being explored. Due to new off-the-shelf products the need for applications to be developed also emerged during the 11 year period from 2003 to 2014. Diamond Touch became available in 2001 and Lumisight Table was introduced in 2004 followed by the SMART Table and Microsoft Surface in 2008. Also, in 2011 Microsoft released Surface 2.0. Such products could likely have affected the research trends in favor of implementing new software applications.

The second-most popular research trend is on proposing and evaluating specific interaction techniques for tabletop devices, which has also been relatively stable for the last decade. This is not surprising given the above mentioned emphasis on implementing new hardware and software. New technological opportunities create a need to study new interaction techniques enabling the full potential of new hardware. Most prominent are techniques supporting touch interaction and research in Tangible User Interfaces.

5.2. Ten Percent Collaboration

The support of collaborative work is one of the main benefits of tabletop technology (Basheri et al., 2012; Fleck et al., 2009; Marshall et al., 2011; Martinez et al., 2011; Pauchet et al., 2007). Numerous of the reviewed articles mention some form of the word "collaboration." However, emphasis in the majority of these lies elsewhere. In the end we only managed to find 56 articles (10%) emphasizing aspects of multiple persons working together while exploring use of tabletop devices.

The current research in collaboration regards e.g. distributed collaboration. In Yamashita, Kuzuoka, Hirata, Aoyagi, and Shirai (2011), a room is built to emulate the presence of remote users in collaborative settings. Another example is Belatar and Coldefy (2010), which studies the interaction in a collaborative setting and found that some interactions between users can be disturbing. In relation to this, some have studied ways of adding new graphical items onto a tabletop without interfering with other collaborators, cf. (Morris, Paepcke, Winograd, & Stamberger, 2006). Another article studies the use of individual audio channels in collaborative settings around a tabletop devices and found that this may positively impact group dynamics (Morris, Morris, & Winograd, 2004). Other themes in collaboration articles regard participant equity, how to hand-off documents to others, territoriality etc.

Thus, the few articles emphasizing collaboration are varied around several topics. Noteworthy are also the seven articles in this category comparing tabletop technology to other established technologies. As mentioned in Fenn and Raskino (2008), the benefits of an innovation must be demonstrated and accepted before it can reach the *Plateau of Productivity*. For that reason it is striking that only 1% of all articles have studied benefits of tabletops over other established technologies in collaborative settings. These articles describe different aspects of collaboration but some of them have overlapping

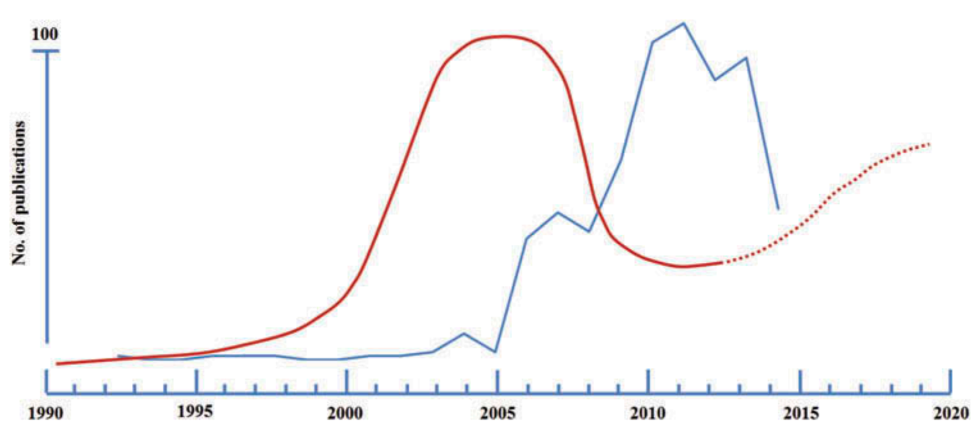

Figure 6. Red line (peak at 2005) = hype cycle graph suggested in Müller-Tomfelde and Fjeld (2012). Blue line (peak at 2011) = hype cycle graph based on number of research publications from our study.

findings, e.g. that tabletops lead to a higher level of participant equity compared to individual screen conditions (Basheri et al., 2012; Buisine et al., 2007; Heilig et al., 2011). Another study found that the tabletop enhanced fluidity of communication between participants compared to individual screen settings (Matsuda et al., 2006). The finding of enhanced fluidity stands in contrast to findings in Heilig et al. (2011). Here there were no noticeable differences in verbal communication between collaborators compared to individual screen setups. Considering efficiency metrics, Kobourov et al. (2005) report that the tabletop condition was superior to single monitor performance in terms of task completion time. This is counterbalanced by the effectiveness metric applied in Buisine et al. (2007), in which it was found that that there were no differences in idea production between tabletop and pen-article conditions. Thus, there seems to be an agreement of increased equity when applying tabletops over other established technologies between different studies. On the other hand, findings in relation to communicative support and efficiency/effectiveness metrics are more elusive. When we also take into account the low number of studies it is questionable that we have demonstrated the benefits of tabletop technology in collaborative settings.

In general, all 56 studies on collaboration are very interesting and several report that findings are "promising," see e.g. Fleck et al. (2009), Heilig, Huber, Demarmels, and Reiterer (2010), Tuddenham and Robinson (2007), and Wesugi and Miwa (2006), which hint toward potential capabilities of tabletop technology but without hard evidence. This is also reflected in a recent article by Nebe et al.: "… there is still a lack of effective tools that support co-located group work. There are promising technologies that can add to this, such as tabletop systems…" (Nebe, Müller, & Klompmaker, 2011, p. 632). In addition, we also identified that several articles have either a non-empirical basis or can be considered as feasibility studies, exploratory studies or early observations. These wordings are used in several of the articles, see e.g. Martinez et al. (2011), Nacenta, Pinelle, Stuckel, and Gutwin (2007), and Tuddenham and Robinson (2007).

Thus, the current studies emphasizing collaborative aspects are few and they represent initial findings with limited hard evidence of the benefits provided by tabletop technology. Such evidence, on the other hand, is not trivial to come by as collaborative aspects involve studying how people interact with each other and not only the device. Other aspects relate to understanding the movements in physical space and how people coordinate their interactions on the shared interface (Lim & Rogers, 2008a). Obtaining such evidence thus requires the capture and analysis of different types of data such as conversations, gestures, movements etc. and representing these at varying levels of abstraction. Such analyses can become complex (Lim & Rogers, 2008b).

There are also very few studies comparing tabletops and other established technologies, and those there are point in different directions. In other words, it still seems to be unclear why is it worthwhile investing in tabletops instead of relying on a well-established (and cheaper) technology. This is also supported in Fleck et al. (2009): "… findings from the few studies carried out to date have tended to show small or insignificant effects compared with other technologies" (p. 189). These indicators are also pointing toward the *Trough of Disillusionment*.

5.3. Few Natural Setting Studies

Fenn and Raskino pointed out that we can only reach the *Plateau of Productivity* when having demonstrated and accepted benefits of an innovation in the real-world (Fenn & Raskino, 2008). We only found 16 studies (3%) emphasizing the application of tabletops in natural public, home or workplace settings. This is also supported in Hornecker (2008): "Most tabletop research presents findings from lab-based user studies focusing on specific interaction techniques. This means that we still know little about how these new interfaces perform in real life settings and how users appropriate them" (p. 113). Also, in a more recent CHI article by Marshall et al. the following is mentioned: "Multi-touch tabletops have been much heralded as an innovative technology that can facilitate new ways of group working. However, there is little evidence of these materializing outside of research lab settings" (Marshall et al., 2011, p. 3033). Furthermore, Schubert et al. mentioned: "… it seems that tabletop applications could be a good means for the learners to reflect on their actions and thereby to favor the knowledge transfer. This interesting point should be tested in a broader context" (Schubert et al., 2012, p. 612).

Our findings show that natural setting studies are primarily conducted in public settings such as museums and schools. Four articles (0.6%) have taken place within organizational contexts of companies. Notably, the study presented in Wigdor et al. (2007) spans an impressive period of 13 months, this, however, is based on a single participant and does not consider collaborative aspects. The study presented in Augstein et al. (2014) spanned a 5-month period and was conducted in collaborative settings. However, the emphasis was on the usability experienced by neuro-rehabilitation therapists and does not include experiences from the collaborative part, i.e. the patients. In total, we only found nine natural setting studies considering longitudinal effects, see Augstein et al. (2014); Cao et al. (2010); Kirk et al. (2010); Marshall et al. (2011) Mazalek et al. (2007); Morris et al. (2008); O'Hara (2010); Perron and Laborie (2006); and Wigdor et al. (2007).

In essence, very few articles emphasize workplace collaboration, e.g. when creating design products such as UML diagrams or mind-maps and how a tabletop facilitates collaboration in such settings. However, there have been experiments in artificial settings examining such use, e.g. Buisine et al. (2007) and Basheri et al. (2012). Also, findings in natural setting studies are not encouraging. Hornecker found that, although museum visitors found the installed tabletop engaging, they did not embark on social interactions (Hornecker, 2008). Also, Kirk et al. (2010) found that a tabletop in a home environment lead to interference in family roles and that they did not use the device together. A similar observation has been done within information systems research where O'Leary (2008) stated that the Trough of Disillusionment is characterized by an emphasis on studies of "things gone wrong." The main point here is that we still have very little evidence of tabletop use in uncontrolled environments and the findings that we do have are not all positive. According to O'Leary, this can have the effect that researchers are turned away from studying tabletop technologies.

The critique of few natural setting studies has also been raised in other HCI literature. In 2000, Kjeldskov and Graham made a literature survey on mobile HCI research methods and found that studies mainly emphasized building new devices and evaluating these in lab settings, i.e. natural setting studies were conducted infrequently (Kjeldskov & Graham, 2003). This bears close resemblance to the findings made in relation to tabletop technology. Kjeldskov and Graham argue that this provides a limitation in our understanding of the use of mobile devices which in turn "inhibits future development of the research field as a whole" (Kjeldskov & Graham, 2003, p. 317). Kjeldskov and Paay revisited the mobile HCI research methods several years later to examine changes made after a 10 year period since the first study (Kjeldskov & Paay, 2012). Findings in this latter study showed that trends have changed to involve a higher number of field studies and that the area had become increasingly multi-methodological.

Similarly, in 2003, Wixon raised a critique on the type of research done in assessing effectiveness of usability evaluation methods (Wixon, 2003). He argued that studies at the time failed to consider implications for practice for two reasons: (1) emphasis was put on the number of identified problems and (2) methods were evaluated in isolation from organizational contexts. According to Wixon (2003), this emphasis was short sighted as it neglected the fact that usability problems should not only be found, but also fixed. Ignoring the broader context in which methods were to be applied would lead to little practical relevance as this omits the influence of factors such as team buy-in, available resources, change-processes etc. (Wixon, 2003). As an example, conventional video based analysis reveals a high number of usability problems, this method, however, is not feasible to apply for many organizations as it is simply too expensive (cf. Bak, Nguyen, Risgaard, & Stage, 2008 and Bruun & Stage, 2012). After Wixons critique more studies began to assess downstream utility of usability evaluation methods in organizational contexts (Hornbæk & Frøkjær, 2008). Examples of such studies can be found in e.g. Bruun and Stage (2012) and Law (2006).

Thus, the issue of few natural setting studies has also been raised as a critique in other areas of HCI research. Our study indicates that we have not yet demonstrated the benefits of tabletop technology in such settings, which is another indication pointing toward the *Trough of Disillusionment*.

The need for natural settings studies, of course, is not relevant for tabletops only. This is critical for other technologies as well, which is also demonstrated in Kjeldskov and Graham (2003), which deal with mobile technologies.

We agree that this statement applies to several technologies and not just tabletops. We also agree that researchers are not responsible for developing business models (that is up to the individual companies). Yet, we believe that research is also about creating societal impact on different levels. So, when a new tabletop implementation is proposed (which is the predominant tendency throughout literature), it is reasonable to assume that the researchers responsible for this technology, would also like to see their project in actual use and that the technology actually plays a role in changing a societal aspect toward the better. Such a societal aspect could be, e.g. increasing work efficiency of molecular biologists within a given company. Fundamental research is indeed different from applied research. Yet, this does not contradict our findings, as one could also say that our study shows the need for more applied research.

5.4. Moving Forward

The purpose of this study is to evoke discussions within the tabletop research community on the current and future research challenges. This study contributes with the following insights:

(1) Establishing visibility on the development in number of tabletop publications over a longer period: The number has peaked and is now decreasing.
(2) Establishing visibility on the types of research foci within the existing tabletop research: Primary focus on developing new technologies over evaluating their feasibility in supporting real-world practices.

Such visibility is necessary in order to reflect on potential challenges that exist. This notion is based on the philosophy of Edwards Deming and Peter Drucker, of which both are attributed to saying: "You can't manage what you can't measure." We show the underlying numbers of the current state-of-the-art by categorizing and measuring the existing literature. This can inform others and help the tabletop research community evoke discussions and manage the direction in which it is heading. The direction should be to steer out the trough of disillusionment.

Returning to the article by Müller-Tomfelde and Fjeld, it is stated that the development of off-the-shelf devices has caused the area of tabletop technology to mature (Müller-Tomfelde & Fjeld, 2012). In our review we found that the most popular trend was about implementing new hardware and software. Thus, most of the applied tabletop devices are self-built, which can be explained by tailoring the technology to specific research needs. There are around four times as many articles reporting the use of self-built technology compared to those applying commercialized devices. We do agree with Müller-Tomfelde and Fjeld that commercially available devices may be more robust than those developed to support particular studies. Furthermore, Müller-Tomfelde and Fjeld argue that the technologies based on Multitouch OLED, Multiuser Multitouch and Interactive Tablecloth would move the field up the *Slope of Enlightenment* and further onto the *Plateau of Productivity*. We do not agree that such technologies will mature the field on their own. Although the technical underpinnings of some tabletop devices can be considered mature, we argue that our understanding of how to use such technology in collaborative settings and its benefits still need heavy exploration.

Based on findings in this study it is our belief that we need to start focusing more on demonstrating the direct benefits of the existing tabletop technologies rather than to keep developing new and unproven ones. We need to move out of the *Trough of Disillusionment* by evaluating this technology against other established technologies and we need to do so in natural settings in order to demonstrate real-world benefits as noted in Fenn and Raskino (2008); Kjeldskov and Graham (2003); and Wixon (2003). Also, we believe that more longitudinal studies of benefits will aid in accomplishing the move toward the *Plateau of Productivity*. Without such further studies, we provide no clear incentives for investing in this technology.

In terms of research methods, it is known that field studies and case provide rich insights leading to a further understanding of the use of technologies and relevant needs in specific contexts (Kjeldskov & Graham, 2003). Again, our literature review shows that the tabletop research community has developed a large array of knowledge on how to implement new technologies with highly advanced interaction techniques. Given the current state-of-the-art, we for instance see ample opportunity for conducting field studies that center around the use of tabletop technologies. Field studies and case studies could be applied to assess and understand collaborative use of tabletops in natural settings. Wynekoop and Conger's renowned article outlines more research methods and provide examples of their use for different purposes, e.g. natural setting studies (Wynekoop & Conger, 1990). A very recent special issue in the Journal of Computer Supported Coorporative Work (JCSCW) partly addresses the above mentioned needs. It includes studies investigating collaborative aspects of tabletops. A noteworthy example from that special issue is the study by Martinez-Maldonado and colleagues, which is an excellent example of a field study and of the opportunities posed by such. They describe a tabletop design to support classroom teaching in small groups, a design which was later deployed in natural settings (Martinez-Maldonado, Clayphan, & Kay, 2015). In their setup, multiple tabletops supported class lectures on which students could solve tasks. Four teachers participated in the study, which spanned a period of 8 weeks. Findings describe the teachers' preferences of having visualizations of teacher scripts on a secondary device. Thus, the JCSCW special issue studies take a step toward the plateau of productivity by emphasizing collaborative aspects in natural settings.

It is also encouraging that the ITS conference in 2013 introduced calls for application articles with the aim of fostering more tabletop studies from real world settings. This shows that the research community has an interest in such types of studies. However, given that (1) we traversed all ITS articles (including application articles) and (2) there are still very few studies in real world settings (3%), we argue that such increased emphasis has yet to manifest itself in actual publications. Our aim with this study is to evoke further discussions by empirically showing the extent of the challenge faced by the research community. Such discussions could potentially lead to more real-world studies, which was also the underlying aim of the study described in Kjeldskov and Graham (2003), which pointed toward similar issues for mobile technologies.

That literature study was repeated 10 years later showing that research trends had changed toward studying mobile technologies in real-world settings and that the research area had become more multi-methodological (Kjeldskov & Paay, 2012).

6. Conclusions

In this article, we have followed the evolution of one of the oldest surface computing technologies: The horizontally oriented tabletop. Although the underlying idea of tabletops stems from the early 1990s, researchers disagree on its maturity.

To determine the level of maturity we conducted two comprehensive studies where we analyzed 542 research publications from the last decade. We applied the Hype Cycle to discuss the current level of maturity and how we should move forward to further nurture this. In our study we have applied multiple evaluation metrics: No. of publications, research trends as well as emphasis on collaboration and natural settings. All metrics indicate that we are now in the *Trough of Disillusionment*.

Findings revealed that the number of publications in the area increased dramatically in years 2006 to 2011. However, in 2014 we observed a steep drop. We also found that main research objectives relate to implementing new hard- and software and the relative extent of this trend has been stable over the last 10 years. In other words, the primary focus in the past decade of tabletop research has been to develop new technology. This bears close resemblance to the typical level of hype and activities surrounding the *Peak of Inflated Expectations* in a Hype Cycle. Historically, this is followed by a period of negative hype denoted the *Trough of Disillusionment*. This period is encountered due to an emphasis on developing new technologies without demonstrating their benefits in real-word settings. This is perhaps the single most critical of our findings: Only 3% of all studies are conducted in natural settings. Thus, there is a clear opportunity for researchers to investigate how this technology performs in the real world. This is crucial if we are to eventually reach the *Plateau of Productivity*.

Also, one of the most widely argued benefits of tabletop technology has been its efficiency in supporting collaborative work. Yet, we found that only 10% of the articles emphasized collaboration, i.e. few articles explore multiple persons working together around tabletop devices in co-work settings. A detailed walkthrough of these articles revealed that seven studies (1%) compared tabletop technology to other established technologies. Thus, there is also ample opportunity to start focusing on studies that demonstrate relative benefits of tabletops over other technologies in collaborative settings. Our review shows that benefits within the existing studies point in different directions, e.g. showing that tabletops lead to enhanced fluidity of communication between participants compared to individual screen setups in one study, while no effect was found in another. Disagreements on the level of effectiveness of tabletops over other established technologies could also explain reluctance toward launching these technologies in real-world settings.

Our aim with this article is to evoke further discussions on research foci within the tabletop research community. We suggest extending the main streams of research related to implementation of new technologies and specific interaction techniques. To move beyond the *Trough of Disillusionment* there is a need to provide clear incentives for organizations (commercial as well as non-commercial) to which such technology has relevance. Our study shows that there are several opportunities for studying how—and to what extent—tabletop technology is beneficial over established technologies in natural and collaborative settings. Such studies can be conducted using methods such as field studies and case studies.

A clear limitation in this work relates to our emphasis on horizontally oriented tabletops. Tabletop technologies are part of the newer and highly diverse field of surface computing where all kinds of surfaces are applied for interaction. As an example, consider a multi-touch surface built from ice to incite people into exploring alternative materials (Virolainen, Puikkonen, Kärkkäinen, & Häkkilä, 2010). Beauty technology has also started to emerge where electromagnetic devices are embedded in beauty products. This could be e.g. RFID nails and conductive makeup which are attached to the body for interacting with different surfaces (Vega & Fuks, 2013). Similarly, in Mujibiya et al. (2013) low-frequency ultrasound propagation is applied to form distinctive profiles useful to infer touch on certain locations of the body. These examples illustrate that we have extended Weiser's initial notion of large interactive surfaces from merely being a horizontally oriented table (or "board") to cover all kinds of surfaces (Weiser, 1991). In doing so, there will be a natural increase in hype around the general area of surface computing and in the number of research publications. This happens simply because we open up new ways of interacting with technology. However, based on the underlying dynamics of the Hype Cycle we can arguably not expect this newer and broader area of surface computing to have reached a level of maturity. This is why we did not consider this broader area of research in our study, nevertheless in the future it will be relevant to replicate our study and consider surface computing in general.

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About the Authors

Anders Bruun is Associate Professor in HCI at the Department of Computer Science, Aalborg University (Denmark). Research interests include theoretical, methodological and practical aspects of measuring UX in real-time. He has also worked as a UX consultant in the software industry with managing UX of small and large scale projects.

Kenneth Eberhardt Jensen is a Microsoft Dynamics CRM consultant at Massive Dynamics IsV. He obtained a Masters degree in software engineering in 2013 at Aalborg University (Denmark). He's main research interests include usability evaluation, interaction design and usability of mobile devices.

Dianna Hjorth Kristensen is Web Developer at DanDomain A/S. She obtained her MSc in Computer Software Engineering in 2013 from Aalborg University (Denmark). Before university she graduated as Multimedia Designer in 2008. Her main interests are Web development and HCI.

Jesper Kjeldskov is Professor of Computer Science at Aalborg University in Denmark within the area of HCI. Jesper's research focus is on mobile and ubiquitous technologies. He has published more than 130 journal and conference articles, and has recently been awarded the degree of Doctor of Science (higher doctorate).

Appendix A

Traceability Table

Collaboration (n = 56)	[32, 37, 40, 44, 49, 53, 58, 59, 75, 97, 100, 103, 105, 107, 118, 139, 159, 160, 191–193, 205, 207, 220, 257, 264, 287, 288, 292, 294, 304, 317, 319, 321, 328, 330, 339, 360, 361, 364, 369, 381, 386, 390, 392, 409, 412, 420, 431, 442, 452, 458, 477, 511, 530]
Cross-device (n = 22)	[32, 48, 110, 113, 164, 182, 204, 205, 245, 300, 301, 303, 304, 349, 368, 388, 413, 414, 431, 465, 467, 513]
Design (n = 86)	[1, 13, 20, 43, 57, 63, 68, 71, 78, 80, 84, 104, 107, 112, 118, 120, 129, 133, 134, 137, 141, 144, 152, 154, 155, 167, 173, 174, 178, 181, 184, 188, 212, 220, 221, 244, 292, 295, 310, 316, 318, 319, 327, 332, 333, 343, 348, 350, 353, 354, 358, 369, 371, 379–382, 391, 392, 396, 403, 407, 418–420, 426, 429, 441, 458, 459, 462, 475, 477, 481, 488, 492, 496, 497, 501, 514, 520, 523, 524, 526, 529, 531]
Implementation (n = 273)	[3–6, 9, 11, 12, 15, 17–19, 21, 27, 29–31, 37, 38, 42, 46, 47, 50–52, 59–62, 64, 66–70, 73–77, 79, 81, 85–89, 91, 92, 94–96, 100–103, 105, 111, 114, 115, 117, 119, 121, 123, 126, 127, 130–132, 134, 135, 138, 139, 143, 146, 147, 151, 156, 161–163, 168–172, 176, 179, 182, 183, 185–194, 196–199, 201, 203, 208, 210, 211, 213, 214, 217–219, 223, 224, 226, 228–231, 233, 235–239, 242–244, 247–254, 256, 258, 260, 261, 263, 265–269, 271, 273, 276, 278, 284, 289, 291, 293, 296, 299, 305, 307, 308, 311, 313, 320, 322, 325, 327, 334, 336–338, 341, 342, 347, 352, 356, 357, 359, 360, 364, 366, 368, 370, 372–377, 380, 382, 384, 385, 387, 388, 390, 393–395, 399, 400, 406, 408, 411, 415, 417, 421–425, 428–430, 432–434, 445, 446, 449, 454–457, 459, 461, 465, 468–472, 474, 476, 478, 480, 481, 483–487, 489, 491, 493, 496, 498, 499, 502, 503, 505, 506, 508–510, 514–516, 518–522, 527–530, 535–538, 541, 542]
Individuality (n = 31)	[32, 36, 69, 108, 154, 207, 209, 222, 231, 273, 274, 291, 307, 311, 314, 317, 329, 351, 386, 394, 395, 400, 401, 404, 410, 412, 413, 449, 532, 534, 540]
Interaction (n = 183)	[2, 4, 7, 8, 14–17, 22–26, 29, 33–35, 39, 42–45, 49–51, 54, 55, 64, 71, 77, 83, 84, 89, 90, 92–96, 98, 99, 104, 106, 112, 113, 116, 117, 119, 123–126, 136, 145, 148–150, 155, 158, 162, 165, 166, 169, 171–178, 184, 201, 202, 206, 218, 225, 227, 232, 234, 240, 241, 248, 253, 259, 260, 262, 263, 268, 272, 277, 279, 282, 283, 285, 286, 288, 295, 298, 300–302, 309, 310, 312, 314, 321, 323, 325, 326, 328, 330, 334, 340, 343–345, 356, 359, 362, 363, 365–367, 372, 378, 383, 389, 397–399, 402, 405, 410, 416, 418, 419, 427, 434–440, 442–444, 448, 450, 451, 460, 462–464, 466, 467, 473, 475, 480, 482, 485, 486, 488, 491–495, 499, 502, 504, 506–509, 515, 517, 524, 528, 531–533]
User (n = 62)	[19–21, 28, 41, 54, 56, 65, 72, 98, 109, 110, 128, 140, 142, 157, 159, 174, 180, 181, 195, 200, 206, 217, 221, 228, 229, 246, 250, 255, 270, 275, 276, 279–282, 287, 290, 297, 298, 306, 316, 318, 331–333, 335, 339, 344, 346, 355, 409, 453, 463, 479, 490, 512, 525, 535, 538, 539]
Visualization (n = 49)	[7, 10, 36, 39, 46, 53, 72, 74, 82, 108, 120, 122, 125, 135, 136, 146, 152, 153, 160, 165, 202, 203, 215, 216, 238, 255, 257, 264, 271, 312, 315, 324, 335, 352, 365, 411, 424, 428, 438, 445, 447, 448, 457, 460, 461, 482, 484, 500, 513]