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Longitudinal Studies in HCI Research: A Review of CHI Publications from 1982-2019

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Abstract: Longitudinal studies in HCI research have the potential to increase our understanding of how human-technology interactions evolve over time. Potentially, longitudinal studies eliminate learning or novelty-effects by considering change through repeated measurements of interaction and use. However, there seems to exist no agreement of how longitudinal HCI study designs are characterized. We conducted an analysis of 106 HCI papers published at the CHI conference from 1982 to 2019 where longitudinal studies were explicitly reported. We analysed these papers using classical longitudinal study metrics, for example duration, metrics, methods, change or stability. We illustrate that longitudinal studies in HCI research are highly diverse in terms of duration lasting from few days to several years and different metrics are applied. It appears that the paper contribution type highly influences study design. While, only a little more than half of the papers discuss or illustrate change/stability during their studies. We further underline considerations of durations vs. saturation, identifying points of measurements and matching contribution types with research questions. Finally, we urge researchers to extend implications presented on perceiving duration as a singular attribute, as well as longitudinal systematic approaches to 'in-situ' studies and ethnography in HCI.

Keywords: Longitudinal, literature review, study design, duration, change

Introduction

Longitudinal studies in HCI (Human-Computer Interaction) research have been applied and discussed for several years, and the potential of conducting studies that are longitudinal by nature are almost quite evident, e.g. the opportunity to measure or observe changes over time [6].

Longitudinal studies or longitudinal research are commonly applied and used in other research disciplines. For example, in social science it has been used to focus on studying phenomena over an extended period of time and to study changes within these phenomena. Pettigrew [16] defines longitudinal research in social science as lengthwise and thereby as research studies that span a period of time. For this chapter, we adopt a definition on longitudinal data in HCI research from Gerken [7], who states "*longitudinal data present information about what happened to a set of research units [in our case, the participants of a study] during a series of time points*". Thus, duration of time and change are highly important for longitudinal studies. But various challenges and obstacles have been identified for longitudinal studies, e.g. that they can be very cumbersome or labour-intensive (high demand on resources) and also risks of panel attrition.

Several conference events have been organized at the annual premier international HCI conference The ACM CHI Conference on Human Factors in Computing Systems (CHI) over the past years, e.g. workshops [4], with these sub-goals "*in-depth discussion of key issues both appropriate methodology and research questions that lend themselves to longitudinal study*" and "*generation and dissemination of best practices for longitudinal research to the CHI community*". Resonating a need for consensus on longitudinal HCI. Also, previous user experience (UX) research has started to shift their focus from initial UX to more prolonged sustained use, thereby requiring longitudinal studies [10].

In this chapter we will give an overview of how previous CHI contributions have conducted longitudinal studies, for inspiration. Additionally, we will present recommendations for future longitudinal HCI research.

It is important to note that longitudinal research should be seen as a specific tool and not the silver bullet to empirical research in any field. So, while it is important to promote the application of longitudinal research, it is also necessary to understand the pitfalls and difficulties that come with it. By providing this analysis we aim to shed some light on these aspects as well.

The challenge of Identifying longitudinal HCI

There is already much HCI research that is longitudinal, but it is also fair to state that much less research is explicitly longitudinal. Various forums at the CHI conference have addressed a need for stronger focus on longitudinal research within HCI, e.g. workshops [3, 4, 8], panels [23], SIGs [7, 22], courses [2]. However, we still have little empirical evidence about how we as an HCI community understand what longitudinal research is for HCI studies, how we should think about it, which methods apply, and how it should be evaluated. Only two small sections are dedicated to this broad topic in a newly updated version of one of the common textbooks on HCI research methods [12] . Ethnographic studies are often longitudinal – at least implicitly – but not always. Case studies often provide a snapshot and hence not longitudinal, but not always. The timespan of experiments is traditionally short, but several are longitudinal. There seem to exist a genuine lack of clarity as to what longitudinal is and should be in HCI research. In our reading of the 106 CHI papers,

we found that only one paper referenced a source text for longitudinal data analysis (appendix reference [41]). Instead, others would reference other HCI publications on HCI longitudinal studies, while most of them included no references on longitudinal studies or research at all. There seem to be no common, unified definition for longitudinal research in HCI, only emerging definitions formed in panels and discussions in the context of CHI, and not even these are referenced that often.

Studying Change

In the social sciences, longitudinal research has been more common, with periodic censuses which aim to understand societal developments being one of the popular and oldest examples [13]. So as a starting point we can state that longitudinal research has been used to focus on studying phenomena over an extended period of *time* and to study *changes* within the phenomena. But how so? From a more technical perspective, we can follow Taris who contrasts longitudinal research with cross-sectional research [21]. In cross-sectional research there is only one single measurement for each individual or case in the study – ideally at the same point in time. Typically, such research is applied in HCI for example when running a survey or to compare different interaction techniques in a controlled experiment. Longitudinal studies however are "*running lengthwise*" as Pettigrew puts it [16]. This means that there need to be at least two measurements for each case and for the same variable at different points in time. This then allows for comparison of data among the time variable and thereby the study of changes.

Change is the primary variable of most interest in longitudinal research, and the appropriate conceptualization of change is central [18]. The emphasis is also here on change and from the point of measurement of variance they claim that longitudinal research must contain three or more repeated measurements. In Pettigrew's longitudinal process research the empirical analysis is directed at understanding the process of change (over time), the contents of the change, and the context in which it happens. Guidelines have been established to inform how to develop and evaluate longitudinal research on change. The necessary conceptualizing of change, they state, requires an explication of a theory of change, duration of change as well as predictors of change. Different aspects should be clarified including the level of change of interest, group average change, intra-unit change, or inter-unit differences in intra-unit change. It is often the relationship between variables that is the most interesting and this can be examined only by a longitudinal study.

Elements of comparison are vital for longitudinal studies and quantitative approaches are implemented for comparison and significant relationships between set variables. Ployhart and Vandenberg [18] address statistical analysis in their guidelines and urge to be aware of potential violations in statistical assumptions inherent in longitudinal designs (e.g., correlated residuals, non-independence). The potential errors have to do with the nature of longitudinal research where variables change; they become more or less heterogeneous, over time. Being precise about which variables are expected to change, why they are changing and (when relevant) the nature of dynamic relationships over time. Time is not the only valid variable, as they emphasize; most constructs do not change, evolve or develop because of time, rather

they do so over time. An example is that time does not make children grow into adults; genetics and environment are the causes. Pettigrew [16, 17] argues that pragmatically judgements in longitudinal research will be made based on the themes and research questions being pursued, the empirical setting of the research, researcher-subject relationships and funding and other resource constraints. What researchers can say something about will be dependent on the variables, which are measured.

METHOD

The primary goal of our study is to explore previous CHI papers where longitudinal studies have been applied and reported. Particularly, we are interested in analysing how CHI papers have studied change or stability over time, what time or duration is in CHI studies, and finally what kind of research methods that longitudinal studies apply. For this analysis, we ground our work in the definition stating "*longitudinal data present information about what happened to a set of research units [in our case, the participants of a study] during a series of time points*" [7].

In our paper selection, we were inspired by the four phase analysis on empirical studies illustrated in Bargas-Avila and Hornbæk [1], but since our analysis focuses on only one outlet (CHI proceeding series), most of the exclusion steps are not applicable for our study. Thus, we conducted three phases when selecting publications for our study namely identification, retrieval, and analysis. For readability, when referencing appendix references outside of Findings, we will clearly mark it.

Phase 1: Identification Of Publications

We used the exact query or search term "longitudinal" in the ACM Digital Library (DL) database and further limited our search to only include publications from the proceeding series Human Factors in Computing Systems conference (CHI). We searched for the query in all ACM DL fields including title, abstract, keywords, and full text. The CHI conference has been held annually since 1982 and the ACM DL include all conference proceedings from 1982 (the first CHI) until 2019 (the latest CHI). We found that the query term "longitudinal" is significantly unique to capture the type of publications that we would like to include.

We have only included published CHI papers in this analysis. We certainly acknowledge that longitudinal studies are also published at other HCI venues. We address this in discussion, referencing a previous analysis that adds interesting and complementary perspective on longitudinal studies in HCI research.

Phase 2: Retrieval Of Selected Publications

We retrieved 137 publication entries out of the 138 entries from phase 1. One entry in the ACM DL included no PDF and referred to a CHI 2008 workshop call on information visualization. This entry was excluded from our set. The 137 publication entries (PDFs) were archived, and we then printed and numbered all entries in alphabetical order after first authors last name. For our study, this phase involved

only the above exclusion of publications as we only had one data source (the ACM DL) and therefore, no duplicates were included in our set of publications. We have included the entire list with all 137 CHI publications in the reference appendix in this chapter.

Phase 3: Publications For Analysis

During this third phase we wanted to exclude papers that did not e.g. report from an empirical study as our goal was to analyse how CHI research conduct longitudinal studies and not only how they talk about these studies. A total of 31 publications were excluded from the analysis, all listed here as appendix references. First, we removed twelve entries where the publication did not report from an empirical study [5, 6, 7, 17, 21, 25, 26, 61, 65, 66, 86, 123]. Secondly, we excluded eleven publications where the term longitudinal referred to something different than the study or research method [35, 50, 52, 56, 67, 69, 76, 102, 129, 130, 137]. Thirdly, we excluded seven publications where the study had not yet been done, but where the authors suggest a longitudinal study should be done [22, 23, 31, 101, 103, 108, 135]. Finally, we removed one publication where the paper did not have sufficient details on how or whether an empirical longitudinal study actually had been conducted [91]. A resulting list of 106 CHI papers was used for our analysis and can be found in the reference appendix of this chapter (they are marked with an "*").

We initially described the 106 publications using themes and characteristics of longitudinal research from related disciplines (as introduced in the background). Here we used the definition from Gerken [7] on longitudinal data on what happens to a set of research units (participants) over a series of time points. Based on this, we constructed a framework for analysis that consisted of entries for duration, variables and metrics, data types, research methods, study context, how the term longitudinal is used and applied, and finally a short summary of the paper. Additionally, the 106 CHI papers were re-read with a focus on argumentation for or against longitudinal aspects, how it was implemented in methods, and how findings were impacted by the longitudinal aspects of the study. Following, papers were sorted and analysed through emergent themes, reflected in the findings. We also analysed and categorised all 106 papers, regarding their specific type of contribution they present, taking inspiration from the CHI contribution types as illustrated in the CHI 2017 website where it is stated that "… *a single paper may often fall between contribution types, or offer its own unique contribution*…" While we certainly acknowledge that CHI papers often make several contributions, we have attempted to determine a primary contribution of each paper for us to discuss different kinds of studies in relation to contribution type.

		Duration (Longitudinal Study)				
		Not Specified (N=22)	**14 days or shorter** (N=16)	**2 to 4 weeks** (N=12)	**1 to 11 months** (N=31)	**1 year or longer** (N=25)
Paper Primary Contribution	**Interface Artefacts or Techniques** (N=29)	20, 40, 47, 73, 79, 80, 93, 134	46, 51, 72, 82, 87, 104, 113, 114, 115, 126, 131, 132	44, 48, 59, 94, 106, 116	15, 18, 94	
	Understanding Users (N=43)	24, 30, 38, 49, 90	58, 122	36, 53, 64, 128	12, 13, 19, 27, 28, 29, 45, 77, 81, 83, 84, 95, 98, 99, 100	3, 4, 10, 16, 32, 55, 78, 92, 96, 107, 109, 110, 111, 112, 120, 127, 136
	Systems, Tools, Architecture and Infrastructure (N=15)	60, 62	70, 85	34, 37	8, 9, 68, 89, 117, 119, 125	33, 71
	Methodology (N=11)	11, 118			41, 42, 43, 54, 57, 63,	75, 88, 105
	Theory (N=5)	2, 14, 74				39, 124
	Uncertain (N=3)	1, 133				121

Table 1: Categorization of the 106 included CHI papers from the period 1982-2019. The x-axis illustrates the duration of the study described in each paper (four types + non specified), whereas the y-axis describes primary contribution type. Numbers in the table refer to the appendix reference list.

Overview of Longitudinal HCI Research

In the following overview, we present key characteristics for the 106 CHI contributions, namely duration, metrics, and change. We would like to stress that when we reference papers in this section, the number refers to the numbers in the Appendix References.

First, our analysis showed that two contribution types amounted for almost 70% of the papers namely "understanding users" with 43 papers (40,5%), while "development and refinement of interface artefacts or techniques" has 29 papers (27%). This is perhaps not surprising as CHI papers deal with developing or creating new user interfaces and interaction techniques, but also studying user interaction with systems. Looking at the other contribution categories we see that "systems, tools, architecture, and infrastructure" have 15 papers, while "methodology" and "theory" have 11 and respectively five papers. Finally, we were unable to categorize three papers towards primary contribution [1, 121, 133]. In the following, we will for practical reasons refer to the contribution types as interfaces, understanding, systems, methodology, or theory.

Study Duration: Plateauing And Evolution

Our findings illustrate that the duration reported in the included CHI papers varies greatly for longitudinal studies. This is shown in table 1. Also, we identified two different but related tendencies in our analysis related to study duration that we refer to as plateauing and evolution. In the following, we will illustrate duration, and we will illustrate plateauing and evolution.

Our analysis showed that duration ranges from only a few days, e.g., [115], up to several years, e.g., [112], and it can be argued that CHI longitudinal studies are measured over days, weeks, months, or years. We identified 22 studies where the duration is not reported or unclear – these are listed as "Not specified" in the first column of table 1. Instead, these papers focus on describing, e.g., the number of sessions carried out, the duration of the individual sessions, interval between sessions, or tasks within this session [20, 47, 49, 72, 73, 79, 80, 93, 134]. In the following, we primarily consider and discuss the papers with a reported duration (N=84), and in the following we will unfold observations regarding CHI paper study durations.

Interestingly, it appears that the contribution type affects the study duration. Interface papers employ relatively short studies (less than a month), whereas papers on understanding have rather long studies (often a year or longer). For the 21 interface papers that do report the study duration, 18 of them (85%) integrate longitudinal studies with duration less than a month. Whereas for understanding papers, 30 of the 43 papers (71%) report from longitudinal studies that are at least one month long; and 17 of the 42 papers (41%) conduct studies that are one year or longer. As the most 'extreme' example, Sillence et al. [112] conducted a study over five years.

However, a few understanding papers employ short study durations (less than two weeks), e.g., Jain [58].

While interaction papers mostly have short study durations, we found it interesting to observe that systems papers have rather long study periods where 9 papers out of 15 (60%) have study duration of at least one month, for example the study in [71] with a two-year study. But systems papers also employ short study periods like [34] with three weeks of study. Furthermore, we only found one study, [34], among the systems papers conducted in a laboratory. Here the participants played a game for approximately one hour in an attempt to learn mandarin as a second language. Language education and self-study took place outside the scope of the study.

Some of the CHI papers report from retrospective studies, where the duration refers to the time the collected data covers. The data collection is done electronically and is already produced, stamped or tagged, and available on servers. For example [4, 110, 127, 136]) are all understanding papers where the data cover over one year. As an illustrative example, Yuruten [136] conducts statistical analysis on a well-known public dataset, previously collected for another purpose and used in other studies. More of these studies explore data from anonymous users of social networks (twitter, discussion forums, collaborative music making site). This has some disadvantages according to Wang and Kraut [127] who argue that due to the snapshot quality of their included measurements, they are not able to make strong causal claims. But Settles and Dow [110] use this kind of data collection as a supplement to their own surveys.

Plateauing in Performance

We identified a focus in several studies on what we refer to as plateauing in performance (i.e. plateauing defines reaching a state of little or no change after a period of activity or progress). While only six of the included papers directly use the term [3, 46, 79, 81, 114, 115], we found that 20 papers discussed issues related to plateauing, and it played a significant role in defining longitudinal characteristics of the studies.

Plateauing in performance was particularly in focus for more papers on interface artefacts and techniques, which were typically carried out in lab environments, e.g. with a relatively modest duration of few days [115] and up to 6 weeks [15]. While [3, 81] are both understanding papers, with a duration of months to years, the plateauing described refers to behavior and habits, not performance. For some duration was not even specified, rather there was a focus on number of sessions. For example, the number of sessions wherein learning a new mapping would still be feasible [47], where the amount of time elapsed for performance with a new input method would settle compared to a familiar one [73] and where the difference becomes negligible [79], sessions required to mathematically project when users would reach expert levels [80]. It is however worth noting that the description of what constitutes a session, at what interval sessions should be carried out and the number of sessions varies wildly. A session might be timeboxed (e.g. [59, 82, 87, 114]) or might consist of a certain task e.g. typing an amount of phrases [44, 46, 72, 94, 113, 131]. Sessions

can be carried out within an interval - as an example [59] held lab sessions at an interval of at least 12 hours and not more than two days. Whereas [115] stated the importance of carrying out sessions at the same time on consecutive days. Conducting lab sessions, there might be practical constraints that dictate session duration, interval and number of sessions, although it is not explicitly argued.

In relation to plateauing, a number of interface artefacts and techniques papers argue that stability in performance can often be reached within days or weeks (e.g. [15, 44, 46, 48, 59, 72, 82, 94, 115]). Of course, different aims necessitate different duration, for [115] the aim was to explore a new input modality in a target acquisition task as well as participants initial attitude towards this modality, thus they planned for five daily sessions, whereas for [15] the aim was to determine the fastest and most consistently stable input of one new and one known condition, after participants passed the label of novice user, thus they planned for 20 sessions. Castellucci and Mackenzie [15] found that while two interaction techniques (graffiti and unistroke) had equally high error correction rates, the new technique was considerably more consistent than the other "*Investing the same time learning unistroke can result in significantly faster stroke time and higher text entry speed*". Whereas, Sporka et al [115] argued the need for a longer study duration for stronger evidence on performance plateauing.

A key plateauing concern is to understand when do users move from being novices to being experts during the conduction of an experiment? Thus, several experiments here involve prospective users where they use a new interface or a new interaction technique over a period of time. As an exemplary study of accounting for longitudinal aspects in plateauing in performance, MacKenzie and Zhang [80] (although not specifying a duration) applied a 2x20 within-subject factorial design to see the development from novice to expert with a new developed text-entry technique. They found that expert levels (theoretical upper-bound) were not reached within 20 sessions, but mathematically projected it would take around 30 sessions. They relate to the longitudinal aspects arguing learning time is a usability issue, therefore longitudinal empirical evaluation is important; "*We want to establish not only a layout's potential for experts, but also the learning time for typical users to meet and exceed entry rates with a QWERTY layout*". MacKenzie and Shawn further describe a so-called "crossover" point, where performance with a new technique would exceed current practice. However, they point out that this "*elusive crossover point*" may not always be reached if the new technique is simply not good enough or needs refinement. E.g. Son et al. argues that in their case for two-thumb typing in VR that although one condition implemented showed improvements, further work is needed to reach an adequate performance level in comparison to non-VR typing [113]. Additionally, MacKenzie and Zhang argue that the number of users for these evaluations are typically lower than usual, however the vital part is that they are evaluated over a prolonged period of time [80].

Majaranta et al. [82] challenged previous evidence that gaze typing is slow by changing the gaze time from constant to adjustable and evaluated on this in a series of ten lab sessions. They concluded that after four 15-minutes sessions, equal to one hour of practice, learning decelerated prominently. They reached a plateau in

learning. However, Jain [59] argues that a concern is to actually pinpoint the exact moment when subjects cross a threshold from novice to expert and through a longitudinal study, they were able to demonstrate that after an hour of practise, their users was able to transition to expert users within their particular system. Reporting on the point where performance plateaued was found in other studies expressed as either minutes/hours of practice or the specific day/session [15, 46, 48, 82].

Evolution

Our analysis showed that 12 studies explicitly concern evolution – something evolving over time. These studies are concerned with how e.g. personal information management behavior evolves over time [10], or how evolutionary patterns of communication strategies emerge over a project lifecycle and how these might affect delivery performance and quality of new product development [16]. The studies had common traits: They were carried out in the field, in low-control situations, or "in the wild" [98], as well as they had a duration equal to or above one month and up to several years. As an example, Chattopadhyay et al. [18] explicitly emphasize the choice of longitudinal methods to explore how use cases of their collaborative presentation plug-in would evolve naturally. In a one-month long deployment, data was collected through observation, interviews, one focus group, supported by system interaction logs and video recordings. This enabled authors to observe and report on "*emerging practices and shifting dynamics*" for evolving presenter and attendee practices. However, the authors qualify this as initial insights and argue for larger scale studies to validate, elaborate and qualify these findings. Likewise, a study from last year by Niemantsverdriet et al. [95] is concerned with social interaction, exemplified by a longitudinal study of shared use of a lighting control system and how social dynamics evolved around coordination.

Many of the evolution studies are concerned with understanding users. A recent exemplary study is Erete and Burrell [32], who explore citizen participation in local government. The study ran for three years and it reports on how online tools were organically adapted by citizens in order to engage in local governance in three communities. One result showed, that they were able to capture change in uses: "*During this study, we observed residents in Community 2 use an open discussion board initially and change to a private email list.*" Through a triangulated approach involving observation, interviews and qualitative content analysis, authors gathered extensive empirical data on a regular basis and subjected these to inductive analysis. Whereas Erete and Burrell's study is mostly descriptive, Parkes et al. [98] address evolution and clear temporal aspects for introducing technological interventions in their research question on how children's use and interpretation of the tangible system Topobo will evolve over time. Here several case studies of monthly use without an explicit study protocol or researcher involvement allow teachers to unfold the possibilities and constraints for Topobo together with children of various ages and in various contexts.

Use Of Metrics, Variables And Methods

A considerable amount of the 106 CHI papers report from studies that apply mixed methods in their research design. We found that 62% of the papers employ both quantitative and qualitative research methods, while 31% employ quantitative research methods, and just 7% employ qualitative research methods.

Metrics and variables

Several quantitative papers deal with interface artefacts or techniques (48%), and they often apply metrics or variables that make results easily comparable to previously reported results, e.g., [44, 73, 113], or to previous models, e.g., [20]. Several of these papers deal with text entry via text input interfaces, and they are often concerned with measuring typed-in words per minute – a common quantitative metric in the quantitative-only papers (e.g., [44, 46, 59, 79, 80, 93, 113, 131, 134]), but also in the mixed-method papers (e.g., [20, 72, 82, 114]). Other metrics or variables used in these papers are number of errors/corrections, error/correction rates, time elapsed between one action/keystroke to the next, stroke duration, etc. varying on the study technology and focus.

Interestingly, twelve out of 33 quantitative research papers (36%) are understanding papers. Here we found a focus on stringent variables and a vocabulary to match, as illustrated in these papers [4, 12, 13, 111, 127, 128]. Although varying in duration (weeks to years), all have an emphasis on variables for statistical analysis on a large dataset from a large sample size. For [4, 13, 111, 127] they outline one to two dependent and several independent variables. White and Richardson [128] set up two primary parameters on which to measure: community size and contact rate. Some studies, e.g. [4, 111, 127] relied exclusively on data retrieved from servers, while other studies, e.g. [12, 13], supplement such data with survey data. Some of the understanding papers are concerned with more abstract constructs; motivation, bias and user experience (e.g., [36, 64, 100]). For example, Fiore et al. [36] compared four conditions which differed in elements of intrinsic or extrinsic motivation. Karapanos [64] uses the AttrakDiff 2 questionnaire to evaluate deployment of a new technology as the author argues: "*For evaluative, high level summary judgments single item measurements are appropriate and commonly used (e.g., to measure subjective wellbeing).*"

Few CHI papers report from a qualitative-only study (7%). As an example, Pasquetto et al. [99] conducts two qualitative case studies, primarily relying on firstly a literature review and secondly ethnographic long-term observations, with a focus on open data policy and practice in major scientific collaborations. Their research questions regard rationales, definitions and infrastructure of open data, as well as their relationship. Categorizing this as an understanding paper. They conclude on how definitions change and how the relationships are more complex than before assumed and how this affects policy and practices.

Some important limitations of longitudinal data analysis are explicitly emphasized in [12, 55] for example, Burke and Kraut [12] state that it is impossible to rule out every possible 'third factor' that might account for a portion of an association

between an independent variable and its effect on the dependent variable. Hutto et al. [55] argue that longitudinal study research inherently has great power as correlational research due to the fact that time-dependent, repeated observations are considered as they state: "*When input A is consistently and reliably observed preceding outcome B for the exact same group of individual's time after time, we have greater confidence in suggesting a causal relationship between A and B.*" Burke and Kraut [12] nuance this for their particular study saying that "*like many large-scale observational social science studies, we cannot draw definitive causal conclusions, even with longitudinal data*" as unmeasured variables unavoidably existed that they were not aware of in their study design. They further speculate that even though they found only few quantitative differences, if qualitative differences had been taken into account, they might have reached a different conclusion.

Research methods and study design

The level of control of studies varies, depending on the context it was carried out in, as well as the objective of the study. Studies in the context of the lab had inherently relatively high control. In a relatively high control field experiment of text input techniques, Ghosh and Joshi [44] presented participants with a guideline for how many sessions that could be carried out when, how often, and what constituted a session. However, some more low control field settings introduced new interface techniques and instructed participants to use it freely over a specified duration while logging their interactions, for example [51, 104, 132]. The study design of Garzonis et al. [40] is somewhat different. They divided their study into 4 stages with one week of field study with daily prompted but randomly scheduled interactions, followed by lab studies and web based surveys, thus triangulating research methods. With five hypotheses, they aimed both at investigating the intuitiveness of two conditions (auditory icons and earcons) as well as hypothesized on the order of lab and field based activities. In line with this, Jain and Boyce [57] in a case study introduced a four-staged model of longitudinal data elicitation, as well as assessed the model with empirical evidence from a case of comparing two mobile applications. Firstly, a usability study was carried out, following three weeks of interacting and diary keeping, thirdly a retrospective reconstruction interview, completed with a follow-up survey after four months of use. With this study design they were able to conclude on how user preferences for the two applications shifted and stabilized, providing a completely different picture than the one from the start of the study.

Mchlachlan et al. [89] reference a concept, as inspiration for their study design, Multi-dimensional In-depth Long-term Case studies (MILCs). They employ this study design for evaluating adoption of a large data set visualization system. In line with this, Gerken et al. [42, 43] employed concept maps, in their case used to evaluate the usability of Application Programming Interfaces. Concept maps, they argue, are particularly good at addressing concerns of qualitative data gathering in longitudinal studies, as they visualize data and make it easier to identify changes over time.

Four studies concern social media and being social online [3, 110, 111, 127]. E.g., Wang and Kraut [127] studied the link between social media participation and work

performance. They analyzed logged activity on social media, and compared these with internal performance ratings. They collected data once every year from the same participants to study baseline performance and year-to-year variability, and concluded that employers should encourage adoption of social media among their employees. Armchambault and Grudin [3] investigated the usefulness of social media for organizational communication over a study period of three years. Here they annually invited 1000 randomly selected employees to answer a survey, upon answering they were subsequently excluded from participating again. By having representable samples, authors reported on growth in use and acceptance over the years, as well as changes in behavior and concerns. Additionally, recently Saha et al. [105] proposes in a case study to view social media as passive sensing for longitudinal studies of behaviour and wellbeing, as one aspect of sensing in a larger project named Tesserae project. Passive sensing as an unobtrusive data collection method, specifically through radio reflections, is proposed by Hsu et al. in response to "*Studies (that) rely on diaries and questionnaires, which are subjective, erroneous and hard to sustain in longitudinal studies*" [54].

Measuring Or Discussing Change

As introduced in the background section, measuring change (or stability) is a primary concern for longitudinal studies. Our analysis revealed that 66% of the CHI papers explicitly report on change (or stability). We have included papers that illustrate, analyse, or discuss aspects of change in their paper. We assessed the studies' points of measurement (PoM) and distinguish between studies with less than three PoMs and studies with three or more PoMs.

For measuring change or stability, 20 papers directly address that issues exist with what they refer to as "snapshot" and cross-sectional studies [3, 10, 12, 34, 41, 48, 53, 55, 58, 81, 85, 89, 97, 100, 109, 117, 122, 125, 127, 134]. However, they do not dismiss these studies, rather they see longitudinal as supplementary for exploring different, temporal aims. As an example, Fan et al. [34] supplemented previous lab studies focusing on short-term recall, with a longitudinal study to focus on measurable improvement in learning otucomes. As well, Gerken et al. argues "*In a purely cross-sectional design, one might come to the conclusion that a much higher difference between mouse and laser-pointer does exist compared to a more realistic test setting including practice*" [41]. For Oviatt et al. [97] the extended study duration over three sessions revealed a stability over time, which they claimed as valuable to inform future design guidelines on 'adaptive temporal thresholds' on multimodal integration patterns.

A little more than half of the included papers (54%) report from studies with three or more PoMs, while they also focus on measuring change or stability. Karapanos et al. [64], for example, argue that longitudinal studies should integrate three or more POMs to enable greater insight into the exact form of change.

Mott et al. [93] found that mastery comes with repetition and they based their study on several POMs of varying length and interval to regularly measure progress. They stress that the longitudinal nature of their study over eight POMs allowed them to

observe user performance with changes over time of two techniques where they expected the learning curves of the two techniques to be different. However, sometimes the change is not captured within the original duration, in which case some studies turn to prediction models in favour of extending the duration, e.g. [80]

The changes and stability of use of technologies is also in focus in studies through observations intended to predict which factors influence sustained use e.g. [68, 81]. Also, change is not always easy to pinpoint, but can happen over long periods of time (e.g. [10, 16, 19]). Several studies point out that conceptual change or stability is inherently time dependent, e.g., motivation, relationships, integration, and habituation [27, 28, 36, 81, 100]. For example, Fiore et al. [36] studied motivation to initiate participation in longitudinal studies through four conditions of incentives, and although they saw effects on recruitment for some conditions, these did not extend to continued participation. This seems to be a particular problem for longitudinal studies, particularly visible in [128] and also addressed in [88, 105]. Longitudinal studies like [81, 100] focus on motivation for exercise, and Macvean and Robertson [81] stress that new products inherently have the problem of novelty wearing off. They found that their prototype iFitQuest successfully facilitated light exercise over a seven-week period. It initially encouraged moderate to vigorous intensity exercise in many participants, but this tended to level out in the last few weeks of the study. Although the novelty of the product or service in itself can wear off, it might inform long term changes in behaviour (e.g. [68, 84, 119]) or the longitudinal study might reveal unintentional consequences of design [77]. Kim and Mankoff [68] and Teevan et al. [119] both found that making the invisible visible, in the form of respectively indoor air quality and changes in web content, saw users reflecting on and changing their behaviour. For Lee et al. [77] their field work on employing a social robot in a workplace resulted in a so-called "ripple effect" where non-participants would become part of the social interaction as observers or directly involved in the interaction. The extend of the ripple effect were perceived to be unanticipated.

We found that 26 papers report from studies with 1-2 POMs (26%), and 12 of these papers address change or stability. Interestingly, a large number of studies (34%) did not describe, report, or discussed change or stability explicitly [1, 4, 8, 9, 11, 18, 29, 30, 37, 38, 39, 40, 45, 53, 57, 58, 62, 63, 70, 71, 75, 83, 84, 98, 104, 106, 110, 116, 117, 120, 126, 128, 132, 136]. These papers typically focus on, e.g., describing, testing, or recommending without mentioning, illustrating or reporting on change over time.

Some studies have pre- and post-measurements [8, 9, 19, 64, 119], Karapanos et al. [64] stress the limitation of having only two PoMs, arguing they are only measuring current states and not the changes that happened in between. Two studies [112, 120] have a particularly long duration, where the duration in these cases could be expressed more appropriately as an interval between two points of measurements. For [112] Sillence et al. studied changes in online health from surveys spaced five years apart and Tullis [121] re-attempted a study, where participants were asked to point out the pictures they chose six years ago to represent a pictorial password. In the cases where studies primarily rely on automated data logs or highly frequent sensor

data, it is not easy to determine PoMs. As an example, Voida et al. [125] used a continuous data log of user interactions, as well as a post-study interview. Although the authors argue they provide initial evidence of shifts in activities with the introduction of their intervention, they also argue for future work to focus on the whole lifecycle of these shifts, which would require more PoMs. Additionally, when data collection is carried out retrospectively, it is not easy to determine PoMs, this was seen for [4, 30, 110, 127, 136].

Considerations for Longitudinal HCI Study Design

While the three themes under findings constitute a primary contribution of this chapter, we will in the following unfold some of the interesting characteristics of longitudinal HCI research. This discussion unfolds themes from our findings and relates them to longitudinal research (questions).

Duration against Saturation

Rogers [19] argued in a feature for Interactions magazine that the burning question in HCI research used to be "*How many participants do I need?*" but that the hotly debated question now was "*How long should my study run for?"* This certainly also characterizes longitudinal studies in HCI research, and our findings show that the publications in our study had very different durations. Rogers and Marshall has echoed the importance of running long-term studies "in the wild" [20]. Stacked up against running such long duration studies, however, is the cost and tenure of researchers involved as "*papers must be written, and research budgets are tight*".

Our findings suggest that the paper contribution seemed to play a role in determining the duration of a study and it seemed somewhat evident that you need to study over extended periods of time if your aim is to understand how people adapt or use technology in real life contexts, often referred to as in-situ or field studies. But on the other hand, new interaction techniques were often tested in terms of learning, as techniques were compared against baselines. We argue that *plateauing in performance* for new interfaces and interaction techniques, often with a short duration, has a stronger focus on data saturation rather than duration, where sessions and interval between sessions are more important, rather than the length of the study. Another trend we found was *evolution* studies focusing on patterns of change or stability, ultimately with the aim of predicting natural and evolving interactions with technologies or in order to infer design decisions, usually manifest over a longer duration. A goal for longitudinal studies is to run for as long as it takes for changes or stability to emerge [18]. When novelty bias wears off, the integration into routines and habits begin and will reveal stability. How long this takes depends on the cycles inherent in the object and context of the study.

Point Of Measurement: An HCI Perspective

Points of measurements receive much attention in related disciplines stating multiple points of measurements as a common definition. In HCI research, Kjeldskov et

al. [11] conducted a longitudinal study involving two usability tests on an electronic patient record system with an interval of one year between measurements. This enabled them to conclude that many usability problems endure, despite interacting with the system regularly in between measurements. They concluded that poor design did not disappear over time even with learning and increased familiarity. We saw such study design in five of our included papers, but Karapanos et al. (appendix reference [64]), emphasize a limitation to this design "… *one may not readily infer time effects as these might be random contextual variation, given that we have only two measurements*."

According to Karapanos et al. [9], longitudinal studies with more than two measurements points are "*the gold standard*" for measuring change. They do argue that it is increasingly laborious when generalizing over large populations of users and products. However, we argue that this "gold standard" of more than two points of measurements is something to pay attention to in longitudinal study design as underlining certainty of change and stability. Karapanos et al. [9] present retrospective evaluation as an alternative to longitudinal studies. The retrospective evaluation relies on the elicitation of user's experience from memory, but our study suggests that study design employ data logging to aid recall or to altogether replace recalling of events. In the event of relying on or supplementing with data logs, continuous measurements was often used. While retrospective or continuous data logging might obscure the distinct points of measurements, here lies possibilities for future research for a negotiation on how this will adapt.

Contribution Type And Research Questions

Besides this comprehensive analysis of CHI papers, we are only aware of one other similar analysis, although less extensive, that has been presented by [6] as part of a proposed taxonomy for research questions in longitudinal research in HCI. In the following, we will show how the main findings of our study relate to this taxonomy. The taxonomy encompasses two main branches: the research interest in average or cumulative data over time and the research interest in changes over time.

Average or cumulative over time is not considered "true" longitudinal research in several other disciplines. But Gerken argues that it is common practice in HCI research to call these longitudinal as they share the characteristic of having multiple points of measurements [6]. This does not mean that this type of contribution is not valuable or appropriate, however in terms of analysis it is comparable to a cross-sectional problem. Without proper framing of research questions and data gathering, you will not get the full benefit of the longitudinal design and can't conclude on change over time. Examples of these studies can be seen in some studies not concerned with change (appendix reference [70, 104, 106, 126, 132]).

Interest in change (over time) is additionally branched into two different contributions namely effect of change and process of change. The effect of change is concerned with the outcome of change or pre- and post-measurements, whereas process of change is concerned with the shape of a change process, what events occur and answering in-depth how and why questions. Interest in the effect of change, can be

seen in research questions regarding the outcome of change and for pre-post measurements. As an example of the first, Gerken et al. (Appendix reference [41]) were concerned with the performance of novel pointing techniques. They compared a laser-pointer to mouse pointing and were interested to see how long it takes participants to learn to use the laser-pointer. So while they applied multiple PoM they were actually focusing on the outcome of a learning process. In line with this are several of the studies concerned with plateauing in performance, where they are interested in learning, comparison or the 'crossover point'. For examples in pre-post measurements see (Appendix reference [8, 9, 19, 64, 119, 128]).

For interest in the process of change, we also recognize plateauing in performance papers as addressing the shape of change. One example are input device experiments which try to fit learning data to the power law of practice, which in itself is a description of the shape of change. Also, what we termed evolution papers are often concerned with the shape of change. An example can be seen in (Appendix reference [16]) as authors were interested in hierarchical communication patterns and strategies of these and how these strategic patterns change during a project lifecycle. According to Gerken's taxonomy, the interest in process of change can also be expressed as interest in occurrences of events or more specifically whether or when events occur. An example of a research question is: "*Whether and when do people adopt a specific new technology in their daily routine?*" [6]. Although not explicitly formulated as a research question, rather formed from inductive analysis, (Appendix reference [32]) saw how one community changed from using one technology to another during the study. However, they do not argue why this happened.

Meanwhile, we also recognize that studies not included in this review concern the shape of change over time (e.g. for field deployments of design artefacts). For example, Odom et al. designing intentionally for slowness (stating regular points of measurements) [14] [15] and Gaver et al. who present empirical understandings on how to overcome the often short-lived effects of most environmental HCI interventions [5]. Often these studies, while not explicitly longitudinal, concern introducing change in the form of new (to the user) technologies and reporting in what ways attitudes, behavior and practice changes.

Implications for Longitudinal HCI Research

Summarizing our overview of common characteristics and three points of consideration above, we will now outline three implications for longitudinal HCI studies, that we perceive as important to consider. These relate to studies that involves measuring longitudinal data on what happens to a set of participants during a series of time points as articulated and pointed out by Gerken [7].

Firstly, time duration should not be considered a singular attribute in longitudinal studies. Our analysis found that it is important for HCI researchers to consider duration not as a singular attribute, but in relation to points of measurements or even expected change rate. Therefore, just conducting a long-term study does not make the study longitudinal, and in fact, sometimes it is not even necessary to run for a

long period of time, if the observed variable changes quickly and can be measured with multiple points of measurements in a short duration.

Secondly, longitudinal data measures should be considered when conducting studies in the wild, or sometimes known as field or in-situ studies. Our analysis further showed that field studies sometimes already have the necessary duration to actually conduct longitudinal measures using multiple and systematic points of measurements to measure changes (or stability) over time. But our study also showed, that despite having the duration for longitudinal collection, many of them lack a systematic study design to express change over time for mainly qualitative approaches.

Thirdly, subject progression is important when conducting laboratory studies. While our analysis found that laboratory studies involving longitudinal aspects have rather different characteristics e.g. duration or session lengths, we observed that for several of these studies, it was important to track subject progression throughout the study, for example when subjects go from being novices to experts (e.g. when learning a new interaction technique or a new type of interface or prototype). This relates closely to plateauing and evolution in longitudinal studies, and involves selecting and defining meaningful measure metrics and variables. Thus, researchers should be careful when designing such studies and decide how progression can be determined.

Conclusion

We have conducted an analysis of 106 publications at the CHI conferences published in the period 1982 to 2019 in which longitudinal studies are reported. Our motivation for this study was the lack of empirical understanding on how previous HCI studies have conducted longitudinal studies and we hope that such an understanding can bring forward discussions of longitudinal HCI, with the ultimate aim to reach common consensus and a shared definition. Our findings illustrated that HCI longitudinal studies are highly diverse in terms of duration lasting from studies conducted over a few days to studies conducted over several years. In our findings we explained two longitudinal trends, namely plateauing in performance and evolution studies. These do not cover the entire pool of included papers, but they do describe important characteristics of several longitudinal HCI studies.

Studies considered in our analysis integrate different metrics, and we found that the paper contribution type highly influences the longitudinal study design. We further found that more than half of the papers discuss or illustrate change or stability during their studies. We analyzed previous longitudinal research published on CHI for researchers wishing to conduct longitudinal studies to take inspiration and advice, as well as learn from past challenges and successes.

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