Twenty Years of Creativity Research in Human-Computer Interaction: Current State and Future Directions

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ABSTRACT
Creativity has been a growing topic in the ACM community since the 1990s; however, no clear overview of this trend has been offered. We present a thorough *survey* of 998 creativity-related publications in the ACM Digital Library collected using keyword search to determine prevailing *approaches*, *topics*, and *characteristics* of *creativity-oriented Human-Computer Interaction (HCI) research*. A selected sample based on yearly citations yielded 221 publications, which were analyzed using constant comparison analysis. We found that *HCI* is almost exclusively responsible for creativity-oriented publications; they focus on *collaborative creativity* rather than individual creativity; there is a general *lack of definition* of the term 'creativity'; *empirically* based contributions are prevalent; and many publications focus on *new tools*, often developed by researchers. On this basis, we present three implications for future creativity-oriented HCI research: develop and employ *clearer definitions* of creativity; go *beyond in-vitro studies* of novel tools; and move toward *interdisciplinary research collaborations.*

Author Keywords
Creativity; creativity support tools; literature review; HCI.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION
While Human-Computer Interaction (HCI) has traditionally focused on enhancing the power of computation, usability, and productivity, the community has also been a driving force in making available and expanding computing into more diverse spheres of human activity. Among these novel spheres is *creativity*, leading Shneiderman [193] to state that the development of *creativity support tools* (CSTs) is one of the grand challenges of HCI. This is reflected in the growing body of work exploring creativity-oriented aspects of HCI over the past couple of decades. The topic of creativity is elusive and multifaceted [66], and while it is clear that HCI researchers have approached the topic in dissimilar ways, no systematic overview of their approaches has yet been given. The diversity of approaches and foci in creativity-oriented HCI research may be seen as a positive, since it offers many perspectives on how computing may be leveraged in creative activities. Still, without a structured overview of the key concerns, concepts, and approaches at work, this diversity also renders the field opaque, and it makes it challenging for academics to engage in fruitful discussions and compare findings across studies. This challenge is the main motivation behind this study, which presents an extensive survey of 998 creativity-oriented publications within the ACM community, as well as an in-depth analysis of a systematically selected sample of 221 publications. The study has been guided by the research question: *What are the prevailing approaches, topics and characteristics of creativity-oriented HCI research?* The result is a bird's-eye view of a subfield of HCI undergoing tremendous development.

The intended audience for this article is HCI researchers and practitioners working on distinctly creativity-oriented aspects of HCI, such as creativity support tools, which, as our study shows, comprise a large and growing part of the CHI community. To aid our colleagues in future endeavors in this field, we include the comprehensive dataset on which this survey and analysis is built as a resource for researchers who might wish to further examine the main trends and developments in the field over the past 20 years.

After briefly presenting creativity research as a specific research field, including its relation to HCI, we outline our reviewing methodology in detail. We explain how, through constant comparison analysis, we arrived at three overarching categories with a total of 18 subcategories that characterize the sample of the 221 publications. Next, we offer general findings from analysis of the initial 998 publications. This conveys a guiding overview of the creativity landscape in HCI over the past two decades. We then offer an in-depth exposition of how, and to what extent, the 221 publications sample reveals the specific trends emerging from the preliminary constant comparison analysis. On this basis, we discuss implications for future research on the topic of creativity within HCI. Our study

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portrays an *emerging wave* of creativity research in HCI that began in the early 1990s and is marked by a focus on *collaborative work*, development of *digital creativity support tools*, and a main grounding in *empirical research approaches*. For each trend, we highlight central issues and examples. Our work is informed by the broad definition of creativity: "creativity is the interaction among *aptitude, process, and environment* by which an individual or group produces a *perceptible product* that is both *novel and useful* as defined within a *social context*" [165, p.90, orig., emphasis].

A note on references: Because we review a large number of research contributions, the list of references is extensive. On the last page, we include the 221 references comprising the sample from the total survey, since we make reference to these specific publications. References to the entire list of 998 publications from the complete survey are included in the auxiliary dataset.

BACKGROUND: CREATIVITY RESEARCH AND CREATIVITY SUPPORT TOOLS IN HCI

On September 5, 1950, J.P. Guilford gave a very influential presidential address in APA (the American Psychological Association) in which he called upon his peers to consider creativity a critical challenge to psychology. This address gave rise to what has come to be seen as the *first wave* of creativity research [182]. This first wave was almost exclusively comprised of work from psychology in which the *individual*'s creative abilities were in focus, including (in-vitro) tests of divergent thinking. In the 1980s, Amabile and others argued that cultural perspectives were lacking in this approach, and in the 1990s, a *second wave* of creativity research arose, focusing on *collaboration* in creativity and the underlying cognitive processes [182]. As Sawyer and DeZutter [183] put it, the second wave: "shows how creativity is embedded in social groups, and how creative products emerge from collaborative networks" (p.81). This new focus sparked a strong interest in real-world (in-vivo) studies and created massive momentum in the field. Although psychology still accounted for the vast majority of contributions at this time (of which many came out in the leading *Creativity Research Journal* established in 1988), management, design, philosophy, and aesthetics research were now increasingly interested in creativity research.

Although the rapid expansion of creativity research since the 1990s has been very beneficial to the (interdisciplinary) research community, it has also led to an inadvertent situation where there are now: "few, if any, 'big questions' being pursued by a critical mass of creativity researchers" due to: "a growing fragmentation of the field" [88, p.571]. This flipside has motivated prominent creativity researchers to stress that psychology should: "open the doors to [...] other disciplines' approaches to creativity" [181, p.17] in order to promote new, potentially unifying, interdisciplinary perspectives and ensure relevance for parties from public and private domains. This openness to other disciplines can be seen as a positive, insofar as: "creativity is precisely the kind of problem which eludes explanation within one discipline" [66, p.22]. This view, however, also entails a severe problem: Creativity is arguably so multifaceted that it cannot be fully captured using a single approach within one discipline. Rather, it can—and arguably should be—studied in several disciplines using different approaches.

One research discipline that has directed much attention to improving insight into modern creativity research's second wave interest in how collaborative creativity unfolds, and how creative activities may best be supported, is HCI. This is a recurring theme in conferences such as *CHI*, *DIS*, and *Creativity & Cognition*. In 2003, Candy and Hori [25] summed up the inaugural ACM Creativity & Cognition conference, stressing the importance of studying *creativity support tools* to help improve: "collective creativity and collaborative learning in problem-seeking environments" [25, p.53] in order to leverage insights: "for the benefit of all people in any domain" (p.54). Shneiderman [193] called this: "a grand challenge for HCI researchers" (p.1). Reporting from a U.S. National Science Foundation workshop in 2006, he and other researchers concluded that: "creativity support tools is a research topic with high risk but potentially very high payoff. The goal is to develop improved software and user interfaces that empower users to be not only more productive but also more innovative" [194, p.62]. This HCI research agenda would mark a move from functional and productivity-oriented application domains toward: "the more risky frontier of creativity support tools" [192, p.22]. The risks, Shneiderman argued, stem from a vague understanding of the creative work domain as compared to the more well-defined domains that HCI had previously addressed: "The risks are high, but so are the payoffs for innovative developers, ambitious product managers, and bold researchers" (ibid.).

Lack of conceptual transparency is arguably to be expected in a nascent field of study, but it can be problematic, since it makes it hard for researchers to establish a shared discourse and compare findings and insights across multiple studies and cases. One of the motivations for our survey has thus been to examine if this lack of conceptual clarity persists. The 2006 NHS workshop outlined the main contemporary research challenges and opportunities, but since then there has not been any systematic overview of creativity-oriented research in HCI, even though interest in the field has clearly continued to grow. This has further motivated the survey.

METHOD

The following sections clarify the process by which we conducted the survey. Acknowledging that even the most rigorous approaches do not exclude prior knowledge of the researcher, which eventually constitutes latent beliefs or biases [162], our goal has been to conduct a transparent, defensible, and systematic process across all steps, so that peers may inspect, evaluate, and build upon the findings. The collection, sampling, and analysis of publications were

performed in three sequential steps comparable to those presented by [162], who provide seven steps to a comprehensive literature review. Additionally, we sought to portray the process in line with the well-known PRISMA statements and flow charts [152], which were developed in 1999 to address suboptimal reporting of meta-analyses of randomized controlled trials.

Step 1: Collecting Relevant Publications

The ACM Digital Library (ACM DL) was chosen as the source for all publications included in this study. The digital library is the most comprehensive database of computing and information technology literature. The terms used to query the ACM DL was *'creativity'* and *'creativity support tool.'* The term 'creativity' alone yields more than 4,400 results, and an initial inspection revealed that the sole occurrence of the word would be too broad of a sampling. To ensure that creativity was a somewhat central concern in the publication, the term also had to be present in the author keyword field, either in form of *'creative'* or *'creativity.'*

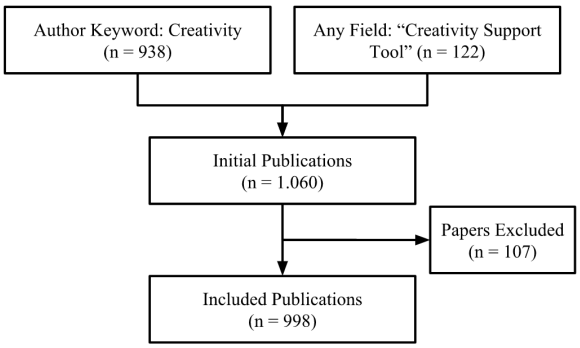

Figure 1. Collecting relevant publications.

The term '*creativity support tool'* covers a distinct research topic emerging in the late 1990s and early '00s, and covers software tools designed specifically with the intention of enhancing creative potential or output [8,56]. The initial pool of publications (n=1,060) was cleared of duplicates, and a total of 998 publications were eventually included.

Step 2: Sampling Publications

To ensure that the most relevant papers were included in the inspection of creativity research in the ACM DL, a further trimming was conducted. We started from the premise that numbers of citations were a reasonable representation of how engaged peers are with a publication. Furthermore, we acknowledge that a publication necessarily has a certain incubation period before peers can be expected to engage with it. Therefore, we excluded all papers published in 2017 and 2016, since they had only been publicly available for fewer than 1.5 to 2.5 years at the time of this study (spring 2017). The cut-off point was set to be the average citations per year (0.669) for the works published from 2015 and earlier. The total sample for further inspection ended up consisting of 221 unique publications.

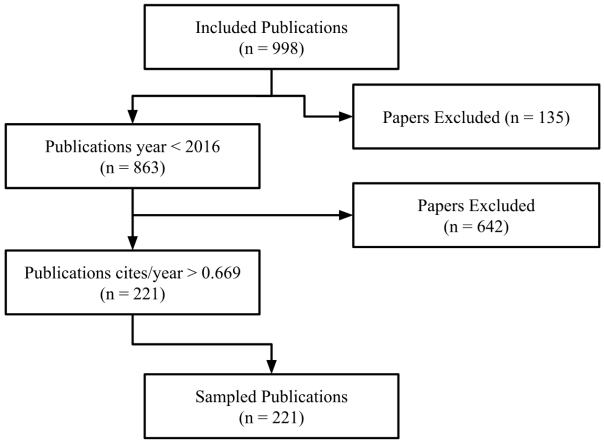

Figure 2. Sampling publications.

Step 3: Reviewing Publications

Our review of the selected publications was conducted through *constant comparison analysis* through which 18 subcategories were developed and collected under three categories. As discussed by Onwuegbuzie and Frels [162], constant comparison analysis can be used to analyze documents following the general three steps of grouping data into codes, organizing codes into categories, which are then followed by integration and refinement. All 221 publications were manually read, analyzed, and categorized by the first author following this particular sequence: 1) A complete read-through of the sample (n=221), focusing on the subsets of introduction, method, and conclusion (or similar terms); 2) Information divided into codes with a descriptive label; and 3) A systematic reading, analysis, and categorization of each individual publication in the sample with regard to existing codes. This sequence is in line with the one prescribed by Onwuegbuzie and Frels [162]. We excluded 13 publications during the reviewing process (e.g., papers describing an algebraic function named 'creative telescoping,' doctoral consortium, or workshop proposals). Thus, 208 publications were categorized. We controlled for interrater reliability by having a research assistant similarly categorize a small, random subsample of 12 publications. Cohen's Kappa for the different categories varied between fair (0.31) to moderate (0.49) with 58% to 75% observed agreement. While such levels of Cohen's Kappa might not fit a domain such as health care [85], the agreement and the ability to replicate each single categorization based on the final table is deemed reassuring. The three categories and their distinct 18 subcategories are as follows.

Subject focus

This first category involves distinguishing between what character of the creative subject in focus. This means determining if it is *individual creativity* like a single person working alone, a *mix between single and collaborative* activities, or an entirely *collaborative creativity* or activity. Furthermore, the category of *machine creativity* includes cases of artificial intelligence and creativity.

Research approach

This category considers the approach and nature of the publication with regard to whether it is *empirical* or *non-empirical*. The first implies any use of data in its broadest sense—from case studies to extensive statistical studies and yearlong ethnographic work. On the contrary, the latter contained no data and is often marked by a theoretical, conceptual, or technical contribution. We further examine whether the empirical work is *in vivo*, i.e., a non-artificially, staged context, task or scenario, *in vitro*, simply implying the opposite case, and, finally, a *mix between in vivo and in vitro*, requiring both types of empirical work. Additionally, we consider if the publications concern an *existing tool*, which is any commercially available tool, a *new tool*, which is proposal of a newly constructed tool by the researchers or collaborators, and, finally, a *mix between an existing and a new tool*, where focus is on studying both existing tools, but also proposing new ones.

Creativity frame

This third category contains two central questions of which the four subcategories are comprised. This targets whether *creativity is defined*, or if *creativity is undefined*, which thus requires any explicit or implicit definition of the concept of creativity by the authors anywhere in the publication. Also, this category addresses whether the *domain is specific*, or if the *domain is generic* in terms of the application domain of the research presented, e.g., creativity for everyday activities, or creativity for composing music for movies.

RESULTS

The following sections provide a set of perspectives on the landscape of creativity research in the ACM DL. Preliminary results are derived from analysis of the total collection of publications (n=998), while final results are derived from the review and analysis of the sampled publications (n=221). The preliminary results thus indicate overarching trends in creativity-oriented HCI research, whereas the final results offer in-depth findings regarding research foci and research approaches.

Findings from the Total Collection of Papers (n=998)

Creativity is on the rise in the ACM DL. The number of publications with creativity as author keyword has grown since the early 1990s alongside the general increase in publications. Not only has the total number of creativity-related publications increased, the share of them has also gone up from 0.03% in the 1990s to 0.19% in the 2000s and 0.33% in 2010s. While this percentage might seem small on the backdrop of all publications in the ACM DL, the numbers indicate that creativity is nonetheless becoming a more central topic of publications in the ACM DL.

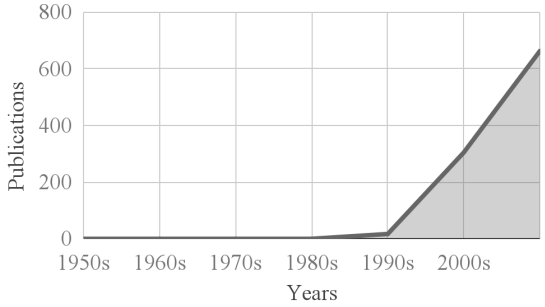

Figure 3. Publications per year in all of ACM DL with author keyword: creativity.

Findings from the Analysis of Sampled Papers (n=208).

As mentioned, 13 publications were not categorized due to lack of relevance, and thus a total of 208 publications were categorized in terms of three overarching categories and 19 subcategories, as described in the *Method* section. For the sake of clarity, and in order to offer a detailed account and discussion of main findings, we have chosen to focus on a portion of the trends and patterns revealed in our analysis. The complete analysis is available in figure 4 on the last page. In order to enable peers to further investigate the data and examine, challenge, and/or expand upon our findings, we have attached the entire dataset to this paper. We hope this might ease the entry into studying the field of creativity within HCI, and we encourage interested peers to dive into the data, either with the final table of this paper or the auxiliary materials.

Creativity frame

Defining creativity is not straightforward. We found that when the HCI community engages with the topic of creativity, surprisingly few (28.37%) contributions directly define or clarify the concept of creativity. As shown in Table 2, the tendency seems to be going from relatively more publications defining creativity to fewer. Less than one quarter (22.31%) of the papers in recent years offer direct definitions or clarifications of the term 'creativity.' This decrease might be a natural result of the field of HCI becoming more confident in designing for and assessing creativity with the term becoming more commonplace at conferences and in journals. As we discuss in the following section, domain specificity has generally been an important topic in creativity research. In general, we found the domain of creativity research in HCI to be almost equally distributed between being specific (57.69%) or being generic (42.31%).

When looking at examples of the different represented categories we found that some of the publications not defining creativity might be considered in the periphery of creativity research within HCI. For example, [78] identified game-jam properties and derived a set of guidelines for designing and facilitating game jams as a ludic craft.

Creativity Frame	**1996-2000** (n=3)	**2001-2005** (n=16)	**2006-2010** (n=68)	**2011-2015** (n=121)	**Total** (n=208)
Defined	66.67%	37.50%	35.29%	22.31%	28.37%
Undefined	33.33%	62.50%	64.71%	77.69%	71.63%
Specific Domain	0.00%	31.25%	63.24%	59.50%	57.69%
Generic Domain	100.00%	68.75%	36.76%	40.50%	42.31%

Table 2. Five-year intervals of the distribution of subcategories in the category of Creativity Frame.

Although the word 'creative' occurs 11 times in the main text, the following noun would often had been sufficient, and thus the topic of creativity seems to be more of an additional attribute to the research. On the contrary, work by Coughlan and Johnson [42] clearly introduced a definition of creativity in their studies on understanding creative interactions between people and artifacts. They incorporated prior theory on design and creativity into a set of perspectives, which were then informed by multiple empirical studies on the different perspectives [42]. The focus is explicitly on the subject of creativity and the creative process, and studies of what could be considered specific domains are incorporated into domain general understandings of creative interactions. When considering generic against specific domains, our findings indicate that niches within creativity-oriented research in HCI where manifold. We found specific domains such as film-making [1,46,64,80], food-making [96,164], music [16,23,34,40,44] or 3D [32,205,230] present in creativity-oriented research within HCI.

Subject focus

We found a tendency for creativity research in HCI to be mostly directed at the *collaborative* aspects (33.65%) when focus is specified. In almost equal amounts (34.13%), the four subcategories were *not applicable* to the reviewed publications, as they did not specify whether they addressed individual creativity, collaborative creativity or a mix between the two. An *individual* subject focus is also relatively prevalent (20.19%) in the sample. The *mix* between individual and collaborative creativity only made up a small part of the samples (7.21%), but still provided a distinct category. Finally, the category '*machine creativity'* is the least represented one with only 5.77% focusing on this topic.

The sample contains multiple examples of creativity research with a clear focus on collaborative creativity. For example, Luther et al. [137] studied the concepts of distributed leadership and distributed cognition—the latter being a core topic in classic creativity research as proposed by e.g. Sawyer [182]—within online creative collaborations on animation projects. The collaborative aspect in this case is evident from explicit accounts and from the analytical perspectives and study context. Another example of research focusing on collaborative creativity is the work by Hornecker [92] on using card exercises to structure idea generations during brainstorms. The focus on collaboration is arguably more subtle compared to e.g. Luther et al. [137], yet the descriptions of the studies included in the publications reveal a focus on the collaborative aspect. There are, however, also multiple examples of research without a distinct subject focus. Yoon et al. [226] presented research on a robotics kit for enabling kids to construct and animate toys. Their study was explicitly meant to encourage creativity, but provided no explicit account, nor any methodological focus indicating whether it implies e.g. a focus on individual or collaborative creativity. Still, an explicit account is not always necessary for determining subject focus. For example, Kim et al. [110] presented a video tool for supporting novice creativity through expert patterns, which we categorized as 'individual' due to both implicit accounts and the evaluation methodology. More precisely, they concluded by proposing new work on groups: "It would be interesting to see if patterns could play a role in facilitating joint meaning-making through story with groups of people" [110, p.1219], as well as a sole evaluation with individual participants [110]. Finally, work by Davis et al. [45] on a co-creative computer agent for a drawing interface is an example of the distinctive category of machine creativity.

Subject Focus	**1996-2000** (n=3)	**2001-2005** (n=16)	**2006-2010** (n=68)	**2011-2015** (n=121)	**Total** (n=208)
Individual	0.00%	25.00%	16.18%	22.31%	20.19%
Mix	33.33%	25.00%	5.88%	4.96%	7.21%
Collaborative	66.67%	43.75%	36.76%	29.75%	33.65%
Machine	0.00%	0.00%	10.29%	4.77%	5.77%
Not Applicable	0.00%	6.25%	30.88%	38.84%	33.17%

Table 3. Five-year intervals of the distribution of subcategories in the category of Subject Focus.

Research approach

Creativity-oriented research within HCI is mostly empirical (73.08%) and usually focuses on a tool (65.87%). We observed a clear increase in the number of publications based on empirical studies in relation to publications without empirical studies over the years. The empirical studies were mainly (55.92%) in vitro with a smaller part (38.82%) being in vivo. Only very few (5.26%) used a mixed initiative with both in-vitro and in-vivo approaches. The strong focus on tools in HCI might not be surprising, but when looking at the types of tools being studied, we found that the majority (62.59%) of them were new tools being proposed, whereas only a minor part (30.94%) made up studies of existing tools or a mix between studying existing and proposing new ones (6.47%). Also, when new tools are proposed, they are primarily studied using in-vitro studies (64.37%), whereas existing tools are studied almost equally much (67.44%) in vivo. In general, empirically based studies come in many different shapes and sizes.

For example, in-vitro methods came in the form of Davis et al. [46], who set up experiments to study how creativity for Machinima novices could be supported by recruiting initially seven participants to an exploratory study and further 20 participants in a Wizard of Oz study. Contrary to this, in-vivo studies like Kim et al. [109] refrain from using artificially constructed situations for their study: "Because we wanted users to behave as naturally as possible, we framed our study around a real competition so that users would focus on writing a good story rather than on the system itself" (p.749). The in-vivo category was not just about testing new tools in real context, but also about studying existing practice to inform new tools. Examples of such include Singh et al. [198] and the vintage publication I-Lands by Streitz et al. [200], which is an early account of creativity research within HCI. Singh et al. studied a dance production process over long periods and appropriated the insights to develop a collaborative web-based video application [198]. In the study by Streitz et al. [200], the authors studied the special workgroups of creative teams in five different companies to inform the development of their interactive environment and creativity support applications. As mentioned, there is also a small body of research using a mix of in vivo and in vitro, such as Myers et al. [156], who initially interviewed Photoshop users about current practice and then evaluated a developed tool with users in an experimental setting.

Even though empirical work accounts for a large proportion of the research, the research also contains rich theoretical or technical contributions such as the conceptual framework on social creativity by Fischer [60] or a collaborative sketching tool for group creativity by Geyer et al. [73]. As pointed out earlier in this section, tools are relatively central in creativity research within HCI, and examples of tools have been mentioned. Nevertheless, the more uncommon category of no tool is also present, i.e., Kuo and Gerber [119] who presented and related design principles to crowdfunding and creativity, or Nisi et al. [159] who explored digital art for promoting sustainability awareness. Contrary to not having a new tool focus, a small collection of publications address both existing tools and propose new tools. In this mix between new and existing tools, Karlesky and Isbister [102] examined current doodling and fidgeting tools before developing and proposing their *Fidget Widget* solution.

Research Approach	**1996-2000** (n=3)	**2001-2005** (n=16)	**2006-2010** (n=68)	**2011-2015** (n=121)	**Total** (n=208)
Non-Empirical	66.67%	62.50%	25.00%	21.49%	26.45%
Empirical	33.33%	37.50%	75.00%	78.51%	73.56%
In Vivo	100.00%	33.33%	41.18%	37.23%	38.82%
Mix	0.00%	16.67%	7.84%	3.19%	5.26%
In Vitro	0.00%	50.00%	50.98%	59.57%	55.92%
No Tool	33.33%	62.50%	30.88%	30.58%	33.17%
Tool	66.67%	37.50%	69.12%	69.42%	66.83%
Existing Tool	0.00%	33.33%	25.53%	34.52%	31.39%
Mix	0.00%	16.67%	6.38%	5.95%	6.57%
New Tool	100.00%	50.00%	68.09%	59.52%	62.04%

Table 4. Five-year-intervals of the distribution of subcategories in the category of Creativity Frame.

DISCUSSION

Our survey indicates a number of clear trends in the past twenty years of creativity research within HCI. There are evident patterns in the research foci and approaches in these contributions, which we now discuss. For the sake of clarity, we structure the discussion around the survey's three categories: creativity frame, subject focus, and research approach. We also consider potentials and limitations of our method and the implications of our findings for future work.

Creativity Frame: The Concept of Creativity Is often Vaguely Defined—If at All

While the interest in exploring creativity-oriented facets of HCI has increased steadily over the past 20 years, this has not yielded joint definitions of creativity or aspects thereof in the ACM community. We find this problematic, since it renders it difficult to compare findings and results across cases and establish joint discussions. As said, the problem of defining creativity clearly in research reaches beyond the ACM community. Indeed, Runco and Jaeger [178] argued that: "[n]o topic is more central to research on creativity" (p.92) than definitions of creativity. Our survey suggests that this is an issue for HCI researchers as well. The concept of creativity is *often vaguely defined*—if at all—in the publications reviewed. Creativity research in HCI has echoed this problem: "Creativity is a complex phenomenon with varying definitions, depending on the context in which it is discussed" [15, p.419], "[i]t is difficult to precisely define creativity" [82, p.146], and "the effectiveness of these CSTs in supporting people in creative tasks is often difficult to evaluate since creativity is not easily defined nor fully understood" [28, p.127].

The word 'define' does not need to be present in the publications for us to have categorized a publication as offering a definition of creativity, but some more or less explicit understanding of the term 'creativity' must be present. An example of a paper that was a *borderline case* in our survey is [150], which provides an expansion of the notion of *everyday creativity* and thereby indirectly defines creativity by continuously specifying details such as: "Our approach builds on the assumption that creativity is at the heart of the dynamic changes of people's everyday experiences and actions" [160, p.33]. An example of a publication in the *undefined* category is [95], which presents a tool for promoting creative musical experiences in children. Despite having 'creativity' as a keyword and mentioning creative activity, creativity, and creative musical experiences, the paper provides no explicit nor implicit definition of these terms. Similarly, [131] presents a tool for creating customized circuit boards with dense circuit layout without chemicals with 'creativity support tool' as a keyword. In the paper, terms such as creative innovation, personal creativity, creative freedom, and creative manipulations are used in describing the tool and the problem addressed without defining the terms 'creative' or 'creativity'. We wish to emphasize that we do not pass judgment on the scientific quality of these two examples, nor of other contributions in our survey. They are only mentioned here as examples of the general trend that much HCI research gives no definition of creativity although the authors clearly identify their work as creativity-focused.

A related issue is whether the contributions address creativity in a broad sense—in our survey labeled *Generic Domain*—or aspects pertaining to a particular domain, here labeled *Specific Domain.* In the light of the historical debate on this topic in creativity research [166], a considerable number of publications in HCI-related fields deal with the domain of design. Consequently, we chose *design* as a cut-off point for what is considered a general domain. This implies that design is a general activity oriented toward changing the current regardless of domain, whereas design and fabrication of electronic circuits [131] or film-making [1,46] is specific. To further explain this, [220] on creativity support for novice portrait sketching is thus considered specific, whereas [51] on prototyping dynamics in design is conversely regarded as generic.

Subject Focus: Studies of Collaborative Creativity Support Tools Dominate the Field

Creativity research is often described as being comprised of *two waves*. The first wave prioritizing personality traits and internal cognitive processes corresponds to the *individual* subject focus in our survey. Similarly, the second wave focuses on groups in contexts, including sociocultural understandings from an interdisciplinary perspective [182]. This corresponds to the *collaborative* subject focus in our survey. Viewing creativity as a fundamental cognitive process exposes it to computational modeling, which means that the notion of some variant of AI-enabled (Artificial Intelligence) creativity comes into play. While it might be possible to break down creativity into distinct components that are then described computationally to be interpreted by a machine, not all components are as easily transformed [19]. AI or machine creativity is already a reality on some levels, although the question of whether we have seen a 'true' creative machine is contested. This hinges on the aforementioned lack of joint definitions in HCI: With no shared definition(s) of creativity, it is very difficult to meaningfully discuss if, when, and how AI-enabled machines can be creative. Works in this field are labeled as *machine* subject focus.

While the categories of individual and collaborative can be hard to distinguish, a *mix* subject focus is further introduced in our categorization of research that addresses both aspects. In practice, it is not always explicit which category a contribution addresses, like [102] on physical margins or [87] on an application for bodily manipulations of music, although this categorization can often be deduced from the experimental design or final conclusions. In other cases such as [137], an explicit account is given. Moreover, some of the sampled contributions, e.g., [212] on everyday design or [55] on remixers for understanding fair use, did not lend

themselves to categorization in this way. To capture such instances, we implemented the *Not Applicable* category in order to avoid labeling them within an ill-fitting category.

Research Approach: Empirical Approaches Focusing on New Tools are Prevalent

Several previous HCI survey articles have examined the types of methods and empirical approaches that have been applied in different areas of HCI. For instance, [12,112,113] examined empirical investigations and methods within User Experience and Mobile HCI. In contrast to these papers that focus on analyzing and categorizing empirical research, we included the parent category of being either *empirical* or *non-empirical* in our study, since a number of contributions in our survey have no clear empirical components. Instead, they may seek to provide an overview of current states and trends in personal fabrication [154], present a novel tool for computational creativity in recipes [164], or a theoretical and conceptual discussion of serendipity [4]. Our delimitation of empirical research approaches comprises publications that clearly reported either qualitative or quantitative studies, including single case-studies. This broad understanding of 'empirical' mirrors the one in the above-mentioned studies [12,112,113]. To provide more in-depth understanding of the research approaches employed, we applied the terms *in vivo* and *in vitro* from the natural sciences. The terms refer to how a given phenomenon can be studied either in isolation (in vitro, i.e., in the glass) or in live conditions (i.e., in vivo) with less control over variables and context. The categories are relatable to the typical design research terminology of *lab* or *field* [116]. The lab approach implies isolating variables, which often involves decontextualization or the intentional manipulation of the subject of study. In this sense, we emphasize that we do not consider 'in vitro' to denote literal test-tube experiments or sterile laboratories, but rather an artificially established setting or context, including researchers actively prompting participants for specific activities or tool-usages.

We distinguish between whether the contributions reviewed examine a *tool* or *no tool*. At first glance, the distinction between tool and no tool may seem rather odd considering the context of HCI. The tool—or perhaps the computer-part of Human-Computer Interaction—obviously plays a central role, and we do not contest that: "Human activity is always mediated by language, traditional tools, or the like" [20, p.178]. However, informed by work-domain studies, which are popular in CSCW and in which coordination may be a central subject of focus [184], we noted a substantial portion of publications with less focus on technology and a greater focus on the work or human behavior loosely surrounding it. Examples could be remixers' understandings of fair use online [56] or a framework for social constructions of user-generated and collaborative content [146] that despite being based on Post-it® note art does not explicitly explore the tool at hand. Building new tools and constructing working prototypes is a core activity in much HCI research. The *UIST* conference is a clear exponent of this focus. However, studying different existing tools, i.e., Google Docs in design collaborations [100] or 3D-modeling and CNC milling in professional furniture craft [33], also contains an obvious theme. Consequently, we reviewed whether the publications that did explore tools dealt with *new tool*, meaning recently developed by researchers (often the paper's authors themselves) and not commercially available, or *existing tool*, i.e., broadly available tools, potentially in use in a context before being analyzed in the given research paper.

Implications for Creativity-Oriented HCI Research

The work presented here offers an overview of key trends and themes in creativity-oriented HCI research, which has thus far been lacking. We see it as a necessary platform for discussing and positioning future contributions and initiatives in creativity-oriented HCI research. On the basis of the trends we have identified, we see some strengths in the current prevailing approaches that we can fortify and build upon, but also a range of issues and shortcomings that we as a community could and should address.

Current strengths

First, it is clear from our review that creativity-related HCI research acknowledges the *collaborative nature of creativity* in the sense that this is the most prevalent subject focus. This aligns well with the second wave of psychology-based creativity research, as outlined in the *Background* section, which focused more on creativity as a collaborative endeavor than on the underlying cognitive processes. Second, there seems to be a *good balance between domain-specificity and generality*. This indicates that we can expect future research to offer insights into broad understandings of creative use of IT, and into particularities of certain types of creative practices and use situations. Third, the focus on *the role and nature of tools* in creative endeavors is a clear and welcome one. Focusing on the role of the tool may seem self-evident to HCI researchers and practitioners, but this perspective is not given in other strands of research. From the perspective of psychology, understanding creativity and the creative process generally appears to focus almost exclusively on the human mind [182]. As evident from the distribution of tool/no tool in the research approaches taken by HCI researchers, this is definitely not the case here. We hope that future efforts toward understanding the interplay between humans and computers in creative endeavors will maintain these characteristics.

Current shortcomings and future opportunities for creativity-oriented HCI research

The survey also indicates opportunities for developing and strengthening creativity-oriented HCI research. For the sake of clarity, we focus here on what we deem to be three of the most promising improvements with regard to balancing effort and potential benefit.

First, as indicated by the survey, *many contributions to creativity-related HCI research are in our view strikingly*

lacking in terms of defining and explaining what 'creativity' means, and how it is studied. This fundamental lack of conceptual transparency in terms of how 'creativity' is construed is highly problematic, since it renders it difficult to compare findings and results across cases and thereby establish joint discussions. The challenge of defining creativity, however, stretches beyond the interest that the ACM community has taken in the topic in the past two decades. It is a major challenge in the creativity research community itself [178]. In terms of offering an adequate definition of creativity, attempts have been made to resolve a long-standing debate between whether creativity should be seen as domain-general or domain-specific. To help bridge this dichotomy, Plucker and Zabelina [166] advocated a both-and understanding based on the idea that this domain distinction does not really matter. We do not tout the streamlining of creativity research with regard to developing a once-and-for-all consensual definition of creativity. However, explicitly stating how a central and often multifaceted term is understood is key in comparing findings across studies and establishing common grounds for dialogue. As mentioned, this issue also stretches beyond HCI, and so we recommend looking to the well-established tradition of psychology-based creativity research to *ground and inform HCI researchers' definition and delimitation of creativity*.

Second, our findings reveal that *many contributions study new tools, often developed by the researchers themselves, in controlled experiments.* In contrast, the field generally lacks studies of how digital tools actually influence creativity in practice. Interestingly, the aforementioned NSF report from 2006 [194], which was authored by a string of prominent researchers midway in the current rise of creativity in HCI, pointed out similar aim. Still, our review here shows that studies of digital tools in real-life creative practices are still few and far in between. As a community, *we could and should shift our efforts to studying in-vivo use of creativity support tools*, not just the ones we build ourselves, but the ones that most creative practitioners employ in practice.

Third, we encourage *further interdisciplinarity* as a possible remedy to some of the shortcomings presented. If not, we risk missing insights from studies in related fields and/or spend time reinventing the wheel, and we might limit the transfer of knowledge to a wider audience. One approach could be *trilateral interdisciplinary collaborations* between a) creativity-related HCI research, b) psychology-based creativity research, and c) the specific domain addressed in the specific project, i.e., music, movie-making, or game-development. The categorization offered in our survey may help researchers better position future contributions and compare and discuss across cases and domains. For example, we might employ the categorization to *position* a future contribution as exploring a single clearly defined aspect of creativity in a specific domain, in which a new tool is explored in an in-vivo study.

Limitations of the Survey

Our survey represents a first attempt at mapping creativity-oriented research in HCI. We find the selected approach successful to the extent that it has identified clear trends and focal points. Our ambition is that it can be of help to both seasoned researchers, who can dive into the dataset (fig. 4) to examine particular areas of concern, and students or newcomers to the field of creativity-oriented HCI. However, it is worth considering the limitations of our approach to reflect on potential shortcomings and indicate avenues for future research. First and foremost, we have only surveyed ACM DL contributions. Extending our search to other databases might potentially show different patterns. Likewise, we could have extended beyond the keyword search for *'creativity'* and *'creativity support tool.'* As we have argued in the methodology section, the term 'creativity' alone yielded a much greater number of publications; however, an initial inspection revealed that this would result in the inclusion of a great number of papers beyond our intended scope. Similarly, our subsequent selection of 221 publications for in-depth analysis could have had different criteria, although we consider the criteria well-founded. Since the survey resulted in an extensive sample size, quantitatively exceeding many other literature surveys, we consider it adequate for the purpose of identifying overarching trends and themes. To some extent, the in-depth categorization rests on the judgment of the reviewers; yet the interrater reliability indicates that the categories are reasonable. Finally, coding through constant comparison analysis also rests on the judgment of the reviewers. For the sake of transparency, we included hte entire dataset, so that others may examine and contest these codes and look for different trends.

CONCLUSION

Creativity-oriented research in HCI took off around 1990 and has expanded rapidly since. In the ACM community, it has mainly been advanced by the field of HCI. While this has led to the exploration of a diversity of topics and perspectives, we have yet to see a consensus on definitions of core concepts. In the surveyed publications, the term 'creativity' is seldom defined, and the subject focus is often on aspects related to collaborative creativity when specified. The research approaches are characterized by a strong emphasis on empirical work, often with a new tool in focus. On the basis of the survey, we propose three ways to advance the study of creativity-oriented research in HCI: develop and employ *clearer definitions* of creativity; go *beyond in-vitro studies* of novel tools; move toward *interdisciplinary research collaborations*. We hope the work presented here spurs further discussions on the topics and approaches that we adopt and advocate for future studies in the growing field of creativity-oriented HCI.

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	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Creativity defined	[58]	[190]	[63,71]		[59]	[52,60,216]	[41]	[50,53,84,90,98,106,169,170,172,192]	[107,114,118]	[4,6,28,40,42]	[5,17,32,92,139]	[7,30,38,127,138]	[29,72,119,185,207]	[43,46,82]	[15,18,31,35,108,128,150,151,157,164,231]	[160,168,204]
Creativity Undefined	[200]		[1,120,134,167,191,203]	[49]	[23,130,140]		[86,101,123,219]	[22,24,148,153,212]	[39,77,135,143,188]	[34,48,69,129,144,175,176,180,206,209,214]	[2,8,9,13,14,26,73,79,117,136,142,145,147,177,197,213,217,218,232]	[47,51,74,87,91,93,94,104,111,124,125,132,146,149,154,159,198,215,229]	[36,62,81,83,105,126,133,161,174,221]	[3,10,16,21,37,61,70,75,76,89,97,137,158,163,173,187,201,208,210,224,225,230]	[11,27,44,54,55,65,67,68,78,95,95,102,109,115,122,131,141,155,171,186,189,220,222,227,228]	[45,57,64,80,96,99,103,110,121,156,179,195,196,202,205,211,223,226]
Specific Domain			[1,120]		[23,130]	[52]	[41,123]	[24,50,53,84,170,172]	[39,77,114,118,135,143,188]	[6,34,40,48,69,129,144,175,176,180,209]	[2,5,13,14,17,26,32,92,117,142,145,147,177,197,217,218,232]	[7,30,87,91,93,94,104,111,124,125,132,146,149,159,198]	[36,81,105,126,174,221]	[3,16,21,46,61,70,75,76,89,97,137,158,163,187,210,225,230]	[11,15,27,44,54,65,68,78,95,109,131,141,150,155,164,171,189,220]	[45,57,64,80,96,99,103,110,121,156,160,199,202,205,211,226]
Generic Domain	[58,200]	[190]	[63,71,134,167,191,203]	[49]	[59,140]	[60,216]	[86,101,219]	[22,90,98,106,148,153,169,192,212]	[107]	[4,28,42,214]	[8,9,73,79,136,139,213]	[38,47,51,74,127,138,154,215,229]	[29,62,72,83,119,133,161,185,207]	[10,37,43,82,173,201,208,224]	[18,31,35,54,67,102,108,115,122,128,151,157,186,222,228,228,231]	[168,179,195,196,204,223]
Individual			[1,63,203]		[130]		[86]	[50,106,170,172]	[114]	[129,175,206,209]	[147]	[38,87,104,127,149]		[10,21,37,82,158,224,230]	[15,65,95,102,151,189,220]	[99,103,110,156,179,196,204,205]
Mix		[190]	[71,134,191]			[52]	[41]			[28,42]	[142]	[51]		[43,89]	[35,128,228]	
Collaborative	[58,200]		[120,167]		[23,59,140]	[60,216]		[22,24,53,84,90,98,153]	[118,135,188]	[6,34,40,48,69]	[8,9,14,26,73,92,136,197,213,232]	[7,47,74,125,132,198,215,229]	[29,72,119,161,174,185,207,221]	[16,61,75,137,187,208,225]	[31,109,115,155,157,222,231]	[80,96,168,195,199,223]
Machine								[148]	[39,107]	[214]	[13,32]			[46]	[44,108,164]	[45]
N/A				[49]			[101,123,219]	[169,192,212]	[77,143]	[4,144,176,180]	[2,5,17,79,117,139,177,217,218]	[30,91,93,94,111,124,138,146,154,159]	[36,62,81,83,105,126,133]	[3,70,76,97,163,173,201,210]	[1,18,27,54,55,67,68,78,122,131,141,150,171,186,227]	[57,64,121,160,202,211,226]
Non Empirical	[58]	[190]	[1,63,71,120,191]	[49]	[59]	[52,60,216]	[101,219]	[22,50,148,153,169,192]	[77,143]	[144]	[17,73,139,145,218]	[93,111,149,154,159]	[36,105,126]	[3,173,201,210]	[44,78,115,122,131,141,164,186]	[64,96]
In Vivo	[200]		[203]		[140]		[86]	[98,170,172,212]	[107,135,143]	[6,34,40,69,129,175,180,206]	[2,8,117,136,232]	[7,30,47,91,125,138,198]	[83,133,174,207,221]	[16,21,61,70,89,137,163,187]	[11,18,31,54,55,67,109,128,189]	[57,80,99,121,202,204]
Mix					[23]		[41]			[42,209]	[142]	[74,124]				[156]
In Vitro			[134,167]		[130]		[123]	[24,53,84,90,106]	[39,118,188]	[28,48,176,214]	[5,9,13,14,26,32,79,92,147,177,197,213,217]	[38,51,87,104,127,132,146,215,229]	[29,62,72,81,161,185]	[10,37,43,46,75,76,82,97,158,208,224,225,230]	[15,35,65,68,95,102,108,150,151,155,157,171,220,222,227,228,231]	[45,103,110,160,168,179,195,196,199,205,211,223,226]
No Tool		[190]	[63,71,120,134,191]	[49]	[59,130,140]	[216]	[101,123,219]	[22,50,153,169,170,172,192,212]	[77,114,135]	[2,22,51]	[17,117,139,197]	[7,30,51,93,94,111,138,146,149,154,159]	[36,105,119,126]	[43,173,201,210]	[18,27,35,55,67,78,115,122,141,151,186,227]	[57,96,160,195,211]
Existing Tool			[203]			[60]		[98]		[6,28,34,40,175,206,214]	[2,8,136]	[91,124,125,127]	[81,174,207,221]	[37,61,70,75,76,89,163,187]	[11,31,54,128,171,189]	[80,99,121,179,199,204,223]
Mix			[167]				[41]			[42,209]		[38,74]		[46]	[102]	[156]
New Tool	[58,200]		[1]		[23]	[52]	[86]	[24,53,84,90,106,148]	[39,107,118,143,188]	[48,129,176]	[9,13,14,26,32,73,79,92,142,145,147,177,213,217,218,232]	[47,87,104,132,198,215,229]	[29,62,72,83,133,161,185]	[3,10,16,21,82,97,137,158,208,224,225,230]	[44,65,68,95,108,109,131,155,157,164,220,222,228,231]	[45,64,103,110,168,195,202,205,226]

Figure 4. All 208 Publications per year sorted in all 18 subcategories.

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