



Research in User-Centered Design 2009 to 2018: A Systematic Keyword Network Analysis

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Abstract. User-centered design (UCD) has become an important concept in Human-Computer Interaction (HCI) and other disciplines. While there is abundant UCD research, keyword analysis research has been less studied even though keywords are important for achieving better understanding of UCD. Therefore, this study provides keywords network a visual analysis of UCD articles published between 2009 and 2018 to answer the following questions: (1) What UCD-related keywords have been studied and in which disciplines? and (2) How have keywords been connected to on another? The study analyzed 304 keywords articles from IEEE, ACM, and ScienceDirect that included “UCD” in their titles. It utilized Gephi 0.9.2 to visualize keyword frequencies, relationships, and authors’ disciplines. The findings presented that the five most frequently mentioned keywords regarding UCD were “usability,” “HCI,” “User Experiences,” “User-Centered,” and “User Interfaces”. The top five most identified disciplines in the UCD articles were Computer Science, Design, Engineering, Education, and Psychology. In visualizing this data, we created a keyword hierarchy with various sizes of texts and circles, and we denoted various relationship levels between keywords by different weights of edges. This visualization of the selected 43 keywords shows a clear relationship between keywords in which UCD is strongly related to usability, UX, user-centered, HCI, Persona, prototype, interaction design, interface design, assistive technology, design thinking. The findings can be valuable in understanding the current UCD research mainstream for researchers and designers pursuing interdisciplinary approaches.

Keywords: User-centered design · UCD · Keyword · Content analysis · Network · Gephi · Interdisciplinarity

1 Introduction

User-centered design (UCD) has become an important concept, philosophy, and method in studies of Human Computer Interaction (HCI) and design [1] since Norman and Draper's publication entitled: *User-Centered System Design: New Perspectives on Human-Computer Interaction* in 1986 [2]. There have been several studies regarding UCD usability and evaluation methods such as user task analysis, expert guidelines-based evaluation, formative user-centered evaluation, comparative evaluation of virtual environments, and the state of user-centered design practice [3, 4].

Keyword analysis has been adopted in diverse disciplines such as business intelligence [5], computer science [6], and education [7], and keyword analysis can also be found in HCI domain. Liu et al. [8] studied co-word analysis published by CHI conference between 1994 and 2013. Liu et al. [8] used co-word analysis to analyze trends and links of Ubicomp in CHI communities [9]. However, although keywords are essential to understanding areas [10] related to UCD, keyword research itself has been less studied, thus the purpose of this study is to reveal the mainstream of UCD research by keyword analysis of UCD publications from 2009 through 2018. We collected 304 articles, including peer-reviewed journals and conference papers from IEEE, ACM, and ScienceDirect databases, and extracted 1234 keywords. We then plotted these keywords using a network analysis and clustering tool called Gephi and proposed three research questions: (1) What keywords have been studied in UCD and in which disciplines? (2) How have keywords been related to one another? The findings would provide meaningful data in understanding the mainstream of UCD research for researchers and designers pursuing interdisciplinary research and design approaches.

2 Keyword Network Analysis and Gephi

Keyword network analysis could be described as investigation of links between items in a given data set displayed by keywords and connectedness between keywords [11], and this characterization of network analysis clearly suggests that important information can be represented by visualization [9]. In particular, keyword analysis provides an explanation of content and reveals links between topics [12]. Since it is assumed that a particular keyword appearing with high frequency may represent a specific research topic [9], keyword network analysis allows us to investigate major patterns and trends of the domain [13–15]. There have been many efforts to present relationships among interdisciplinary research areas through visual network mapping [6]; the first visual map of scientific trends was proposed by Garfield, Sher, and Torpie [16], and the first keyword network map was introduced by Small, Sweeney, and Greenlee in the form of the Science Citation Index (SCI) [17]. Recently, Gephi, an open source software that provides visual representation of data [18], has been applied to discovery of a network. Since Gephi provides real-time data visualization as well as many different types of export [18], it has been used in a variety of disciplines. For example, Ortega et al. [6] used Gephi to seek the most shared labels by creating a keyword map of computer science-related domains. Wan et al. [19] generated a keyword map with Gephi for investigating recommendation method based on e-learning systems.

3 Method and Procedure

This study used a quantitative method to find answers related to keywords that have appeared in UCD research publications and what disciplines have collaborated in conducting UCD research. The study followed the systematic keyword review analysis process shown in Table 1.

Table 1. A systematic keyword review process and screen eligible articles or keywords.

Steps	Review process	Total number of articles or keywords
1. Title search	Search all titles that include “User”, “centered” & “design”, “User-centered” & “design”, and “UCD” in the three main digital libraries of “IEEE”, “ACM”, and “Science Direct” between 2009 and 2018	347 articles
2. Title-duplication filtering	Remove duplicate titles from the list developed in step 1	338 articles
3. Title-unrelated topic	Remove unrelated topics – inaccurate abbreviations – from the list produced in step 2 result (e.g. UCD: urethral catheterization device)	304 articles
4. Keyword search	Search all author-chosen keywords from the step 3 result	1234 keywords
5. Keyword-merge same meaning	Edit/merge keywords with identical meanings (e.g. User-Centered Design to UCD, User Experience to UX)	1234 keywords
6. Keyword-duplication filtering	Remove duplicate keywords from the step 5 result. Each keyword is designated as a node in Gephi	752 nodes
7. Keyword relation connection	For visualization in Gephi, keywords in the same article must each be linked in Excel; each link is designated as an edge in Gephi	5582 edges
8. Discipline search	Search authors’ fields of studies and disciplines from ResearchGate	619 authors’ disciplines in 24 disciplines

We searched peer-reviewed articles published between 2009 and 2018 that included keywords “user,” “centered,” “design,” “user-centered,” “design,” and “UCD” in their titles via three digital database repositories: IEEE Xplore Digital Library, ACM Digital Library, and ScienceDirect. These three selected digital database repositories are well-known digital libraries describing technical, scientific, and medical research [20]. This title search as a first step found 347 articles from journal articles, conference proceedings excluding videos, magazines, and books. From these 347 titles found during the first step, duplicate titles (9 articles) were removed as a second step. As a third step,

we filtered 34 inaccurate abbreviations (e.g., UCD: urethral catheterization device) from the results of the second step. As a fourth step we searched all author-chosen keywords and gathered 1,234 keywords from the 304 articles. To produce a proper keyword network and accurately count keywords, we merged keywords representing identical same meanings, e.g., User Centered Design and User-Centered Design merged to UCD, User Experience merged to UX. This methodology utilized Microsoft Excel and Gephi 0.9.2, a software tool for open-source network analysis and visualization [18], to visualize keyword frequencies, relationships of keywords, and authors' disciplines. In creating a keyword network via Gephi, this study created 752 nodes by removing duplicate keywords and generating 5,582 edges from an article that should be linked to one another. For example, if an article contained three keywords – UCD, UX, and UI, three nodes: UCD, UX, and UI, and six edges: UCD-UX, UCD-UI, UX-UCD, UX-UI, UI-UCD, and UI-UX, were generated. As the last step in the systematic review, we searched for authors' disciplines using the ResearchGate website, a social networking site for sharing papers and looking for collaborators that in 2020 contained names of than 15 million researchers [21]. In ResearchGate a user can self-define his/her disciplines in terms of up to 3 of the 24 discipline names.

4 Results

Through 8 steps of analysis, the researchers found what keywords appearing most frequently in UCD studies, which disciplines have been primarily involved in UCD studies, and how the keywords have been linked to one another. The top five UCD-related keywords other than UCD appearing most frequently were “Usability,” “HCI”, “UX,” “User-Centered” and “UI” as shown Table 2. The percentiles in Table 2 indicate the percentage use of a specific keyword relative to the total number of keywords (e.g., Usability = $\text{Frequency}/\text{Total} = 34/1234 = 2.78\%$).

Table 2. Frequencies of keywords related to UCD.

Rank	Top 10 UCD-related keywords mentioned in articles	Frequency	Percentile
1	UCD (User-Centered Design)	160	13.09
2	Usability	34	2.78
3	HCI (Human-Computer Interaction)	25	2.05
4	UX (User Experience)	23	1.88
5	User-centered	14	1.15
6	UI (User Interface)	12	0.98
7	Assistive technology	8	0.65
7	Design method	8	0.65
7	Prototype	8	0.65
7	Usability test	8	0.65

Figure 1, Fig. 2, and Fig. 3 are visualizations produced by Gephi. The sizes of letters and circles in these figures reflect the keyword frequencies found through the systematic keyword review. The various relationship levels between the two keywords are represented by different line weights, e.g., the line thicknesses in Fig. 1, Fig. 2, and Fig. 3 represent the number of connections between keywords revealed by the systematic keyword review. Figure 1 is a visualization of the relationships between the total author-chosen keywords ($N = 1234$) from the filtered articles that include UCD ($N = 304$). Figure 1 has 752 nodes and 5,582 edges resulting from steps 6 and 7 of the systemic keyword review.

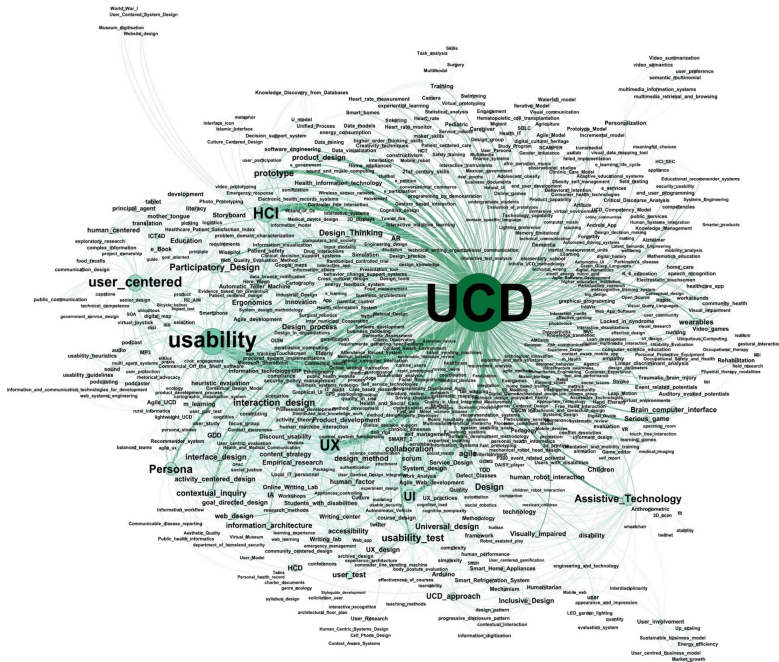


Fig. 1. UCD related keyword network, a total of 752 nodes and 5582 edges.

Figure 1 shows that, using this form keyword visualization, it would be difficult to clearly identify relationships between nodes, thus we filtered the degree range of keywords to visualize it more simply (see Fig. 2). The upper left of Fig. 2 describes connectivity of all 752 nodes, the upper right of Fig. 2 shows the connectivity of 80 nodes, the lower left of Fig. 2 shows the connectivity of 21 nodes, and the lower right of Fig. 2 shows the connectivity of 7 nodes.

Figure 3 describes the associations among the 43 most frequent keywords found in UCD articles. According to the visualization, while UCD has strong connections with keywords usability, UX, user-centered, HCI, Persona, prototype, interaction design, interface design, assistive technology, and design thinking, all keywords do not have

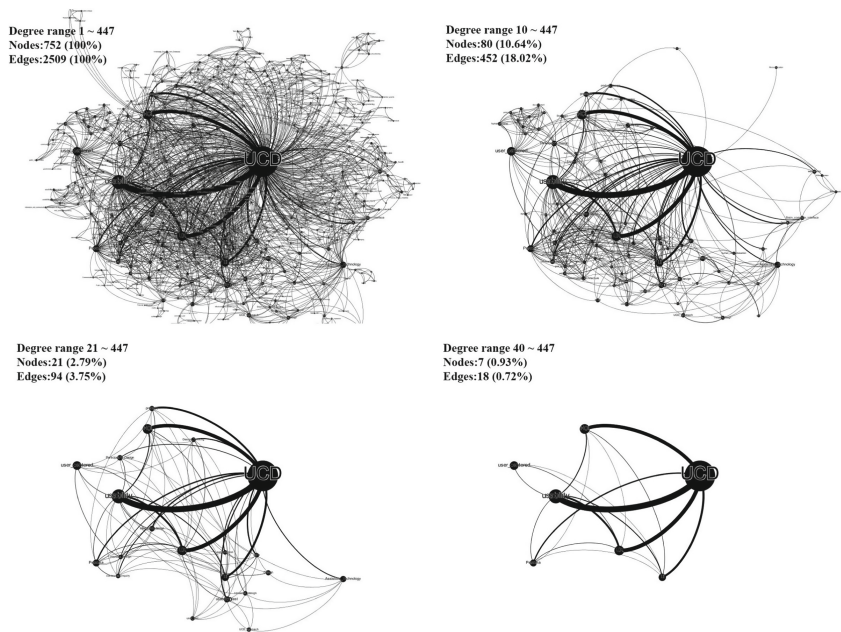


Fig. 2. UCD related keyword network (four levels).

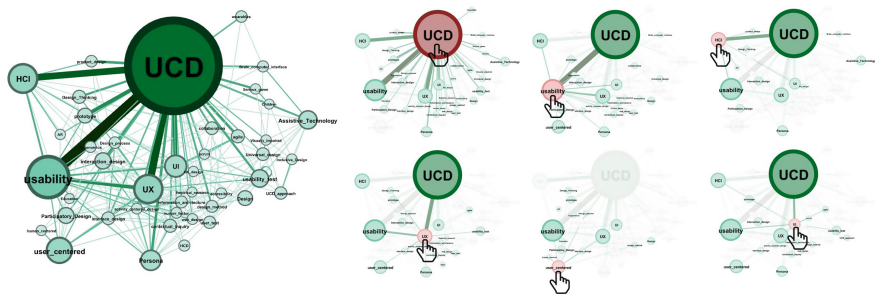


Fig. 3. Visualized results from Gephi of the selected 43 nodes network (on left) and the top six node's network (six images on right): the highlighted nodes and edges show the keywords' association from the selected keyword in red. (Color figure online)

links to one another. For example, while UCD connects to 37 out of the 43 keywords, HCI has connections only with 13 out of the 43 keywords.

From the systematic keyword review of step 8, we found the five disciplines post actively participating in UCD research were Computer Science (N = 194), Design (N = 113), Engineering (N = 72), Education (N = 44), and Psychology (N = 34) (see Table 3), with the percentiles in Table 3 indicating the percentage associated with each specific discipline (e.g. Computer Science, N = 194) relative to the total number of disciplines (N = 619).

Table 3. Frequencies of keywords related to UCD.

Rank	Top 10 fields/disciplines related UCD of authors	Frequency	Percentile
1	Computer science	194	31.34
2	Design	113	18.26
3	Engineering	72	11.63
4	Education	44	7.11
5	Psychology	34	5.49
6	Medicine	31	5.01
7	Economics	29	4.68
8	Social science	27	4.36
9	Entertainment and arts	15	2.42
10	Linguistics	15	2.42

5 Discussion

This study described an attempt at integrated analysis based on the findings from a systematic keyword review. The 7 most frequently mentioned keywords in the 304 articles are Usability, HCI, UX, User-centered, UI, Assistive technology, and Design method. Our finding revealed that these keywords are highly associated with UCD because they are related to the characteristics of UCD, the methods of practicing UCD, a field of the study area in UCD, the philosophical approach of UCD, and disciplines associated with UCD. Regarding the disciplines, the outcome of this study clearly indicates that the disciplines related to UCD are not only in product design and HCI but also in computer science, design, engineering, education, psychology, medicine, economics, and other disciplines. Thus, we could confirm that UCD has been studying actively in various domains and has great potential to collaborate each other.

This study had several limitations. We observed a keyword hierarchy represented by various node sizes, providing at a glance a view of organic connections among keywords using data visualization provided by Gephi. Although this visualization represents clear correlations between keywords by thickness of edge, for future studies the consistency between these visual results and results of consistent statistical analysis results need to be confirmed. Moreover, the visualization complexity makes it difficult to determine how each keyword is derived and connected to the sub-levels of UCD. Therefore, future studies should consider how to efficiently simplify data visualization. Since this study describes the current research mainstream in UCD, our finding would be helpful to researchers, designers, and practitioners through knowledge of UCD keyword research in determining future research topics.

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