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Mapping child–computer interaction research through co-word analysis

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ABSTRACT

This paper employs hierarchical clustering, strategic diagrams, and network analysis to construct an intellectual map of the Child–Computer Interaction research field (CCI) and to visualize the thematic landscape of this field using co-word analysis. This approach assumes that an article's keywords constitute an adequate description of its content and reflect the topics that the article covers. It also assumes that the co-occurrence of two or more keywords within the same article indicates a linkage between those topics. This study quantifies the thematic landscape of the CCI field and elaborates on emerging topics as these are manifested in publications in the two primary venues of the CCI field, namely the proceedings of the annual IDC conference and the International Journal of CCI. Overall, a total of 1059 articles, and their respective 2445 unique, author-assigned keywords, are included in our analyses — all papers have been published between 2003 and 2018. The results indicate that the community has focused (i.e., high frequency keywords) in areas including Participatory Design, Tangibles, Design, Education, Coding, and Making. These areas also demonstrate a high degree of ''coreness'' (i.e., connection with different topics) and ''constraint'' (i.e., connection with otherwise isolated topics). The analysis also highlights well-structured yet peripheral topics, as well as topics that are either marginally interesting, or have the potential to become of major importance to the entire research network in the near future. Limitations of the approach and future work plans conclude the paper.

1. Introduction

Child–Computer Interaction (CCI) is a multidisciplinary area of scientific investigation that concerns the phenomena surrounding the interaction between children and computational and communication technologies [1]. The research community that investigates this area, combines inputs and perspectives from multiple scientific disciplines informing and supporting an area of research and industrial practice that concerns the design, evaluation, and implementation of interactive computer systems for children, and the wider impact of technology on children and society [2]. During the first years of the community the children of interest ranged from 3 to 12 years old; during recent years the community has extended its interests and today is concerned with children ranging from toddlers to teenagers [1]. CCI is a field that is continuously evolving and growing, so it is important to evaluate and understand the core foundations of its current state, as well as to reflect and identify emerging trends that could have a major influence in the future.

A content analysis of all papers published in the proceedings of the Interaction Design and Children (IDC) conference series between 2002 and 2010, focused on aspects related to the values and motivations of the analyzed papers [3]. Another survey of the IDC literature by Jensen and Skov [4], examined the research methods used in CCI and demonstrated that in most cases CCI researchers used methods borrowed from HCI and adapted them for use with children where possible. This review included articles published until 2004. More recent literature reviews have aimed to capture and present the state-of-the-art in specific areas (e.g., game-based learning in primary education [5], learning technologies for children 8 years old and younger [6], maker movement [7]), to demonstrate and elaborate on the intersection of CCI with other relevant research fields such as tangible interaction [8], storytelling [9] and autism [10], and to provide a synopsis of the overall progress in CCI [1,2].

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As the CCI research community evolves and matures, it is useful, in order to guide future research, to systematically identify core topics, marginal contributions, under-developed themes, and forthcoming ideas that are worth investing in. Furthermore it is instructive to characterize how topics transition between these states, and to describe the association strength of topics developed in this discipline. In order to contribute towards a systematic mapping of the big picture of CCI research, the present study focuses on identifying the concepts that reflect the thematic areas of interest of the CCI community, using hierarchical clustering, strategic diagrams, and graph theory.

To achieve this ambitious objective, the paper employs a method called "co-word analysis". This scientometric method examines the associations and networks among concepts, ideas, and issues that have contributed to the maturation of the field to date [11]. A core simplifying assumption for co-word analysis is that an article's keywords provide an adequate summary of its content, and thus can be utilized to reduce a large space of descriptors (i.e., article text) to a network graph of smaller related spaces (i.e., keywords) [12]. Co-word analysis is based on the assumption that the co-occurrence of two (or more) keywords within the same paper indicates a linkage between those topics, whilst the presence of many co-occurrences around the same keywords (or pair of keywords) suggests a locus of strategic alliance within articles that may reflect a research theme [12]. As such, co-word analysis can support researchers to identify key patterns and trends that point to a particular change in a research topic (e.g., emerging or declining research interests) or a change in research direction (e.g., paradigm change), based on the graph of keywords [13].

The present study maps the intellectual progress of the CCI landscape, as reflected in the publications of the IDC conference and the ijCCI. IDC and ijCCI were chosen because of being the flagship publication venues of the CCI community. As such, they provide a solid foundation to the related work published to date. During the last 16 years, 1059 papers have been published in IDC and ijCCI and to a large extent constitute currently the corpus of the CCI field. Although the field is relatively new, considerable work has been published, allowing us to observe where the field currently stands, what are the current challenges and opportunities that researchers face, and what will be the potential driving forces in the near future. Accordingly, this work contributes as follows:

- It maps the intellectual progress of CCI research;
- It identifies declining or emerging CCI research themes;
- It highlights CCI topics as popular or core research topics within the discipline;
- It facilitates the process of understanding differences and commonalities of the various sub-fields of CCI.

2. Background and related work

The evolution of a scientific community can be studied as a complex and dynamic system [14]. Both qualitative and quantitative indices can be employed in this process. In fact, different measures (e.g., inclusion index, centrality, density) have been developed to quantify and evaluate the impact of growing scientific communities [15]. This section summarizes previous efforts to map and reflect on the intellectual progress in CCI through literature reviews, it gives a brief overview of co-word analysis and illustrates how this method has facilitated analyzing and understanding intellectual progress in other fields.

2.1. Review studies in Child–Computer interaction

CCI's genesis (the topic not the term) goes back to the 1960s [2], when pioneering researchers such as Seymour Papert, Marvin Minsky, and Alan Kay explored the design of computer systems for children. In the 1990s, CCI research produced a steady flow of works stemming largely from the HCI field. However but as a multidisciplinary research community CCI is directly connected with several research areas (e.g., psychology, learning sciences, interaction design, engineering, computer science and media studies) [1]. A representative collection of early works can be found in the seminal volume edited by Druin [16].

In 2002, the increasing number of CCI related publications appearing at a range of general HCI and learning conferences triggered the establishment of a specialized annual IDC conference series [17]. Since then, IDC has been the center for CCI research. IDC is now an official ACM SIGCHI conference with recent attendance numbers in the 200-to −400 attendee range and average acceptance rate of 30% and 150 submissions (full papers and notes). In 2013 the community also initiated a dedicated journal (i.e., ijCCI), with an aim to further boost CCI research.

Throughout the last two decades several literature review works in CCI related areas. One of the first literature review works published in IDC was by Jensen and Skov [4] who demonstrated the variety of methods used in CCI and flagged certain problems regarding these methods (e.g., that they were not always properly adapted for children, they did not always consider the individual needs of participating children, and were not always properly reported). During the past decade we have seen presentations and adoption of novel methods [17], as well as systematic offerings or courses and tutorials (e.g., [18,19]), and calls for action [20] that allow the CCI community to advance its research methods and contribute towards a fruitful discussion around this thematic area.

In a more recent and systematic work, Yarosh et al. [3] analyzed the first 9 years of IDC proceedings in order to examine the values held by CCI researchers. This work discussed the types of contributions IDC papers have made, the behaviors and qualities they sought to support in children, the audiences for whom designs were generated, the role of children in creating designs, the theories and models that informed the research, and the criteria that informed design decisions. The analysis questioned whether researchers in CCI always identified or reported their real motivations for their work and raised concerns about the extent to which approaches used had undergone ethical scrutiny. Yarosh et al. [3] provided an important analysis of CCI's intellectual progress until 2010, which has provided valuable insights for self-reflection and has helped shape the future of the community.

With the inception of ijCCI, the Founding Editors conducted a brief review of CCI landscape [1] and identified four future challenges for the CCI community. First, closing the gap between theory and design by developing models and guidelines that could guide the design of interactive artefacts for children. Second, further exploration of children's participation in CCI research (e.g., as social actors, as designers, as users etc.). Third, the role of mobile and pervasive technologies, tangible, and embodied interaction and the opportunities these technologies offer for CCI application areas (e.g., play, learning, communication). Fourth, the penetration of social and cloud technologies in CCI (e.g., storytelling) and potential risks regarding children's privacy and security.

Another notable review contribution in the CCI comes from Juan Pablo Hourcade. In 2008, Hourcade [21] conducted a review of research on children's cognitive and motor development, related to technologies and design methodologies and principles. Hourcade [21] also provided an overview of research trends in

CCI and grouped them in 13 thematic areas. Seven years later, he extended his initial work into a book called "Child-Computer Interaction" [2]. This book focuses primarily on research published at the CHI and IDC conferences, and includes guidelines through the ten pillars of CCI namely: work in interdisciplinary teams, deeply engaging with stakeholders, evaluating impact over time, designing the ecology not just the technology, making it practical for childrens reality, personalizing, being mindful of skill hierarchies, supporting creativity, augmenting human connections, and enabling open-ended, physical play.

The aforementioned works are mainly based on an analysis of contributions coming from the CCI community, with few of them being systematic efforts (e.g., [3]) and the most recent one dating from 2015. The CCI field has significantly grown since Yarosh's last systematic review (e.g., new journal, increase in submitted/published papers). Thus, it is of great interest to the CCI community to be able to observe where our field currently stands, the current challenges and opportunities we are facing, and what are expected to be the potential driving forces in the near future. To do so, this article applies co-word analysis, which is an established technique hat has been widely used in several areas of Computer Science (CS), such as Information Retrieval [22], Software Engineering [23], Internet of Things [24], non-CS areas, such as creativity research [25], strategy [26], STEM Education [27] and other neighboring to CCI communities, such as CHI [28] Ubiquitous Computing [29] and digital games [30]. Here co-word analysis allows us to analyze the intellectual progress of the CCI community, through the lens of the two main CCI publication venues - articles published in IDC and ijCCI.

2.2. Brief overview of co-word analysis

Co-word analysis has been proposed as a content analysis technique to map the strength of relation between terms in texts and to trace patterns and trends in term association [11]. Specifically, the keywords used for the description of the content of a publication can be seen as the basic building blocks of the structure of a research field. The idea is to understand the conceptual structure and evolution of a field directly from the interaction between keywords: if two keywords co-occur within one paper, then the two research topics they represent are related; higher co-word frequency implies stronger correlation in keywords pairs, which further suggests that two keywords are related to a specific research theme [12]. As such, co-word analysis has the potential to effectively reveal patterns and trends in a specific discipline based on the co-occurrence patterns of pairs of words [22], and it has been commonly utilized to discover connections and interactions among research themes [15].

As a method, co-word analysis is a widely-applied bibliometrics approach that examines the evolution and structure of scientific disciplines, using as source the keywords, titles, abstracts, or other publication data fields [31]. For example, it has been employed to examine the status of the UbiComp community [29], to map the conceptual network in the field of education considering the emergence of the web [32], to analyze the landscape of games research [30], and to map the intellectual progress of the CHI community [28]. Given the evidence that co-word analysis could be a powerful tool for knowledge discovery, the present study puts into practice this technique in order to identify the conceptual structure and development trends, as well as to elaborate on the emergence and maturation of research topics in the CCI field.

3. Method

3.1. Co-word analysis

As stated in the previous section, this study employs co-word analysis to shed light on the current state and future opportunities and threats in the CCI research community. The idea behind co-word analysis rests on the assumption that keywords are adequate descriptors of the article's content and links that the authors establish to connect ideas within their work [33]. In this study, the main units used in the analysis are keywords, networks, (i.e., graphs of two or more keywords linked with the same paper), and clusters (i.e., set of closely-related keywords) [29].

Co-word analysis is applied to reduce the broad network of keywords into a smaller network of related topics using graph theory [34]. Graphs consist of nodes that represent the keywords, and links that represent the interactions between the nodes. Given a network of keywords, a combination of clustering, network analysis, and strategic diagrams is used to model the conceptual structure of a field and to characterize it [33]. In this study the graph theory concepts employed to map the field of CCI are density and centrality. Density refers to the coherence of a cluster and is a measure of a theme's development over time [15]: as the strength of a cluster's internal ties up a theme increases, the cluster's capacity to maintain itself and to develop over time increases as well [33]. Centrality pertains to the strength of the links from one research theme to others, indicating its significance in the development of the community [35]: as a cluster obtains stronger links in a network of themes its position becomes more central and this cluster becomes more central to the whole network as well [36]. In simple terms, higher density means that the cluster has stronger internal ties between the nodes it contains, compared to other clusters, whereas, higher centrality means that the cluster has stronger external links to other nodes in the network, compared to other clusters. Combining density and centrality allows for the creation of two-dimensional strategic diagrams [33]. The x-axis shows the strength of an interaction between nodes (i.e., centrality), while the y-axis shows the internal coherence of a cluster (i.e., density) (Fig. 1).

As one can observe, Quadrant I (QI) holds the motor themes (i.e., mainstream research themes) that have strong centrality and high density. Quadrant II (QII) contains themes that are internally well-structured, but have insignificant external ties. These research themes are more specialized and peripheral to mainstream work that is central in the research field. Quadrant III (QIII) includes the themes with low density and low centrality, representing either emerging or disappearing research themes. Finally, Quadrant IV (QIV) covers weakly structured, underdeveloped themes that hold the potential to become significant to the field as a whole. For example, given a cluster in QI, if its centrality decreases for a reason, the theme this cluster corresponds to might end up in QII, and become isolated; if, on the other hand, its density decreases, then the theme might be identified as a transversal one, and the cluster might move to QIV (over time). Themes in the QIV are important for a research field as a whole, but are not well-developed [35]. "Transversal" means that prior works in these themes has the potential to be of considerable significance to the entire research network [28,29], i.e., they can influence the development of all other themes; their centrality means that they relate to many topics (e.g., can be methods, tools, approaches, technologies, etc.) of the network. It should be clarified that themes are not transversal within a specific quadrant, but across the entire network; so QIV is a quadrant of such themes. Furthermore, the combination of a cluster's centrality

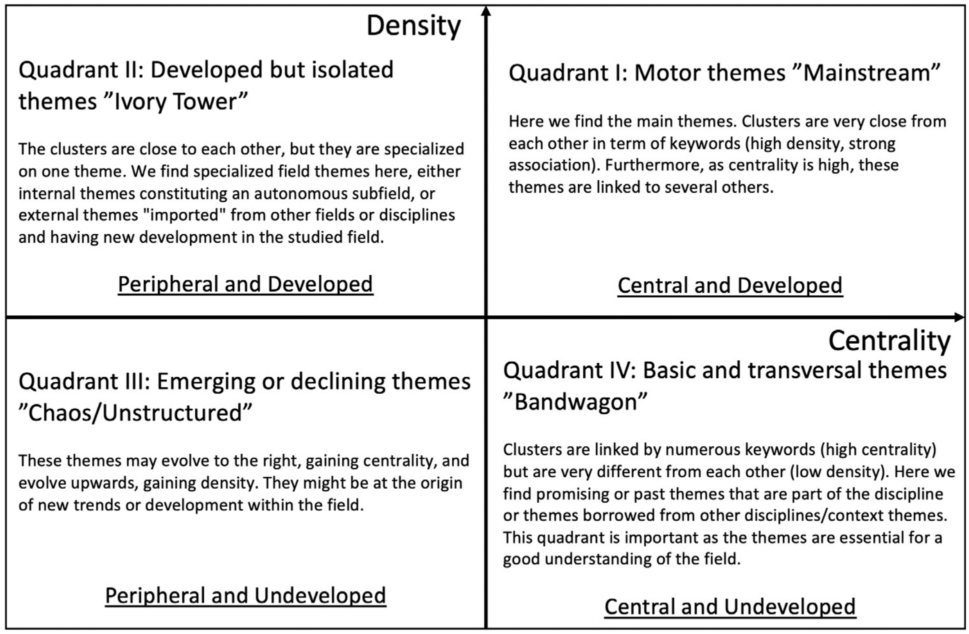

Fig. 1. Strategic diagram of density and centrality.

and density represents the relative position of a cluster within a Quadrant, and reflects the intellectual progress of the theme.

By creating associations between keywords, multiple networks associated with different themes are also created. In this case, bridges are built between keywords represented as nodes, to allow communication and information flow between isolated regions in a network, known as structural holes [37]. Keywords with a high number of structural holes serve as a "backbone" of a network: if removed, the network will lose its cohesion and will disintegrate into separate and unconnected concepts. Thus, the network's core–periphery structure needs to be computed, in order to determine which nodes are part of a densely connected core (i.e., with a higher number of bridges) or a sparsely connected periphery core [38]. Core nodes are reasonably well connected to peripheral nodes, while peripheral nodes are sparingly connected to a core node or to each other. Hence, a node belongs to a core only if it is well-connected to other core nodes and to peripheral nodes [38].

Co-word analysis visualizes connected topics and presents the overall structure of a field as a map of interrelated concepts [33], supporting researchers to trace changes and unexpected surprises (e.g., contradictions) in the conceptual space of the CCI field. Hence, in a network of keywords, as the body of knowledge grows, research topics with a high core value represent important knowledge-growing points in the CCI corpus. In these networks, it is expected for peripheral nodes to become core nodes, leaving room for new peripheral nodes to emerge.

In summary, co-word analysis identifies clusters of keywords that often appear together in papers (called themes). For each theme we calculate density (the internal cohesion of the theme) and centrality (how "central" a theme is to the whole field), map them to a strategic diagram (Fig. 1) to identify in which of the four distinct states a theme can hold. A theme begins its life with low centrality and density in the chaos/unstructured quadrant. As the theme becomes more central to the community, it moves to the bandwagon quadrant. The theme eventually matures its internal cohesion and moves to the mainstream quadrant, where the motor themes of a community lie. Finally, a theme will lose its centrality in relation to the field and move to the Ivory Tower quadrant, subsequently dying away by returning to the chaos/unstructured quadrant.

3.2. Data collection

The data analyzed in this study have been provided by the ACM Digital Library (i.e., papers published in IDC proceedings between 2003 and 2018) and Elsevier (i.e., articles published in ijCCI between 2013 and December 2018).

Overall, a total of 1059 peer-reviewed articles with keywords were published within the CCI community (954 coming from IDC and 95 from ijCCI) between 2003 and 2018 (December), excluding editorials and papers of 3 pages and shorter. Given that IDC's publication guidelines significantly change from one year to another (e.g., in 2013 we see best workshop papers included in the proceedings, from 2016 onwards both long and short papers were allowed, etc.) and due to the fact that different tracks (e.g., workshop descriptions, works in progress) contribute to some extent in the evolution of our community, we decided to include all the articles that are 4 pages and more and have been peer reviewed (either in a single or double blind manner). From the collected papers, only the author-assigned keywords were extracted from the metadata of each paper and were used as a unit of analysis. The papers that did not contain any keywords were excluded from the analysis. From the 1059 papers that meet the inclusion criteria, 5617 keywords (mean of 4.91 per article) were extracted of which 2445 are unique. Those articles are distributed over time as shown in Fig. 2. While this distribution does not necessarily portray the popularity of the conference each year (due to different rules in proceedings inclusion), we can safely say that both IDC and ijCCI venues are growing overtime substantially.

3.3. Data analysis

The retrieved keywords were manually pre-processed and standardized by merging words that conveyed similar meaning (e.g., "codesign" and "participatory design" were merged into "participatory design"), fixing misspelled keywords (e.g., "paticipatory design"), following a common spelling for UK and US terms (e.g., "behaviour" and "behavior"), filtering broadly used terms (e.g., "CSCL" and "Computer Supported Collaborative Learning") and removing the root-keywords (i.e., CCI, IDC) - this was

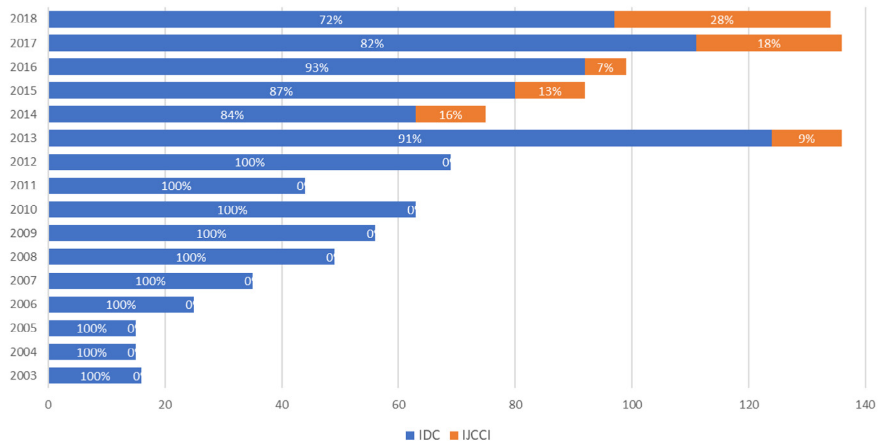

Fig. 2. Number of CCI publications (IDC-ijCCI) per year.

made following the approach recommended by previous co-word analysis (e.g., [13,28,31]) after the consensus of 3 experienced CCI researchers (i.e., with more than 10 years in IDC community). On the contrary of CCI and IDC terms, the terms "design" and "interaction design" were kept. This is because of two reasons, first they did not have an extremely high frequency (as CCI and IDC that were added to most of the papers) and after evaluating their use in some papers, it was evident that authors added them to depict the central role of those two terms in the paper. Keywords appearing in singular and plural forms of nouns, gerunds, abbreviations, and acronyms were also merged. At the end of this preprocessing, 1966 (80.4% of the originally unique author-assigned keywords) were identified as unique keywords, and were subjected to further analysis. At a later stage of the analysis, network preprocessing was also undertaken, to remove isolated nodes, less important links between nodes, etc.

The Kolmogorov Smirnoff (KS) test showed that the frequency of keywords follows a power-law distribution with an alpha of 2.65 ($R^2 = 0.78$). Networks whose degree distribution follows a power law, at least asymptotically are "scale-free": the fraction P(k) of nodes in the network having k connections to other nodes goes for large values of k as $P(k) \sim k_{-\gamma}$ where γ is a parameter whose value is typically in the range $2 < \gamma < 3$ although occasionally it may lie outside these bounds [39,40]. In scale-free networks, some nodes (called "hubs") have many more connections than others, and the network as a whole has a power-law distribution of the number of links connecting to a node. In other words, the research landscape of CCI is a scale-free network, with a small number of popular keywords acting as "hubs": these keywords connect different topics, capture major research directions and influences in the field, and shape the overall intellectual structure of the CCI research landscape [13,31]. Across domains (social, biological, technological, and informational sources), scale-free networks are rare [41].

A scale-free network also suggests that major research themes can be detected with a small subset of popular keywords (higher frequency) [42]. Previous analyses (e.g., in Information Systems, STEM Education, HCI, etc.) demonstrated that less than 100 keywords are enough to describe the intellectual progress of a field [27,28,43]. Thus, in the present study we decided to include only those keywords that appear more than ten times ($n \geq 11$) in the period 2003–2018. This decision was grounded on two facets: (a) the frequency of a keyword reflects its significance for a research community, i.e., the higher the frequency is, the more significant the keywords is for the research community (the more commonly the keyword attracts the researchers' attention/interest); and (b) the N = 53 highly frequented keywords that were retained (each keyword's frequency ($n \geq 11$) and total frequency = 1960, 34.9% of the total keywords), cover 876 of the 1059 articles published, i.e., 82.7% of the papers are represented by at least one of these keywords in the final dataset. Furthermore, for the given dataset of keywords and papers, n = 11 is the minimum keyword frequency (lower limit) that achieves the highest inclusion of the papers in the dataset. For keywords with $n \geq 10$, N = 66 keywords that cover 82.9% of the papers, whereas for keywords with $n \geq 12$, N = 49 keywords that cover 77.3% of the papers in the dataset. In other words, with fewer yet highly frequent keywords we could reliably describe the CCI network of keywords. This is in accordance to previous studies utilized the same methodology, in areas such as Stem Education [27], digital games [30], information systems [43], ubiquitous computing [29] and CHI [28], to mention a few.

To gain a first understanding and insight from those keywords, correspondence analysis (CA) was applied. CA is a descriptive, exploratory technique suited to handling categorical data, both graphically and numerically, as an extension of Principal Component Analysis (PCA). The technique can form the basis of co-word mapping [44]: (a) CA uses a contingency table to produce results and the frequencies of keywords can be summarized in a cross-tabulation; (b) a co-word map comprises a chart in which keywords are positioned on a common set of axes in such a way that the relative locations of keywords represent some aspects of the relationship between them. The standard coordinates show the position of the keywords on the underlying dimensions (i.e., factors). The results are interpreted based on the relative positions of the points and their distribution along the dimensions; the more words are similar in distribution the closer they are represented in the map [45]. In other words, CA is employed to draw a conceptual structure of the field in combination with clustering, the method allows to identify clusters of keywords that express common sub-topics (i.e., themes).

In order to identify the major research themes in the CCI domain, hierarchical clustering analysis on a correlation matrix with the 53 retained keywords was performed, using Ward's method with Squared Euclidean Distance as the distance measurement. The supervised clustering method allows to maintain content validity and cluster fitness for the highest number of clusters [13,28]. Each cluster represents a research theme or sub-field. The co-word network (i.e., clusters) was further analyzed using the following measures:

- **keywords:** set of keywords that constitute a particular cluster (i.e., theme);
- **size:** number of keywords in the cluster;

- **frequency**: the average number of keyword appearance (for all keywords in the cluster);
- **co-word frequency:** the average number of two keywords appearing on the same paper; Computing the frequency of two keywords appearing together in the same paper results in a symmetrical co-occurrence matrix based on the keyword co-occurrence [46,47]. In this matrix, values in the diagonal cells were keyword frequencies, and values of non-diagonal cells were co-word frequencies. Two keywords occurring in the same article is an indication of a connection between the topics that they represent. The higher the frequency of co-occurrence between keywords, the closer the research theme is [48].
- **transitivity**: how tightly connected is the cluster (the clustering coefficient), i.e., how close the key-terms are to being a "clique". Transitivity is the frequency of loops of length three in the cluster; a loop of length three is a sequence of nodes x, y, z such that (x, y), (y, z) and (z, x) are edges of the graph [49]. The value range for transitivity is [0, 1];
- **centrality:** the degree of interaction of a theme with other parts of the network [33]; Centrality refers to a group of metrics that aim to quantify the "importance" or "influence" (in a variety of senses) of a particular node (or group) within a network. Examples of common methods of measuring "centrality" include betweenness centrality, closeness centrality, eigenvector centrality, alpha centrality, and degree centrality. Here we used betweenness centrality and the range for centrality values is 0–1.
- **density:** the cohesion of the cluster of keywords making up the research topic [33]. Density corresponds to the proportion of direct ties in a network relative to the total number possible. In mathematics, a dense graph is a graph in which the number of edges is close to the maximal number of edges. The opposite, a graph with only a few edges, is a sparse graph. The distinction between sparse and dense graphs is rather vague, and depends on the context and size of the graph. As such, the range for density is also graph-dependent, and can be any positive real number.

Based on the clustering results, we plotted the strategic diagram for the years 2003–2018 to visualize the cohesion and maturity of the research themes in CCI, using the centrality and density of each cluster [28,29,33]. Further to that, we also performed clustering analysis for the periods 2003–2012 and 2013–2018, i.e., before and after the ijCCI started, and we plotted the respective strategic diagrams, in order to showcase the intellectual progress of the field over time. In addition, a keyword network graph was created. In this graph, each keyword is represented as a node, and the keywords that co-appear on a paper are linked together. A follow-up core–periphery analysis was performed to spot the core research topics from the perspective of the whole network. In this analysis, keywords were categorized according to their popularity, coreness (i.e., connectedness with other topics) and constraint (i.e., backbone topics that support the topic structure).

4. Results

4.1. Correspondence analysis

To show how the articles published each year, contribute to the field by introducing new research topics with regard to emerging topics, we performed a correspondence analysis (CA) between the publication years and the 53 keywords. Briefly, CA performs a homogeneity analysis of an indicator matrix to obtain a low-dimensional Euclidean representation of the original data [50]. The indicator matrix is typically a contingency table. CA is used to analyze frequencies formed by categorical data (i.e, contingency table) and it provides *factor scores (coordinates)* for both the rows and the columns of the contingency table. These coordinates are used to visualize graphically the association between the row and column variables in the contingency table in a two-dimensional space, based on the chi-squared statistic associated with the contingency table. In the two-dimensional outcome chart, all rows of the contingency table (i.e., a set of variables in the original dataset) and all columns of the contingency table (i.e., a different set of variables in the original dataset) can be displayed on the same axes. All data should be on the same scale for CA to be applicable, keeping in mind that the method treats rows and columns equivalently. The results of the correspondence analysis for CCI for the years 2003–2018 are illustrated in Fig. 3. The CA factor map positions all of the keywords and years on a common set of orthogonal axes.

As Fig. 3 shows, different years have contributed to the emergence of different topics to different degrees. Take 2003–2004 for example, these first years there was a contribution to knowledge on the topics of cooperative inquiry. It is worth noting that several keywords are placed at the edges of the figure and far from most of the years. This may imply that publication years have diverse preferences as to topics for publication, which may contribute to the diversity of the field. It is interesting to note that several publication years are close to each other, as shown in Fig. 3. We can observe that 2012–2016 are close to each other, as shown in Fig. 3, and hence can be regarded as a cluster (incl. constructionist, child-robot interaction). Meanwhile, the triangle formed by the years 2005–2006–2007 is positioned on the right in the figure, implying a different cluster (incl. educational technology, collaborative learning). In other words, research focus in CCI shifts throughout the years, with the latest years occupying the left of the diagram (incl. STEM, Making, Computational Thinking). Furthermore, as is shown in Fig. 3, articles published 2003–2012 are located on the right side of the diagram and articles published from 2013 are located on the left side of the diagram; depicting a clear shift in topics published.

The percentages on the axes correspond to the variance explained by the two dimensions considered together. Summing up the proportion of variance explained by the horizontal and vertical dimensions (shown in the axis labels), portrays how much of the variance in the data can be explained by the visualization. In this study, the visualization displays 35.4% of the variance in the data.

4.2. Identifying the major research themes

4.2.1. Major research themes for the period 2003–2018

The clustering analysis on the retained 53 keywords led to 14 clusters (labeled as C01-C14, in Table 1), each representing a research theme or a subfield. Based on the results, and in order (a) to better understand the relative "position" of these clusters within the overall CCI field (i.e., what is the distance from each other in terms of cohesion and maturity of research themes they correspond to); and (b) to create the conceptual structure of the CCI discipline, we constructed a strategic diagram using the centrality and density of each cluster [28,33,35]. In this plot (Fig. 4), both axes are centralized to the average centrality and density respectively (i.e., 0.734, 3.802). The overall network density, indicating how cohesive is the whole research field, was found to be 0.309. The overall results can be seen in Fig. 4 and Table 1 together.

As it can be observed from Fig. 4, the CCI field has four motor themes (Mainstream research themes), that are represented by the following clusters: C01 (i.e., computational thinking, computer science education, block based programming, coding), C02

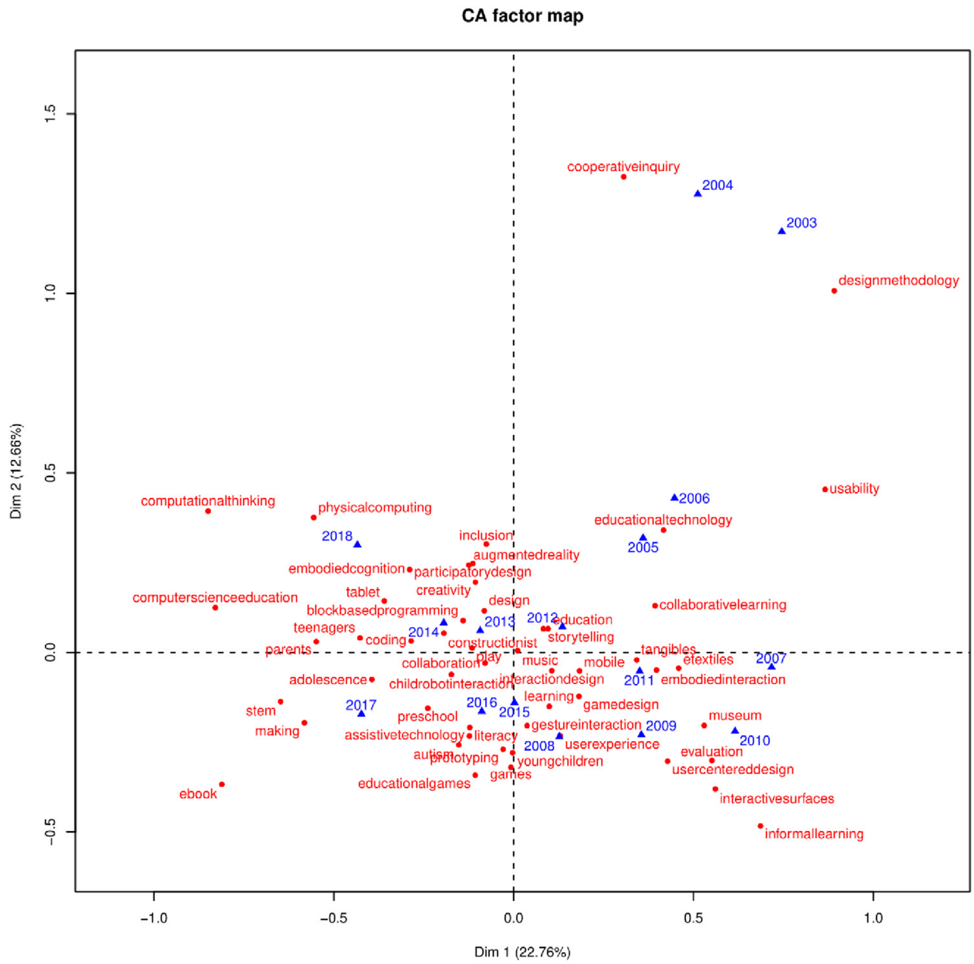

Fig. 3. Correspondence analysis map for CCI for the period 2003–2018.

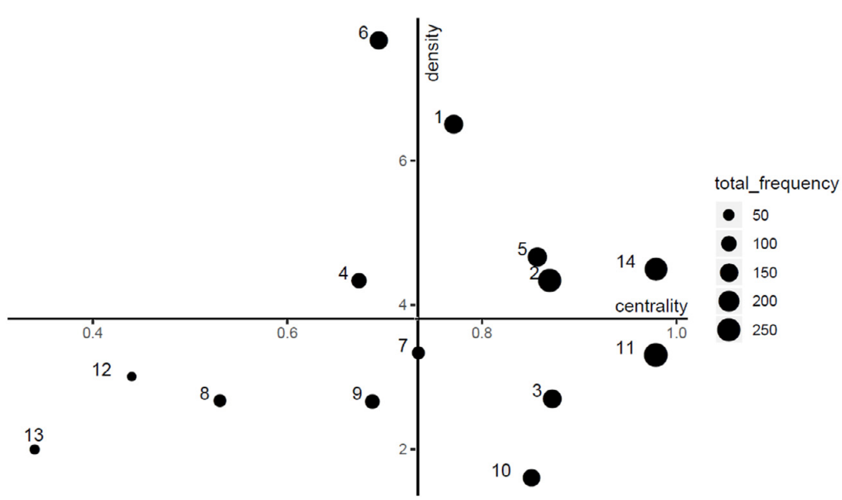

Fig. 4. Strategic diagram for CCI for the period 2003–2018.

(i.e., physical computing, constructionist, e textiles, stem, making, education), C05 (i.e., interaction design, play, child robot interaction) and C14 (i.e., design, learning, autism, user centered design) respectively.

Furthermore, from Fig. 4 it also becomes apparent that the community has some developed but isolated research themes (Ivory Towers), those themes are internally well-structured, but they have rather weak external ties. These topics act as peripheral nodes to the global network and are classified in the following clusters: C04 (i.e., educational technology, embodied cognition, embodied interaction) and C06 (i.e., participatory design, design methodology, cooperative inquiry).

It is also clear that the researchers have developed a considerable number of themes that are either emerging or disappearing (Chaos/Unstructured), i.e., with marginal interest in the global CCI

Table 1
Major research themes in CCI for the period 2003–2018.

ID	Q	Keywords (with the most frequent(s) being in bold)	Size	Total Freq	CW-Freq	Transitivity	Centrality	Density
C01	QI: Motor	computational thinking, computer science education, block-based programming, **coding**	4	160	259	1.000	0.771	6.500
C02		physical computing, constructionist, etextiles, stem, making, **education**	6	251	434	0.875	0.869	4.333
C05		**interaction design**, play, child robot interaction	3	165	216	1.000	0.857	4.667
C14		**design**, learning, autism, user centered design	4	240	364	1.000	0.979	4.500
C04	QII: Ivory Towers	**educational technology**, embodied cognition, embodied interaction	3	98	129	1.000	0.673	4.333
C06		**participatory design**, design methodology, cooperative inquiry	3	148	184	1.000	0.694	7.667
C07	QIII: Emerging/ Declining	**tablet**, collaborative learning, preschool	3	67	122	1.000	0.734	3.333
C08		**parents**, literacy, ebook	3	63	83	1.000	0.531	2.667
C09		**evaluation**, young children, usability, user experience	4	89	143	0.900	0.688	2.667
C12		adolescence, **teenagers**	2	31	55	N/A	0.440	3.000
C13		assistive technology, **inclusion**	2	37	40	N/A	0.340	2.000
C03	QIV: basic/ transversal, bandwagon	**mobile**, museum, gesture interaction, interactive surfaces, informal learning	5	155	245	0.708	0.872	2.700
C10		augmented reality, creativity, **storytelling**, prototyping, game design	5	133	211	0.833	0.851	1.600
C11		collaboration, **tangibles**, games, music, educational games	5	262	423	0.555	0.979	3.300

network, classified in the following clusters: C07 (i.e., tablet, collaborative learning, preschool), C08 (i.e., parents, literacy, ebook), C09 (i.e., evaluation, young children, usability, user experience), C12 (i.e., adolescence, teenagers) and C13 (i.e., assistive technology, inclusion).

Finally, a substantial number of basic and transversal themes Bandwagon, those themes that are strongly linked to specific research interests throughout the network, yet are only weakly linked together have been detected as well. These are categorized in the following clusters: C03 (i.e., mobile, museum, gesture interaction, interactive surfaces, informal learning), C10 (i.e., augmented reality, creativity, storytelling, prototyping, game design) and C11 (i.e., collaboration, tangibles, games, music, educational games).

4.2.2. Major research themes for the periods 2003–2012 and 2013–2018

In order to examine the paradigm changes in CCI over the 15 years in question (2003–2018), we split the sample into two sub-samples of 10 years: 2003–2012 and 2013–2018. This decision was made for two reasons. First the ijCCI was founded in 2013 and second in that way we split our sample two groups of comparable size. Since both IDC and ijCCI have shown an increase in the number of published articles in recent years. The keywords from the 2003–2012 sub-sample resulted 10 clusters, due to the smaller number of keywords (cf. with the initial dataset). Each cluster represents a research subfield or research theme in CCI. The overall results can be seen in Fig. 5 and Table 2 together.

Furthermore, from Fig. 5 it can be observed that during the first period (2003–2012) the community had 3 developed but isolated research themes (Ivory Towers). These topics are classified in the following clusters: CA06 (i.e., informal learning, museum), CA07 (i.e., embodied interaction, play) and CA09 (i.e., interactive surfaces, evaluation, usability). In this period the community had developed a considerable number of themes that are either emerging or disappearing (Chaos/Unstructured), i.e., with marginal interest in the global CCI network, classified in the following clusters: CA01 (i.e., tablet, music, games, parents), CA03 (i.e., participatory design, design methodology, cooperative inquiry, prototyping), CA04 (i.e., interaction design, young children, literacy), CA05 (i.e., storytelling, child robot interaction, educational games, augmented reality) and CA08 (i.e., educational technology, autism, user centered design, e-textiles). When it comes to basic and transversal themes (Bandwagon), the community had developed one weakly structured cluster: CA02 (i.e., block based programming, coding, mobile, constructionist, collaboration). Finally, the CCI community had one motor theme (Mainstream research themes): CA10 (i.e., design, education, learning, tangibles, inclusion).

The keywords from the 2013–2018 sub-sample resulted 10 clusters as well, this is reasonable since it is of similar size with the first period. The overall results for this period can be seen in Fig. 6 and Table 3 together.

Furthermore, from Fig. 6 it can be observed that during the second period (2013–2018) the community had 3 developed but isolated research themes (Ivory Towers). These topics are classified in the following clusters: CB01 (i.e., computational thinking, computer science education, block based programming, coding), CB03 (i.e., participatory design, design methodology, cooperative inquiry) and CB09 (i.e., tablet, collaborative learning, preschool). In this period the community had developed a considerable number of themes that are either emerging or disappearing (marginal interest in the global CCI network), classified in the following clusters: CB04 (i.e., adolescence, assistive technology, autism, teenagers), CB06 (educational technology, embodied cognition, embodied interaction), CB08 (parents, literacy, young children, prototyping, user centered design, ebook, user experience). When it comes to basic and transversal themes, the community had developed 2 clusters: CB05 (i.e., augmented reality, mobile, gesture interaction, evaluation, usability) and CB07 (i.e., design, games, music, stem, museum, play, learning, game design, informal learning). Finally, during the second period of its life the CCI community has developed 2 one motor themes: CB02 (i.e., physical computing constructionist, interaction design,

Table 2
Major research themes in CCI for the period 2003–2012.

ID	Q	Keywords (with the most frequent(s) being in bold)	Size	Total Freq	CW-Freq	Transitivity	Centrality	Density
CA10	QI: Motor	design, education, learning, **tangibles**, inclusion	5	159	298	0.900	1.000	5.300
CA06	QII: Ivory Towers	**informal learning**, museum	2	22	33	N/A	0.500	3.000
CA07		**embodied interactio**n, play	2	32	44	N/A	0.471	3.000
CA09		**interactive surfaces**, evaluation, usability	3	51	72	1.000	0.576	3.000
CA01	QIII: Emerging/ Declining	tablet, music, **games**, parents	4	40	86	0.778	0.656	1.667
CA03		**participatory design**, design methodology, cooperative inquiry, prototyping	4	57	77	0.708	0.594	2.000
CA04		**interaction design**, young children, literacy	3	40	72	1.000	0.667	1.667
CA05		**storytelling**, child robot interaction, educational games, augmented reality	4	46	62	0.833	0.656	0.833
CA08		**educational technology**, autism, user centered design, e-textiles	4	66	77	0.778	0.656	0.833
CA02	QIV: basic/ transversal, bandwagon	block based programming, coding, **mobile**, constructionist, collaboration	5	85	165	1.000	0.871	2.200

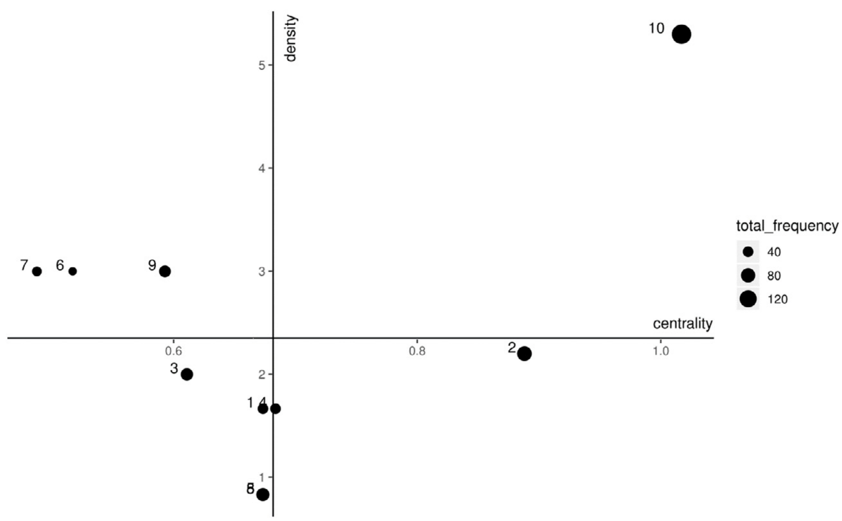

Fig. 5. Strategic diagram for CCI for the period 2003–2012.

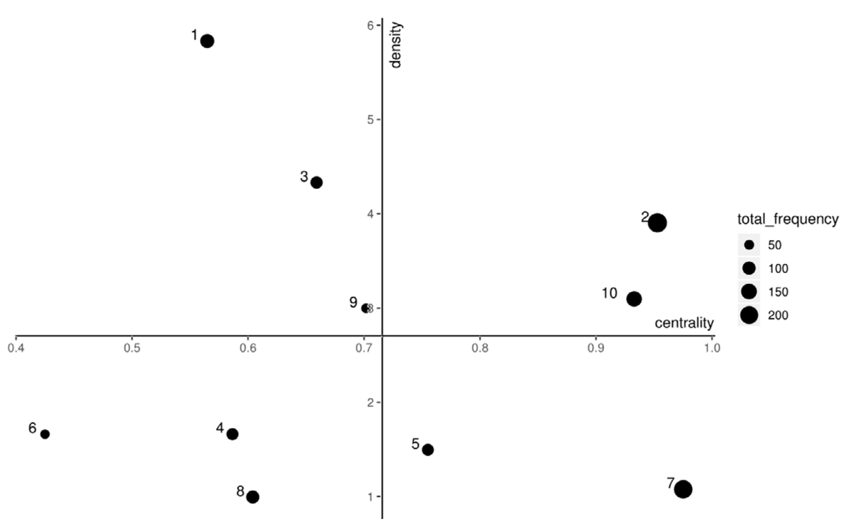

Fig. 6. Strategic diagram for CCI for the period 2013–2018.

Table 3
Major research themes in CCI for the period 2013–2018.

ID	Q	Keywords (with the most frequent(s) being in bold)	Size	Total Freq	CW-Freq	Transitivity	Centrality	Density
CB02	QI: Motor	physical computing constructionist, interaction design, **making**, inclusion, education, child robot interaction	7	233	402	0.923	0.953	3.905
CB10		collaboration, creativity, **tangibles**, storytelling, interactive surfaces	5	143	236	0.867	0.933	3.100
CB01	QII: Ivory Towers	computational thinking, computer science education, block based programming, **coding**	4	114	187	1.000	0.565	5.833
CB03		**participatory design**, design methodology, cooperative inquiry	3	84	112	1.000	0.659	4.333
CB09		**tablet**, collaborative learning, **preschool**	3	47	93	1.000	0.702	3.000
CB04	QIII: Emerging/ Declining	adolescence, assistive technology, **autism**, teenagers	4	80	107	0.778	0.587	1.667
CB06		**educational technology**, embodied cognition, embodied interaction	3	44	54	0.333	0.426	1.667
CB08		**parents**, literacy, young children, prototyping, user centered design, ebook, user experience	7	98	136	0.714	0.605	1.000
CB05	QIV: basic/ transversal, bandwagon	augmented reality, **mobile**, gesture interaction, evaluation, usability	5	78	121	0.750	0.756	1.500
CB07		**design**, games, music, stem, museum, play, learning, game design, informal learning	9	212	330	0.611	0.976	1.083

making, inclusion, education, child robot interaction) and CB10 (i.e., collaboration, creativity, tangibles, storytelling, interactive surfaces).

4.3. Development and trend topics in CCI

4.3.1. Correspondence analysis

From the CA map (Fig. 3) it becomes apparent that there is a shift of the community's interest in the research topics throughout the years from 2003 to 2018, and that new topics have recently risen and attracted the researchers' attention. The maturity of the field and how it has been established in time is also depicted in this map. The intellectual progress of the field is reflected on the clusters of keywords distributed in terms of years. For example, from design methodology that was a core topic in 2004, the community has recently shifted the focus on other topics, like physical computing or computational thinking in 2018. At the same time, topics such as participatory design and block based programming remain the core areas of interest for more years, spanning from 2012 to 2018, and constitute central themes to the network.

4.3.2. Analysis of the strategic findings (co-word network)

QI includes four clusters (i.e., C01, C02, C05, C14) that have high density and high centrality. In other words, these four research themes are internally coherent and central to the CCI network (motor themes). The presence of these four themes as motor themes is not a surprise. Their main elements (i.e., interaction design, making, computational thinking, coding and education) are core terms in our field and were to be expected to serve as a connecting glue to other sub-areas.

QIV covers research themes that appear to be under-developed (i.e., low cohesiveness), but hold the potential to be of considerable significance to the entire research network (i.e., high centrality). The themes in clusters C03, C10 and C11 (include: tangibles, mobile, storytelling, games, music) are likely to be core and transversal for CCI. These themes reflect the challenges identified in [1] (i.e., the role of mobile and pervasive technologies). Our analysis suggests that these themes have the potential to become future motor themes. This suggestion is grounded on the fact that in quadrant IV we find multiple research topics such as "tangibles", games and mobile of very high frequency, comprising evidence that the field is expanding. These themes are likely to become mainstream themes in the future, reflecting the community's conceptual development.

QIII covers themes that exhibit low centrality and low density, or in other words, research themes that are either emerging or declining. In this quadrant we find clusters C07, C08, C09, C12 and C13 (e.g., preschool, parents, e-books, assistive technology). Some of these themes either might not have had enough time to establish strong ties to other research themes (e.g., new terminology was introduced), or may involve isolated topics (e.g., usability). These themes are indicative of research that is either fading or emerging, but in its current state, still of interest to the work being carried out in the global network.

Finally, in QII, are research themes that are developed and have high cohesion within the clusters (high density), but are weakly linked to other research themes, appearing peripheral into the global network (low centrality). For example, C04 (e.g., educational technology, embodied interaction) and C06 (e.g., participatory design, cooperative inquiry) are both well-focused and developed research topics, but are not well connected to other research topics (e.g., coding, interactive surfaces).

Unlike other communities that debate about the lack motor themes and focus of the research (e.g., [51,52]; Fig. 7), CCI conceptual structure provides a "healthy" balance between the four states of a theme (emerging/declining, basic/transversal, isolated and mainstream/motor). Thus, CCI researchers do get behind a small number of topics to advance them sufficiently into the mainstream (e.g., coding, making, education, play, child robot interaction), but at the same time they also try to renew the focus of the community with emerging topics (e.g., tablet, parents, ebook).

Comparing CCI's major research themes (Tables 2 and 3) and strategic diagrams (Figs. 5 and 6), one can further confirm the aforementioned observations (i.e., topics that case as emerging and in the second half they became motor themes). QIII themes (potentially emerging) and QIV themes (underdeveloped that hold the potential to become motor) of the first period, managed to become more central and even motor themes in the second period. For example, themes such as storytelling, child-robot interaction, constructionist and collaboration, moved from QIII or QIV to QI; in addition, the topics of making and interactive surface appear only in the second period and becomes directly a motor

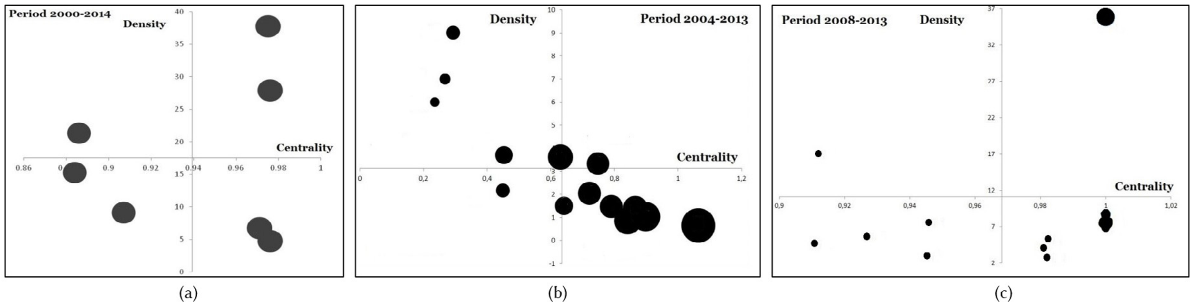

Fig. 7. Strategic diagrams for (a) Games [30], (b) CHI [28], and (c) UbiComp [29]. Note: Node size represents the frequency of the keywords included, node sizes are determined per field, so the reader should not make comparison across diagrams but only within.

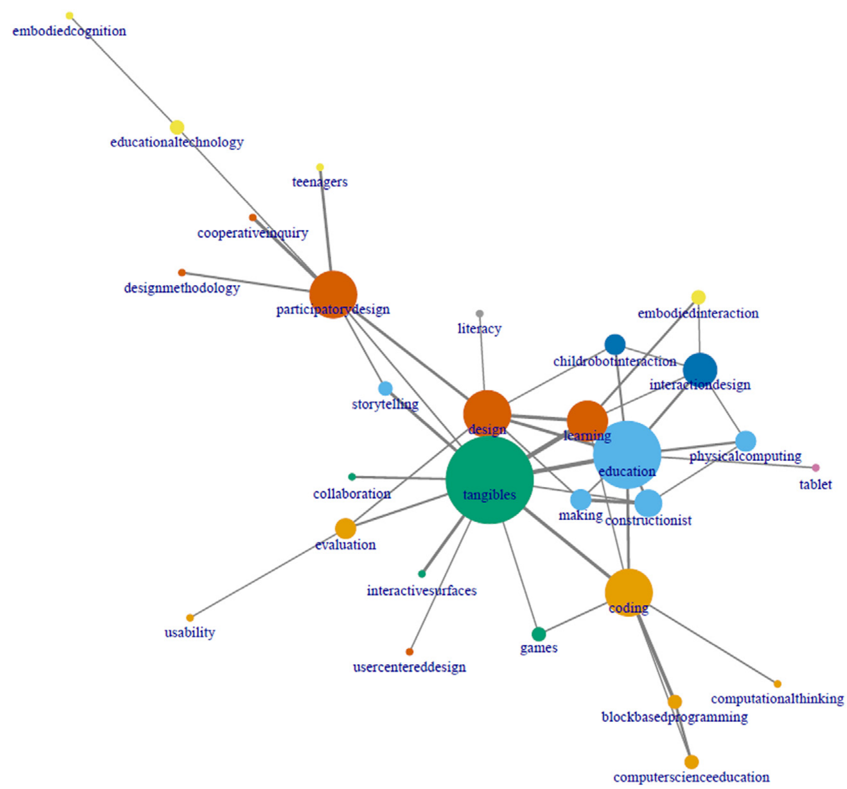

Fig. 8. Keywords network map for CCI (the line represents the link between two keywords with correlation coefficient ≥0.306).

theme. Three themes are part of QI in both the periods, those themes are tangibles, education and inclusion.

Comparing the results of the first period (Table 2 and Fig. 5) with the results coming from the analysis of the whole lifetime of CCI (Table 1 and Fig. 4), also gives us interesting insights. We can notice that several topics that are part of QIII and QIV in 2003–2012 (e.g., block-based programming, coding, constructionist, etextiles, autism, UCD, child-robot interaction) become part of QI in the 2003–2018 analysis, with some of them not being in QI in 2013–2018 analysis. This means that in some cases, looking the 6 last years window does not necessarily give an accurate result, this is an interesting insight and can be based on several reasons we cannot know from this analysis (e.g., groups of people who participate every 2–3 years and sustain a certain topic).

4.4. Keyword network map

4.4.1. Keyword network map for the period 2003–2018

Overall, a keyword network demonstrates the relationships among different research themes. To better understand and visualize the interactions between the CCI research themes presented in Table 1, network analysis was performed to create a granular network map of the keywords. Fig. 8 displays these results, in which each node in the graph represents a keyword that is linked to other keywords that appear on the same paper. The size of the nodes is proportional to the frequency of the keywords, the color of the node corresponds to the cluster the keyword has been classified in, and the thickness of the links between the nodes is proportional to the co-occurrence correlation for that pair of keywords. From this analysis, keywords that appeared less than 11 times in the initial dataset were excluded (as explained in the previous section) as well as keywords with less than 6 strong ties,

Table 4
Summary of popular, core and backbone topics in CCI, in bold are the topics that appear in all categories.

#	Popular topic	Frequency	Core topic	Coreness 0–1	Backbone topic	Constraint 0–1
1	**tangibles**	132	**tangibles**	0.636	**tangibles**	0.162
2	**participatory design**	103	**design**	0.528	**participatory design**	0.188
3	**design**	80	**education**	0.527	**education**	0.249
4	**education**	79	**coding**	0.500	**coding**	0.292
5	**learning**	67	**participatory design**	0.491	**design**	0.301
6	interaction design	66	**learning**	0.490	**learning**	0.352
7	**coding**	64	constructionist	0.444	evaluation	0.401
8	autism	58	storytelling	0.431	interaction design	0.428
9	**making**	58	evaluation	0.424	constructionist	0.454
10	mobile	57	games	0.418	educational technology	0.500
11	games	53	**child robot interaction**	0.406	child robot interaction	0.519
12	educational technology	47	**making**	0.400	**making**	0.522

i.e., weak ties, that would lead to a highly disconnected network. To reduce visual clutter, Fig. 8 illustrates a centralized subset of the complete network, omitting isolated nodes (for the full keywords network map, please see Appendix A).

Finally, core–periphery analysis was performed to identify the core research topics in the field, from a whole-network perspective, as individual keywords, regardless of the cluster they belong to. The analysis yielded twelve core research topics in each of the following categories (Table 4):

- **Popularity:** how frequently a keyword is used;
- **Core:** how connected is a keyword with other topics; coreness is measured on a [0–1] scale
- **Structural holes (constraint):** how connected is a research keyword with other otherwise distinct topics (i.e., if the topic creates a backbone of the field); constraint is measured on a [0–1] scale.

A higher core value indicates a topic that is well connected to other topics. Higher structural holes suggest a keyword that brings together otherwise isolated topics. Burts constraint (i.e., Constraint: [53]) is commonly used as a measure of structural holes (accurately speaking, the lack of it, because the larger the constraint value, the less structural opportunities a node may have for bridging structural holes). In other words, keywords that "act" as bridges between topics have lower constraint values. Topics with high scores on Popularity and Coreness and low score on Constraint can be considered as the driving force for advancements in the field: without these topics, the field of CCI would be fragmented.

4.4.2. Keyword network map for the periods 2003–2012 and 2013–2018

Similar analysis was performed for the periods 2003–2012 and 2013–2018. The results coming from the analysis of the first and the second period can be seen in Table 5. Looking at that table, we can observe that tangibles seem to lose some of their "domination" (is the most populous, core and backbone topic in the first period, but not in the second), while topics such as PD, coding, autism and education are significantly strengthened (doubling their frequency and increasing coreness) and other topics such as making, constructionist and child robot interaction appear only in the second period. Interestingly, three topics with high frequency in the first period (i.e., interactive surfaces, mobile, educational technology) do not appear in the second period.

Similarly with the analysis performed for 2003–2018, we also developed the keyword network for the first and second periods of CCI (Figs. 9 and 10). Looking at those two figures, we can confirm that tangibles were dominating during the first period, while they became less central and populous in the second period. At the same time, in the second period, we can see the genesis of two clusters, one in the areas of coding, CS education, computational thinking and block-based programming and another one in child–computer interaction. At the same time, we can also observe the further development of two clusters, one around design (that connects play, learning, evaluation, making, etc.) and another one around PD (that connects cooperative inquiry, design, education, etc.). One more observation is the appearance of the topics, STEM, making and constructionist, as "satellite" topics of education.

5. Discussion

5.1. Challenges

During the last decade the CCI community has witnessed steady growth, as evidenced from the increasing number of publications each year (Fig. 2). This expands our community to new areas (e.g., wearables) but also helps to develop mainstream/established areas where CCI is mature [1]. Since our research field is constantly progressing and moving towards new research themes, it is important to map the intellectual progress, identify emerging, declining as well as popular and core research topics in order to facilitate the process of understanding our community and the respective sub-fields.

In the early stages of the CCI community the focus was on making coding accessible to children, and in general allowing children to think about powerful ideas (e.g., mathematics, coding, music) [54], as well as influencing a broad vision for the use of computers in education [55,56]. As shown from our analysis, those initial thematic areas have nowadays reached a relatively high level of maturation and centrality in the field (although some can claim that are not as mature as we would have liked). Throughout the years, CCI now has its own thematic areas, such as games, child robot interaction, storytelling, and connecting families and these seem to be developing core topics in recent years (Table 4). This expansion allowed us to bring together various disciplines (e.g., design, computer science, learning sciences) and methodological traditions (e.g., from social sciences, engineering) that help us to develop a clear epistemological position and further our knowledge landscape and horizons.

Table 4 identifies the most popular (i.e., high frequency), core (i.e., high connection with other topics) and backbone (i.e., connection with otherwise isolated topics) thematic areas that emerged during the period 2003–2018. Seven of the most popular themes are also core and backbone themes in the field, suggesting a high consistency between research interests and scientific efforts to maintain the sustainability of the field. Participatory design, tangibles, design, and education are the top four most popular and at the same time, core themes of CCI, with coding, learning, making, and games scoring very high in both categories as well. This confirms the clear connections between CCI, design and learning science as well as the participatory nature of the field. Confirming the challenge indicated by Read and Markopoulos [1] about closing the gap between theory and practice/design,

Table 5
Summary of popular, core and backbone topics in CCI for the 2 periods.

First period (2003–2012)						
#	Popular topic	Frequency	Core topic	Coreness 0–1	Backbone topic	Constraint 0–1
1	**tangibles**	70	**tangibles**	0.773	**tangibles**	0.201
2	**participatory design**	34	**education**	0.531	**participatory design**	0.337
3	**education**	30	**learning**	0.515	mobile	0.500
4	**learning**	27	**design**	0.500	**coding**	0.501
5	mobile	27	**participatory design**	0.500	collaboration	0.506
6	educational technology	26	**interaction design**	0.500	**design**	0.516
7	**interaction design**	26	**coding**	0.485	evaluation	0.537
8	**design**	25	embodied interaction	0.472	**education**	0.544
9	**coding**	20	evaluation	0.472	**learning**	0.548
10	**games**	20	collaboration	0.472	**interaction design**	0.568
11	interactive surfaces	20	**games**	0.459	**games**	0.628
12	autism	19	user centered design	0.447	embodied interaction	0.675

Second period (2013–2018)						
#	Popular topic	Frequency	Core topic	Coreness 0–1	Backbone topic	Constraint 0–1
1	**participatory design**	69	**education**	0.697	**education**	0.202
2	**tangibles**	62	**design**	0.622	**design**	0.211
3	**design**	55	**coding**	0.575	**tangibles**	0.232
4	**making**	53	**tangibles**	0.548	**coding**	0.270
5	**education**	49	**making**	0.500	**participatory design**	0.299
6	**coding**	44	block based programming	0.489	tablet	0.337
7	interaction design	40	**participatory design**	0.479	storytelling	0.375
8	**learning**	40	**child robot interaction**	0.479	**making**	0.378
9	autism	39	**constructionist**	0.469	**learning**	0.390
10	games	33	**learning**	0.460	**child robot interaction**	0.408
11	**constructionist**	32	tablet	0.451	block based programming	0.428
12	**child robot interaction**	31	physical computing	0.442	**constructionist**	0.497

* In bold are the topics that appear in all categories.

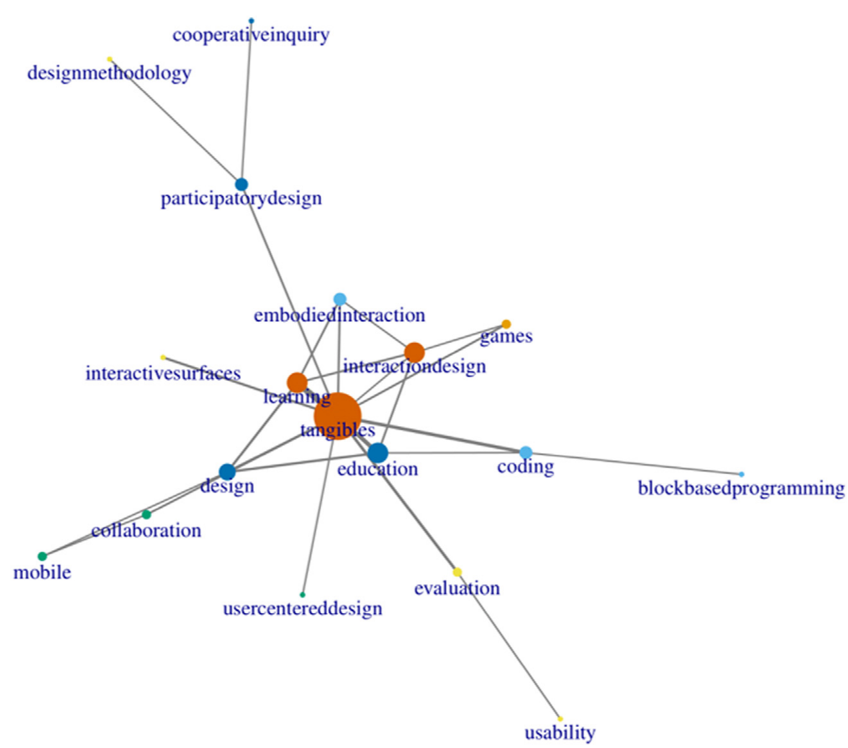

Fig. 9. Keywords network map for CCI for the period 2003–2012 (the line represents the link between two keywords with correlation coefficient ≥0.307).

we notice that no popular terms relate to theory or any other intermediate level knowledge, supporting previous findings [20] that CCI focuses in ''artefacts-centered evaluations'' and fails to look beyond particular artefacts in order to develop intermediate-level knowledge. This is likely to slow progress in our field and fail to achieve cohesiveness and universality.

5.2. Reflections and implications

Looking at the overall results, reading Fig. 4 and Table 1 together, we can easily see that the clusters with high centrality are the ones that are the most frequent ones. Observing the clusters identified as motor-themes in our analysis (i.e., Q1), we can see that they all are of good size and relatively coherent. The first

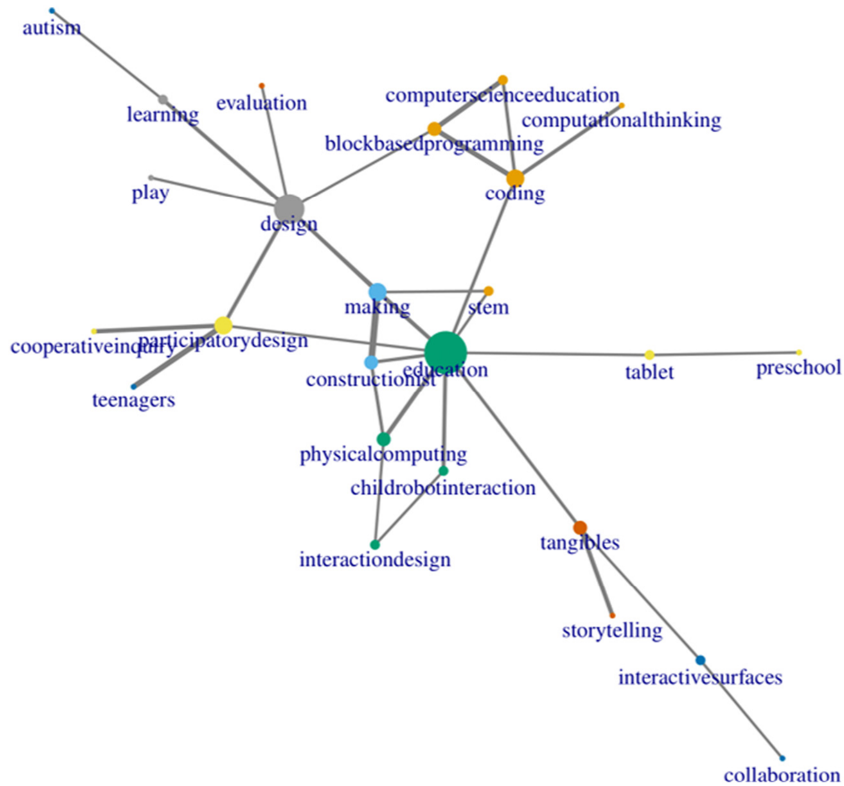

Fig. 10. Keywords network map for CCI for the period 2013–2018 (the line represents the link between two keywords with correlation coefficient ≥0.114).

cluster (i.e., C01) includes works in the areas of coding, computational thinking and computer science education in general. The appearance of C01 as well as its position as a motor theme is not a surprise, since making coding accessible to children has been one of the initial goals of the community [2]. Along the same lines, the second cluster includes works in the area of making, STEM, e-textiles, constructionism, physical computing, and education. This is another expected cluster and it is also not a surprise to find it as a motor theme. The thematic areas of C01 and C02 are also closely related, this can be clearly seen in Fig. 6 where C01 and C02 have several interconnected keywords, but are not that close to formulate one cluster. One can argue that the keyword education is generic and might have been appropriate to other clusters as well. Indeed, education is a very frequent keyword that appears on the border of C02 with other clusters (Fig. 4) and appears to be a core and backbone topic (Table 4). Thus, although it belongs to C02 it also contributes to neighboring topics (e.g., tangibles, learning, coding).

The other 2 clusters (C05, C14) identified as motor themes seem to include keywords that are less thematically robust, but apparently there are several authors that use them together. This can happen because there are sub-fields that use this co-occurrence of keywords frequently (e.g., play, child-robot interaction) or specific methodology that applies to certain areas (e.g., User-Centered Design, autism, learning). Either way, it is clear that those two clusters include keywords with high frequency (e.g., design, learning) that play major role (as motor themes) in CCI.

C04 and C06 were identified as developed but isolated themes (i.e., Q2). Given that both clusters include some very frequent and central keywords (e.g., participatory design and educational technology) this is a bit of a surprising result. But looking at the network of CCI (Fig. 6) is clear that those two clusters are well-developed, but at the same time isolated from other networks. For C04 the results show that while there is a significant amount of work on educational technology there is perhaps more emphasis on embodiment, and thus there is probably an opportunity for cross fertilization between CCI and the EdTech community. For C02, the co-occurrence of participatory design with design methodology and cooperative inquiry is not a surprise, but the fact that this cluster belongs to Q2 is an indication that participatory design is not very widespread and there is a developed but isolated group of people working in that area.

In the emerging or declining clusters (i.e., Q3) we see five different clusters, with all of them having a relatively small size. None from the five clusters is a surprise and all of them are thematically robust. It is interesting to point out that the keywords mix populations (e.g., parents, teenagers) with methodologies (evaluation), technologies (e.g., tablet, ebook) and application areas (e.g., literacy). It is very interesting to identify these keywords in the emerging or declining clusters, and not in the motor-themes one. One could argue that IDC/CCI authors do not always use keywords that describe the population, methodology and technology to define their paper, thus it might be a good idea to have this information requested for IDC/CCI papers. By providing such keywords, e.g., specifying age group, this will allow us to to make studies comparable/easily retrievable, and will also help identify more appropriate reviewers and areas where we might need to intensify our research.

In the basic and transversal themes (i.e., Q3) we see three clusters. C03 is a cluster we expected, linking different technologies (e.g., mobile, interactive surfaces) with informal learning and museums. C11 is a very interesting cluster, since it connects tangibles, collaboration, games and music; all these areas are very central in CCI with tangibles being the most frequent topic (Table 4). C10 is a thematically heterogeneous cluster, mixing game design, with storytelling, prototyping, creativity and AR. Storytelling and creativity are very common topics in CCI, however it is unclear how the other topics are connected. Of course, this Quadrant has the basic and transversal themes (i.e., themes that are strongly linked to specific research interests throughout the network, yet are only weakly linked together) and thus the connections between them are not strong anyway (can also be observed from the network of CCI (Fig. 8)).

Overall, the CCI community seems to have a very healthy distribution of topics, covering all the four quadrants of the strategic diagram. Looking at Table 4 and Fig. 8, one can easily observe that important keywords relating to the age-group or methodologies applied are not used frequently and there are several clusters that do not connect with such keywords (e.g., there is no keyword related with age-group in the motor-theme clusters). Thus, an important implication is that proper use of keywords or even indexing of papers should include keywords such as age-group, sample, and methodologies, or perhaps have a dedicated section where those critical aspects are described (like we do for ethics in IDC). This is likely to increase the impact of the CCI community, but also boost meta-analyses and approaches that produce highly generative knowledge, as well as allow comparison/transfer of knowledge from one age-group to another.

5.3. CCI as a field of research

Discussions about the development of a scientific community, enable researchers to reflect and engage in a constructive and critical dialogue about the identity and future of the community. Neighboring communities such as HCI and interaction design, have such a dialogue from time to time. For example, Kostakos [51], based on Liu et al. [28], highlights how the CHI community does not seem to systematically get behind a number of topics to advance them sufficiently into mainstream (motor themes); rather most research topics remain (and fade out) as weakly structured, emerging, or underdeveloped topics. While the diagnosis comes from a systematic data-driven approach and seems to be undisputed, the conclusions and implications are less so. Following Liu et al.'s, (2014) analysis, Blackwell [57] analyzed HCI projects from the Crucible network and confirmed the lack of convergence, but he also argued that the developments in HCI are a catalyst (or source) of innovation. In the same vein, Reeves [52] suggests that we should stop worrying about the scientific nature of HCI, and instead focus on developing appropriate forms of rigor and embrace our nature of being interdisciplinary. Along the same lines, Frauenberger [58] proposes to adopt the philosophical foundation of "critical realism" that avoids the danger where knowledge construction becomes arbitrary and isolated in its context. This will allow the field to embrace diverse scientific inquiries that often complement each other and potentially reconcile the variety of approaches, practices, and stances.

In the area of interaction design, Höök et al. [59] organized a workshop at the CHI conference about knowledge production in interaction design. The outcome of the workshop recognizes that knowledge comes in various forms, ranging from highly general knowledge (e.g., universal laws) to highly contextualized insights [60]. In between, there is Intermediate-Level Knowledge, which consists of representations of knowledge in-between general theories and particular artefacts in terms of abstraction and generalizability. Intermediate-Level Knowledge is formulated in various forms, such as strong concepts or annotated portfolios that are increasingly used to communicate research through design outcomes [61]. Such intermediary knowledge, resonates with Reeves' proposition about appropriate rigor and Frauenberger's philosophical stance of critical realism.

In the CCI community there is an ongoing discussion about the development of CCI as a field of research. There have been sporadic expressions towards cultivating higher-level knowledge. This occurred in the form of papers [20], workshops [62], special issues[1] and keynotes (IDC 2016) that have surfaced at the IDC conference in the last few years. In particular, Markopoulos held a keynote concerning the development of the CCI field since its inception, one of the observations in his talk was whether the CCI community tends to follow the latest technological developments (e.g., papers exploring the application of new technology to the CCI domain) and producing "artefact-centered papers". A year later, Barendregt et al. [20], inspired from Markopoulos keynote, analyzed a selection of IDC artefact-centered papers and argued for their potential to construct intermediate-level knowledge, that can help us to advance our community.

Our contribution in this paper recognizes the previous debates and provides an analysis of the CCI body of publication. The results of our analysis showcase that CCI has a very healthy distribution of topics covering all the themes (emerging/declining, basic/transversal, isolated and mainstream/motor). It demonstrates that the CCI community has a focus on a small number of topics as motor themes (e.g., coding, making, education, play, child robot interaction), but at the same time the CCI community engages with emerging and potentially underdeveloped topics (e.g., tablet, parents, ebook). Our goal in this work is not to argue about the scientific nature of CCI, but to provide a mapping of its research through a generally acceptable approach in order to initiate a fruitful dialog within our community, as well as, facilitate the process of understanding differences and commonalities within the various sub-fields of CCI.

5.4. Limitations

This work does not claim that provides a comprehensive review of the field, but rather provides quantitative insights in order to support the CCI community in its further maturation and development. The selection and execution of each step of our methodology was extensively discussed and agreed within the authors and conducted with care. However, as with any methodology, we are aware that our methodological choices entail certain limitations.

First and foremost, the analysis includes only IDC and ijCCI publications, which despite being the flagship venues of CCI, as selection, bring some bias to the study (e.g., a conference that takes place between the USA and Europe so CCI researchers from other continents might not be able to regularly participate). In addition, CCI papers are published in other HCI venues and therefore not included in the analysis (e.g., several CCI special issues were published during the last decade, other conferences like CHI and CSCW publish CCI research papers etc.). Thus, the fact that other CCI contributions from "neighboring" conferences and journals were not considered in this analysis, introduces a selection bias. However, it is valid to say that the process of selecting CCI contributions from "neighboring" conferences and journals will also introduce certain selection bias. Nevertheless, the input included in our analysis (i.e., IDC, ijCCI publications), presents clear insights on CCI evolution seen through the lens of the publications coming from our flagship venues.

Another crucial issue is the extent to which author-assigned keywords accurately reflect a paper. The majority of authors do not follow the same approach when assigning keywords to their papers (e.g., frequency, different backgrounds), and this might lead to inconsistencies. Although our analysis is not vulnerable to some of the inconsistencies and has certain protection mechanisms (e.g., very low frequency keywords do not play a significant role), the analysis still has a certain bias from authors' habits and perceptions. This limitation has also appeared in previous similar

1 http://ixdea.uniroma2.it/inevent/events/idea2010/index.php?s=102&link=call40

studies (e.g., [28–30]) and can be overcome with future work that uses text mining techniques to extract the keywords. However, in order to investigate the evolution of a scientific community it is important to consider how the main actors of this community (i.e., authors) assign keywords, and thus the results of our analysis can offer useful insights for self-reflection, challenge the contemporary research directions, and highlight opportunities for future CCI contributions.

6. Conclusion and ongoing work

CCI is a growing community with its flagship annual conference (IDC) and journal (ijCCI), as well as several neighboring conferences and journals (e.g., CHI, CSCW, ToCHI). Although the genesis of the community goes back to the 1960s, CCI is continuously growing and evolving. As the community grows, there is an acute need to map the intellectual progress of the different topical areas, facilitate the understanding of where we are, debate on where we want to be, and initiate a dialog on how to get there.

The present study performed a co-word analysis of the CCI flagship publication channels in order to quantify the conceptual structure of the field and identify its intellectual evolution (e.g., core, popular, emerging topics). The current findings suggest that CCI is significantly growing during this decade. It has several motor-themes, (e.g., interaction design, play, child-robot interaction, learning, education, making, to mention a few), that are summarized in 4 big clusters (see Fig. 4 and Table 1 together). The results coming from the analysis of the two periods depict that tangibles seem to lost some of their "domination", while topics such as PD, coding, autism and education are significantly strengthened, and other topics such as making, constructionist and child robot interaction appear in the second period, taking the positions of interactive surfaces, mobile, educational technology in the 12 most frequent keywords of the second period.

Overall, PD, tangibles, design, coding, making, learning and education, appear as a driving force in CCI. In addition, the results cluster into 14 major research themes (Table 1) that can help us to facilitate the process of understanding the similarities and differences in the various well developed sub-field (e.g., constructionism; assistive technologies; connecting families; tangibles; informal learning etc.) and use it to gradually create more dense and internally connected network.

Future work, can put into practice different analyses (e.g., authorship or citation analysis) or more qualitative approaches like systematic literature review and systematic mapping. In addition, text mining techniques can be used to extract the keywords and overcome authors' bias. Moreover, future endeavors can include CCI publications coming from other venues and journals, (e.g., dedicated special issues to CCI or selection of CCI contributions coming from CHI, CSCW, ToCHI etc.). Finally, further analysis should consider investigating potential differences of the use of terms after the inception of IDC (e.g., the community did not use the term Child Computer Interaction early on). Such an analysis will reveal areas that emerged recently, areas that disappeared, and areas that simply transformed into something new (e.g., merged or changed their terminology).

Declaration of competing interest

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to https://doi.org/10.1016/j.ijcci.2020.100165.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.ijcci.2020.100165.

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