IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 4 December 2023, accepted 18 December 2023, date of publication 4 January 2024, date of current version 18 March 2024.

Digital Object Identifier 10.1109/ACCESS.2023.3345036

RESEARCH ARTICLE

Usability Study to Promote Co-Creation Among People With Disabilities, Developers, and Makers With a Focus on the Assistive Technology Open Platform in Korea

EUN RAE RO[1], KWANG OK AN[1], AGNES JIHAE KIM[2], SUNG UK JANG[3], EUN JOO KIM[4], AND SEON DEOK EUN[1]

[1]National Rehabilitation Center, Rehabilitation Research Institute, Seoul 01022, Republic of Korea
[2]Korea Advanced Institute of Science and Technology, Daejeon 34141, Republic of Korea
[3]National Science Museum, Daejeon 34143, Republic of Korea
[4]National Health Insurance Service, Wonju-si, Gangwon-do 26462, Republic of Korea

Corresponding author: Seon Deok Eun (esd7786@korea.kr)

This work was supported by the Assistive Technology Research and Development Project for People with Disabilities and the Elderly funded by the Ministry of Health and Welfare, Republic of Korea, under Grant HJ20C0002.

This work involved human subjects or animals in its research. The authors confirm that all human/animal subject research procedures and protocols are exempt from review board approval.

ABSTRACT Assistive technology plays an important role in facilitating independent living and a high quality of life for older adults and people with disabilities, who depend on the provision of customized assistive devices for various physical functions. Technological advances such as 3D printers have facilitated responses to some of these needs; however, the lack of relevant policies, information, and services makes proper use of these facilities difficult. Therefore, the National Rehabilitation Center established the AT Open Platform—an open-source sharing platform for AT. The AT Open Platform revitalized the customized assistive device industry by using appropriate advanced technologies. In the AT Open Platform, older adults and those with disabilities propose needs, developers develop solutions for these needs and share products as open sources, and manufacturers provide services for older adults and those with disabilities using open sources. Having these various stakeholders interacting on one platform requires high usability. In this study, the usability of open platforms was evaluated by categorizing each stakeholder (idea proposer, developer, and maker); efficiency was evaluated by thematic think-aloud analysis; effectiveness was evaluated by task analysis; and satisfaction was evaluated using the System Usability Scale and the e-government website UI/UX quality evaluation table. Additionally, the functions, content, and visual designs of the open platforms were evaluated. Through this investigation, we suggested ways to improve open-source assistive device websites to meet the needs of each stakeholder. We expect that this open platform with improved usability will improve user accessibility and make it easier to find and use assistive devices that are essential in daily life.

INDEX TERMS Assistive technology, people with disabilities and older adults, platform, usability test.

I. INTRODUCTION

Assistive technology (AT) supports the improvement of mental and physical functions that enable independent living and a high quality of life for older adults and those with disabilities. As the number of older adults and those with disabilities increases, approximately 2.5 billion people worldwide need assistive products to perform independent activities of daily living [1], [2], [3]. Assistive products fulfill important functions and roles in ensuring the quality of life and enabling the

The associate editor coordinating the review of this manuscript and approving it for publication was Orazio Gambino.

TABLE 1. Various usability definitions.

Classification	Contents
ISO 9241-11 [16]	efficiency, effectiveness, satisfaction
Schneiderman [17]	performance speed, learning time, memory, error rate, subjective satisfaction
Nielsen [18]	efficiency, learnability, recall, error/safety, satisfaction
Dix et al., [19]	learnability (predictability, universality, familiarity, integration, and consistency), flexibility (efficiency-related factors such as adaptability and substitutability), and robustness (stability, recoverability, and responsiveness).

independent living of older adults and those with disabilities. Nonetheless, high costs, policies, and lack of services mean that an estimated one billion people with disabilities do not have access to assistive products [1], and only 3% of potential users in low-income countries use AT [1]. Therefore, it is necessary to improve accessibility to assistive technologies.

As the types of assistive devices required vary according to the degree of functionality of each person with a disability, it is necessary to customize them [4]. In recent years, 3D-printing technology has been used in various industries to produce customized products in small quantities and has increasingly been used in the field of assistive devices and rehabilitation. However, to activate services using 3D printers, a combination of physical and systematic support is required [5]. The Open-source AT website approach improves the accessibility of assistive devices [6]. Recent developments include growing communities of open-source assistive devices influenced by Do-It-Yourself and Maker Movement activities [7], [8], [9]. Open-source assistive devices are prototypes based on Open-source Hardware and Open-source Software. These open-source aids have advantages such as high accessibility, low cost, and reusability [10], [11], [12], [13], [14].

Platforms with shared open-source AT include Makers Making Change, Careables.org, and Open Assistive. In South Korea, a platform has been created that not only shares open-source AT as others do but also co-creates an open source with users and developers. Therefore, it is necessary to provide a simple and intuitive interface for users to accept and activate open-source AT websites and essential to evaluate the usability of an open-source AT website that considers the needs of assistive device users. In this study, we reviewed the characteristics of the open-source AT website and analyzed the inherent difficulties through a usability evaluation of the AT open-source platform. On the basis of this study, we suggest strategies to improve open-source AT websites to meet the needs of AT stakeholders. Open-source websites for assistive devices are expected to boost the customized assistive device industry by providing intuitive services and usage methods to stakeholders, thereby making it easy to find, develop, manufacture, and use assistive devices essential for daily life.

II. THEORETICAL BACKGROUND

A. USABILITY

Usability refers to how ''good'' a system of human–computer interaction is [15]. Other definitions of usability include ISO 9241-11 [16]; Schneiderman [17]; Nielsen [18]; and Dix et al. [19], as shown in Table 1. Despite these differences, usability can be broadly characterized as the degree to which an experience is effective in helping users achieve their goals. Some common elements in the various definitions of usability are efficiency, effectiveness, ease of learning, and satisfaction.

The Web standards specified by the World Wide Web Consortium (W3C) provide four guidelines for usability: perceivability, operability, readability, and compatibility. They also provide considerations for understanding the challenges faced by people with visual, mobility, hearing, and cognitive disabilities, and complying with web accessibility requirements for them. Additionally, Web Content Accessibility Guidelines were created to provide guidelines [20]. This study employed the usability content presented in ISO 9241-11.

B. USABILITY TEST

A usability evaluation is meant to discover problems with a system and improve it to achieve an exact understanding of users' needs and expectations [21]. High usability refers to making the user experience positive and enabling them to accomplish tasks efficiently, resulting in a sense of satisfaction and accomplishment [22]. To properly implement usability, it is necessary to know the motivation, expected results, and behavioral procedures of the service in people's heads, which is used as a measure of whether users can easily and efficiently use the service in a given environment [23].

Website usability is also very important for government portal websites [24]. From a citizen's perspective, ''many key functions of government to its citizens involve the provision of web-based information and services'' [25]. Studies on the usability of government websites suggests that if they are not easy to use, they will turn off citizens, and the evolution of an e-government will be hindered because citizens will not have satisfactory contact with their government [26]. Son [27] suggests that usability is as important as design when developing a website. Customer satisfaction with a website depends on how easy and convenient it is to use, and this usability is directly related to the value to the government or company that runs the website. Therefore, website developers and designers should consider user perspectives and provide a web environment through usability evaluation tools.

However, many studies of information systems used a survey method. One limitation of this method is that it is difficult to measure the unconscious behavior of participants or problems of which respondents are not fully aware [28], [29].

Therefore, in this study, we separated the various stakeholders of government portal websites and examined their usability from their respective perspectives. Additionally, all

interviews were conducted face-to-face, and two interviewers analyzed both the unconscious behavior of the participants and their conscious expressions through think-aloud methodology. This study's significance is that it improves the utilization of information provided by the government and lays the foundation for the continuous and smooth provision of information on AT, which contributes to the quality of life of people with disabilities and older adults.

A review of studies [18], [30], [31], [32], [33] on the areas that constitute usability evaluation identified three areas as commonly included: function implementation, content design, and visual design. First, the area of ''function design'' may include factors such as ease of use, effectiveness of navigation, immediacy of feedback, and system flexibility. Second, the domain of ''content design'' can include educational factors such as the degree of cognitive load, appropriateness of media integration, congruence between interface and learning content, and clarity of instructions. Finally, the domain of ''visual design'' can include factors related to visual elements such as visual aesthetics and effective placement and organization of text and graphics.

In this study, we analyzed functional implementation through task analysis, content design through thematic analysis, and screen design through thinking-aloud, as presented in Table 2.

TABLE 2. Usability test content and tools.

Usability Classification	Content of Usability Test	Test Tools
efficiency	visual design, content design	thematic analysis of data collected with think-aloud
effectiveness	function design	task analysis
satisfaction	visual design, content design, function design	SUS, website UIUX

III. METHOD

This study evaluates the usability of an open-source platform. Usability refers to the fulfillment of effectiveness, efficiency, and satisfaction criteria to achieve goals in a specific context [16]. Effectiveness was determined by the success or failure of tasks that were evaluated to determine whether a platform achieved the users' goals. Efficiency refers to both the performance time and learning time needed to grasp how tasks can be performed effectively, easily, and quickly. Finally, satisfaction was evaluated using questionnaires on a Likert scale or facial expressions. This study evaluated effectiveness and efficiency by task analysis, and satisfaction was evaluated by thematic analysis [34] using the think-aloud method, System Usability Scale (SUS), and the e-Government Website UI·UX quality scorecard.

A. RESEARCH PLATFORM

In this study, a usability evaluation was conducted on the website of an assistive-device open-source platform, which opened on March 2, 2022, and is operated by the National Rehabilitation Center's Assistive Device Research and Development Project for the Elderly and people with disabilities. The platform consists of three services: an Assistive Device Open People, Open Lab, and Open Page. The Open People service provides a meeting place to enable networking in the AT industry. An Open Lab facilitates the collaborative development of assistive devices. The Open Page is used to share the results of the research and development of AT.

TABLE 3. Information of participations (n = 20; site: republic of Korea; year: 2022).

Demographics	Values, n (%)
Sex	
male	14 (70%)
female	6 (30%)
Age (Years)	
20s	4 (20%)
30s	5 (25%)
40s	8 (40%)
50s	3 (15%)
60s	0 (0%)
70s	0 (0%)
Role of AT Open-source Platform	
AT user	6 (30%)
Developer	8 (40%)
maker	6 (30%)

The main features of the open-source platform are as follows: 1. suggesting ideas, 2. participating in the development of AT, 3. sharing developed open sources, 4. recruiting open people, and 5. obtaining portfolios and certificates. The ''suggesting ideas'' function allows users to share daily difficulties or suggest ideas for assistive devices. This function was designed to be simple to write to enable more consumer participation. The ''participating in the development of AT'' function allows developers to express their intentions to participate in the suggested projects. With this function, idea proposers and developers can communicate, and it is possible to evaluate how many idea proposals and assistive device studies and development are being conducted on the main screen. The ''sharing developed open sources'' function allows developers to share original files or files for 3D printing on an open-source platform, along with production manuals. This program was intended to benefit older adults and those with disabilities. Moreover, the ''recruiting Open People'' function recruits developers with specific skills or people who want to participate in usability evaluation. The ''getting portfolio and certificate'' function attracts various consumers and developers and certifies activities (number of idea proposals, number of assistive devices developed, etc.) performed on the assistive-device open-source platform by the National Rehabilitation Institute. In this portfolio, the numbers of likes and downloads for each post can be checked.

The functions described above can be evaluated on five pages of the assistive-device open-source platform (i.e., main screen, idea suggestion page, assistive device information, My Page, news, and information) and on one page with a quick menu. Therefore, in this study, a usability evaluation was conducted for six detailed pages, including the quick menu.

B. PARTICIPATIONS

The usability evaluation was conducted for six idea proposers, eight developers, and six makers, who comprise the stakeholders of the assistive-technology open-source platform. The three idea proposers and one developer were persons with physical disabilities who had difficulty using their hands but were recruited as users of assistive devices to help them access the Web. A usability evaluation was conducted for those who agreed to participate after receiving an explanation of the usability evaluation. Twenty participants received USD 50 each as compensation. The participants' information is shown in Table 3.

C. PROCEDURE

Data were collected according to the ethical principles and code of conduct of the American Psychological Association [35]. Potential participants were told the study's purpose, procedure, time taken, expected benefits, and privacy policy, and they consented to provide information through audio recordings, photographs, and recording of the screen process. Two researchers conducted interviews, assigned tasks, and completed a questionnaire for each participant with the following components: (1) introducing the study, (2) explaining the privacy policy and obtaining consent to provide information, (3) interviewing about the screens of each menu of the open-source platform of the assistive device, (4) conducting tasks, and (5) completing a survey questionnaire. All usability evaluations were conducted in Korean.

An interview was conducted on the main screen of each menu to explore the six menus (main screen, idea suggestion, assistive device information provision, news and information, My Page, and quick menu) of the assistive-device open-source platform. The interviews evoked verbal descriptions of the expected functions and elicited information using the thinking-aloud method [36].

Tasks were assigned to different scenarios of the assistive-technology open-source platform according to the types of stakeholders (idea proposer, developer, and maker), and the task performance score and execution time were recorded, as shown in Table 4. The tasks were performed immediately after instructions were provided, and the time from the completion of instruction delivery to task completion was measured. Depending on the task level, 100 points were assigned for complete success, 75 and 50 points for partial success, and 0 points for failure. A score of 75 was assigned when a task was completed after the facilitator provided a crucial hint about the relevant menu or task, whereas a score of 50 was assigned when a task was performed but a significant error was encountered in the process of performing the task [37].

The survey included two questionnaires: the SUS and an e-Government Website UIUX quality scorecard. SUS is a fast and reliable tool for measuring usability and consists of 10 items rated on a 5-point Likert scale (1–5 points) from ''strongly agree'' to ''strongly disagree'' [38]. The SUS scores can be converted into the parameters of acceptability, grades, and adjectives, which enables the wide application of SUS as a usability assessment tool [39]. The e-government website UI/UX quality scorecard measures users' satisfaction with service usability and evaluates the overall user experience of e-government websites based on qualitative satisfaction; the responses can be converted into 100 points and indexed using the 5-point scale item [40].

TABLE 4. Usability evaluation topics.

1	2
six tasks for idea proposers: suggesting new ideas, finding similar suggested ideas, finding information on assistive devices related to similar ideas, commenting on assistive devices, requesting the production of assistive devices, and finding partners for assistive device manufacturing seven tasks for developers: finding ideas, participating in development, inquiring about ideas, participating in projects, inquiring about development to developers, uploading open sources of assistive devices, and recruiting open people five tasks for makers: finding assistive devices, downloading open sources, inquiring about idea proposers, inquiring about development to developers, and uploading usage stories	one common task: getting portfolio and certificates

D. ANALYSIS

Fig. 1 schematically presents the analysis process for the four usability evaluations (interviews on main screens by menus, task analysis, SUS, and Website UIUX). The content derived from the interviews on the main screens for each menu and task analysis using the think-aloud method was analyzed thematically using ATLAS, a qualitative data analysis and research tool. Four researchers analyzed the usability of the assistive-technology open-source platform and designed a coding frame. The results were categorized into 32 codes and grouped into nine main themes. From the main themes, the concepts ''new functions on each page'' and ''functions that need improvement on each page'' were derived. The task analysis and survey results were analyzed by frequency and means using SPSS, a quantitative data analysis tool.

IV. RESULTS

A. THEMATIC ANALYSIS

When evaluating the main screens by menu and task analyses, participants were asked to talk about problems, questions, and positive aspects at each step using the think-aloud method [41]. The content thus obtained was coded by each page of the platform using ATLAS.ti and new UXUI functions, and the aspects to be improved were derived for each page.

A total of 415 issues were identified for each page (Fig. 2), with 100 (23.9%) issues related to the main screen, followed by 81 issues on idea suggestions (19.4%), 66 on information about assistive devices (15.8%), 61 on quick menus (14.6%), 59 on My Page (14.1%), and 51 on news and

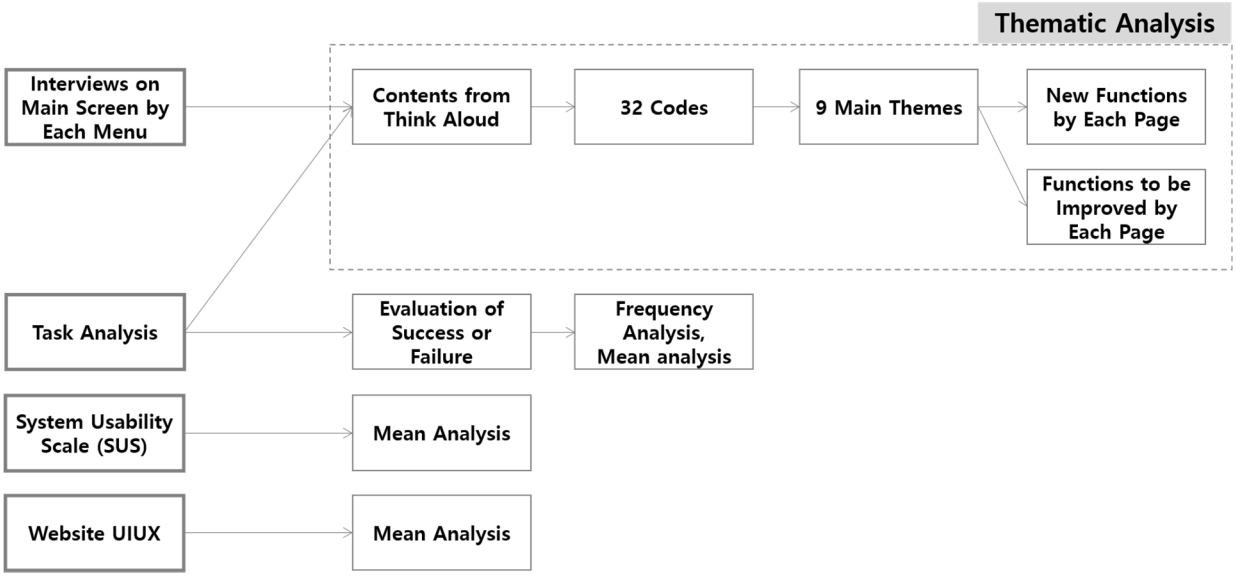

FIGURE 1. Schematic depiction of the research analysis process.

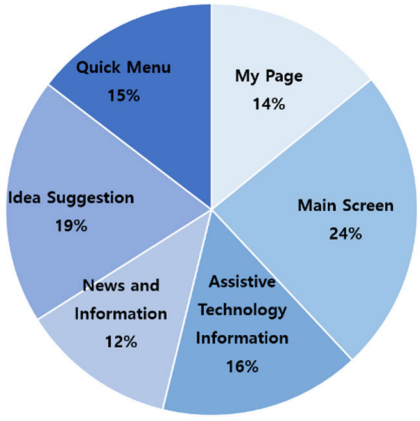

FIGURE 2. Results of the thematic analysis.

information (12.2%). It could be that the reason most issues were concentrated on the main screen is because this screen was the most content-rich.

A total of 32 codes were derived using ATLAS.ti (Table 5). The most frequent code was difficulty in grasping the service content (n = 61, 14.6%), followed by the need to improve operational convenience (n = 41, 9.8%), the need for visualization that is easy to grasp at a glance (n = 41 cases, 9.8%), and difficulty in finding menus (n = 35, 8.4%). On the main screen page, the most frequent codes derived were ''difficulty in grasping the service content'' (n = 13, 13%), ''difficulty in grasping accurate information'' (n = 12, 12%), and ''need to improve operational convenience'' (n = 11, 11%). On the ''idea suggestion'' page, codes for ''the need to relocate the registration button'' (n = 17, 21%), ''difficulty in understanding the service content'' (n = 14, 17.3%), and ''the need for visualization that is easy to grasp at a glance'' (n = 13, 16.0%) were derived. On the ''AT Information'' page, codes for ''the need for visualization that is easy to grasp at a glance'' (n = 12, 18.2%), ''need to improve operational convenience'' (n = 10, 15.2%), and ''difficulty in grasping the service content'' (n = 9, 13.6%) were derived in that order. On the ''quick menu'' page, codes for ''difficulty in finding the menu'' were the most frequent (n = 35, 57.4%). On the ''My Page'' page, the code for ''difficulties in grasping the service content'' was the most frequent with 19 cases (32.2%), followed by ''need to redefine the category'' (n = 8, 13.6%) and ''need to improve the operation convenience'' (n = 5, 8.5 %). On the ''news and information'' page, codes for ''not providing expected information'' (n = 12, 23.5%), ''do not know the terminology'' (n = 8, 15.7%), and ''need of visualization that is easy to understand at a glance'' (n = 7, 13.7%) were derived.

As shown in Fig. 3, the 32 codes derived from six pages were grouped into nine main themes (design and usability issues, information structure improvement, service identity, UX writing, good aspects, improvement of errors, membership and communication, new development issues, and operational issues). Design and usability issues were most frequently reported (n = 175, 42%), followed by information structure improvement (n = 108, 26%), service identity (n = 56, 13%), UX writing (n = 24, 5%), good aspects (n = 20, 5%), membership and communication (n = 11, 2%), new developments (n = 4, 1%), and operational issues (n = 3,1%).

The number of issues related to the nine main themes on each page was analyzed, and the results are shown in Fig. 4. The pages with the most design- and usability-related improvement needs were ''idea suggestions'' and the ''quick menu,'' whereas the pages that needed the most information structure improvement were the main screen and My Page. The pages where the service identity was not clearly visible were the main screen and assistive device information pages.

TABLE 5. Codes for each page.

Codes	Main Screen	Idea suggestion	Assistive technology Information	Quick Menu	My Page	News and Information	Total
difficult in grasping the content of the service	13	14	9	-	19	6	61 (14.6%)
need to improve operational convenience	11	6	10	7	5	2	41 (9.8%)
need visualization at a glance	9	13	12	-	-	7	41 (9.8%)
difficulty in finding the menu	-	-	-	35	-	-	35 (8.4%)
did not provide the information expected	9	6	6	-	-	12	33 (7.9%)
I do not know the terminology	4	3	1	3	5	8	24 (5.7%)
need to improve font and icons	9	11	-	-	-	-	20 (4.8%)
need to relocate the registration button	-	17	1	-	-	-	18 (4.3%)
need to reconstruct menu hierarchy	4	1	5	-	2	4	16 (3.8%)
category override required	-	-	-	8	8	-	16 (3.8%)
I do not understand the value of the service	7	2	3	-	1	1	14 (3.3%)
difficult to get accurate information	12	-	-	-	-	-	12 (2.9%)
good screen composition	7	2	1	-	-	-	10 (2.4%)
screen configuration needs to be rearranged	3	1	2	-	3	-	9 (2.2%)
does not provide the expected functionality	-	1	3	-	1	4	9 (2.2%)
need consistent form reflection	-	-	7	-	-	-	7 (1.7%)
need to think about smooth communication function	-	3	-	-	2	2	7 (1.7%)
others	8	1	6	8	13	5	41 (9.8%)
Total n (%)	100 (23.9%)	81 (19.4%)	66 (15.8%)	61 (14.6%)	59 (14.1%)	51 (12.2%)	418 (100%)

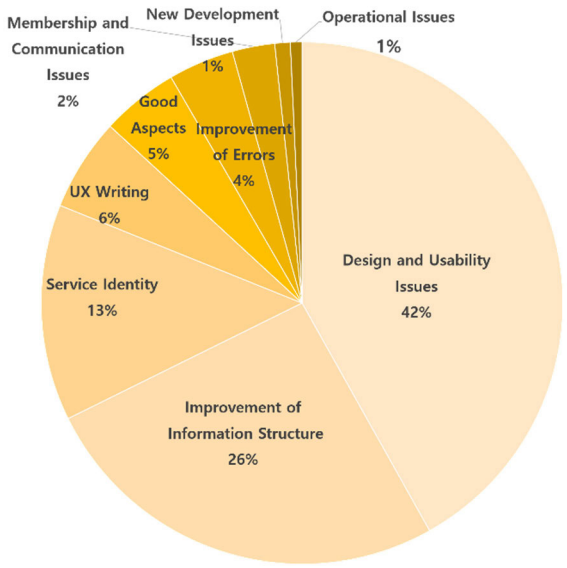

FIGURE 3. Analyzing the 9 main themes.

The pages that needed to improve UX writing were news and information and My Page. The pages with the most frequent positive aspects were the main screen and My Page. The pages with the most issues related to membership and communication were the main screen and idea suggestions, whereas the page with the most frequent new development issues was the main screen. The pages with the most operational issues requiring improvement were the news and information pages.

In terms of design and usability issues on the main screen, ''the need to provide visualization data that can grasp services for Open Platforms, Open People, Open Lab, Open Pages, etc., at a glance'' was highlighted. Regarding the issue of improving the information structure, participants expressed concern that ''it is difficult to recognize the graph on the main screen at a glance.'' On the idea suggestion page, participants suggested introducing a function that makes it easier to find the idea by moving the idea registration button to the top, a function to view the idea suggestion list as a photo or picture, and a function to visualize the content of the idea at a glance by dividing it into tabs, which were derived from the design and usability issues. On the issue of information structure improvement, participants ''wish[ed] to be connected to a related AT when clicking an arm tag.'' On the assistive-device information page, comments such as ''function of selecting and uploading multiple attachments at once and function of displaying a list of assistive devices registered with the same tag when selecting a tag'' addressed the design and usability issue. To improve the information structure, participants called for a ''function to distinguish between assistive devices developed on open platforms and assistive devices with open source from other countries using a tab.'' Furthermore, in terms of service identity, participants

commented ''there is a partner organization that manufactures assistive devices, and there is open source, but there is no function of requesting for production, which is confusing. I do not know which service is the main service.'' In the quick menu, participants insisted on ''modification of the screen composition so that the quick menu can be easily found'' under the rubric of design and usability issues. To improve the information structure, they urged introducing a ''function to integrate and use the quick menu and term search into one.'' In My Page, they requested improving the information structure, such as by ''redefin[ing] it so that there is no conflict between categories that distinguish open people.'' Regarding design and usability, ''[i]t would be nice to make the certificate or portfolio more visible by putting a button at the top of the screen.'' On the news and information pages, the need for a library function to share related data and a function to request production/development from partner organizations were identified as service identity issues. Concerning improvements to the information structure, participants complained that ''too much depth is required from the existing portal site to the recruitment announcement of open people.'' As a design and usability improvement, participants suggested a ''map-based, partner organization location display function visualization in a gallery format.''

B. TASK ANALYSIS

The results of the task analysis are presented in Table 6. We compared the average time taken to complete the tasks by 20 participants who had direct or indirect experience with AT Open Platform research and three experienced participants who had built and operated the AT Open Platform themselves. Compared to those with experience, participants required, on average, 38.1 additional seconds to complete the tasks. It took an average of 47 seconds for idea suggestion tasks, 60 seconds for developer tasks, and 32.2 seconds for maker tasks. In the case of the idea suggestion task, the task with the largest deviation was ''commenting on the assistive device,'' and the task with the smallest deviation was ''requesting the production of the assistive device.'' In the case of developer tasks, the task with the largest deviation was ''uploading open source of assistive devices,'' and the task with the smallest deviation was ''inquiry of ideas.'' In the case of the creator tasks, the task with the largest deviation was ''uploading usage story,'' and the task with the smallest deviation was ''downloading open sources.''

Tasks with large time deviations were commonly related to inputting ideas, assistive devices, and usage stories. These tasks are not simple but require users to understand the written content and are, therefore, more time-consuming. Moreover, tasks with small time deviations, such as requesting the production of assistive devices, participating in projects, and downloading open sources, were simple. These tasks could be performed if the button was properly located.

The probability of complete success (S) was 50% on average for the idea suggestion tasks, 71.4% for the developer tasks, and 79.2% for the maker tasks. Among the idea

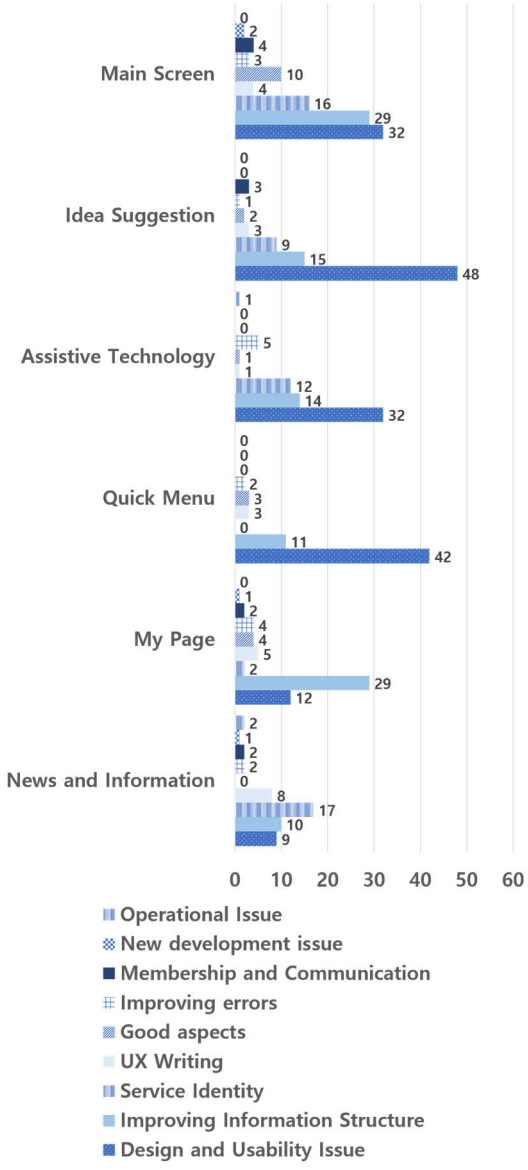

FIGURE 4. Analyzing the nine main themes on a per-page basis.

suggestion tasks, the task with the lowest total score was ''finding a partner organization for the production of assistive devices,'' at 375 points, and the task with the best score was ''new idea suggestion,'' at 550 points. The task of finding a partner organization to produce assistive devices also required users to move to another page to look at the details, which was complex and reduced their performance levels.

In the developer tasks, ''finding ideas'' scored the lowest at 550 points, and ''participating in development'' scored the highest at 775 points. The participants thought that the process of finding ideas should be performed on the assistive device information page, but it was on the idea suggestion page that they were able to find ideas, making the search difficult.

Among the maker tasks, the task of ''contacting the idea proposer'' scored the lowest at 200 points, and

TABLE 6. Task analysis evaluation criteria.

Classification	Tasks	Average Time to Complete (Seconds)			S (n)	P1	P2	F	E	Score
		Participants	Experienced Users	Time Gap		(n)	(n)	(n)	(n)	
idea proposer (6 people)	propose new ideas	117	41	76	4	2	-	-	-	550
	find similar idea suggestions	72	14	58	2	4	-	-	-	500
	find assistive device information related to similar ideas	49.2	11.3	37.9	1	5	-	-	-	475
	comment on assistive devices	78	13.7	64.3	3	3	0	-	-	525
	request for the production of assistive devices	31.3	8.7	22.6	5	-	-	-	1	500
	find a partner organization for assistive device manufacturing	40.3	17	23.3	3	1	-	2	-	375
average score/total score (standard deviation)			487.5/600 (±55.4)							
developer (8 people)	find ideas	53	18.7	34.3	3	2	2	1	-	550
	get involved in the development	66	23.7	42.3	7	1	-	-	-	775
	contact for ideas	39.1	12.7	26.4	5	1	2	-	-	675
	participation in the project	40.1	15	25.1	5	1	-	2	-	575
	ask the developer about the development	36.8	20	16.8	6	2	-	-	-	750
	uploading assistive device open source	293.9	108	185.9	4	3	-	1	-	625
	recruitment of open people	154.4	65.3	89.1	5	3	-	-	-	725
average score/total score (standard deviation)			667.9/800 (±81.0)							
maker (6 people)	find an assistive device	32.3	19	13.3	5	-	1	-	-	550
	downloading open source	23.7	23	0.7	6	-	-	-	-	600
	contact person who suggested ideas	34.8	34	0.8	2	-	-	1	3	200
	ask the developer about the development	52.2	21.7	30.5	5	1	-	-	-	575
	upload your story	177.3	61.7	115.6	2	3	1	-	-	475
average score/total score (standard deviation)			480/600 (±146.1)							
common task 3	getting portfolio and certificates — idea proposers (6 people)	27.2		14.9	6	-	-	-	-	600
	getting portfolio and certificates — developer (8 people)	23.5	12.3		8	-	-	-	-	800
	getting portfolio and certificates — maker (6 people)	25.8			6	-	-	-	-	600
average score/total score (standard deviation)			666.7/800 (±94.3)							

"downloading the open source" scored 600 points, reflecting perfect performance by all participants. Inquiring about the idea proposer could be performed using a direct message or a 1:1 inquiry, but the UI of the direct message was too small to be seen. This is why participants had difficulty performing the tasks.

C. SUS

The overall results of the usability evaluation were analyzed, as shown in Table 7. When the SUS results were interpreted by acceptability, grades, and adjectives, the overall mean was Acceptable, B-, and Good [39], [42].

D. WEBSITE UIUX

The overall mean score of the E-Government Website UI·UX quality evaluation was 75.07, indicating a good result.

Seventy-five points or more were interpreted as good, and 50–75 points were interpreted as reflecting a partial need for improvement [43]. The E-Government Website UI·UX quality evaluation is divided into seven types of

TABLE 7. Results of SUS.

No.	Category	Average SUS
1	average of idea proposer	70
2	average of developer	73.61
3	average of producer	76.67
4	overall mean (standard deviation)	73.45 (±3.34)

TABLE 8. UI·UX evaluation results by stakeholders.

No.	Category	Mean Scores (Points out of 100)
1	mean score of idea proposers	74.36
2	mean score of developers	74.64
3	mean score of producers	76.44
4	overall mean (standard deviation)	75.07 (±1.13)

UI·UX design criteria [40]. The mean scores for each stakeholder are presented in Table 8, and the overall mean scores for each of the seven criteria are shown in Fig. 5 and Table 9.

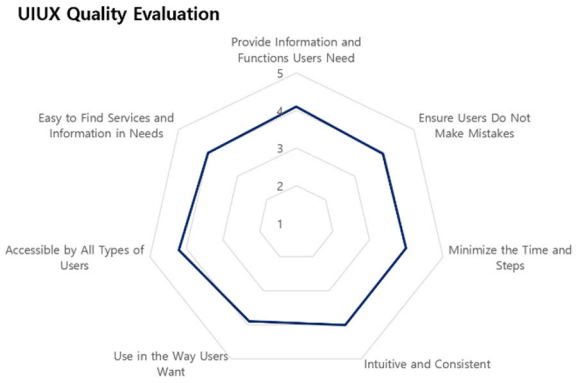

FIGURE 5. UI·UX research analysis.

TABLE 9. UI·UX evaluation results by questions.

No.	Category	Mean Scores (A 5-point scale)
1	It provides users with the information and features they need.	4.21
2	It minimizes the time and steps required for the tasks.	3.98
3	It is intuitive and consistent.	3.98
4	It allows users to use it in the ways they want.	3.89
5	It ensures users do not make mistakes.	3.89
6	It is accessible to all types of users.	4.33
7	It makes it easy to find the services and information users need.	4.08
8	overall mean (standard deviation)	4.05 (±0.17)

V. DISCUSSION

Content from interviews on the main screen for each menu and think-aloud sessions derived from the task analysis were subjected to thematic analysis. The detailed content was categorized into 32 codes and nine main themes. Each of the nine themes identified on each page was then analyzed to determine which themes required the most improvement for co-creation. On the main screen, idea suggestions, assistive device information, quick menus, design, and usability issues required the greatest improvement. On My Page, the information structure improved, and in news and information, service identity required the greatest improvement.

A. PROVIDING INTUITIVE SERVICE AND CONTENT

Understanding each stakeholder's role is key to ensuring that the AT open platform works properly. Therefore, when planning the platform, the most important service is presented on the home screen as a button menu by configuring the service flow for each stakeholder. Nevertheless, the code that was most frequently derived from thematic analysis was "difficult to grasp the content of the service (n = 61)." Additionally, many participants were confused about the service of this platform, such as not providing expected information (n = 33) and not knowing the value of the service (n = 14). The platform in this study was a new concept that did not exist in the previous assistive device market, so it seemed difficult for participants to grasp the content of the services. Additionally, older adults and those with disabilities familiar with customized services at the regional assistive device center would have been easily confused with similar services on this platform. Many users want to read only enough to achieve their online purpose, and if they do not find useful information, they tend not to use the website again [44], hence the need to develop a way to convey the role of the platform intuitively with a more sophisticated service identity and slogan.

B. PROVIDING UX WRITING

From the thematic analysis, many opinions reflected the sentiment "I do not know the terminology" (n = 24), probably owing to the confusion about the platform's service through use of unfamiliar terminology such as "Open Platform, Open Lab, Open People, and Open Pages." As the importance of verbal experience is increasing more rapidly than that of visual information in Web experiences [45], [46], it is necessary to provide information that can be intuitively understood by implementing UX writing for the terms used in the platform.

C. PROVIDING INTUITIVE METHODS OF USE

An open-source platform for AT should be an intuitive method of use and convenient to operate. In the case of the UX·UI quality evaluation, ''making users able to use it the way they want'' and ''making it so that users do not make mistakes'' received the lowest scores. This indicates the need to increase the intuitiveness of using the assistive device open platform to reduce mistakes and increase the convenience of operation, so that users can use it the way they want.

Thematic analysis showed that the second most frequent codes were the ''need to improve operational convenience'' ($n = 41$) and the ''need for visualization that is easy to grasp at a glance'' ($n = 41$). In particular, the ''need for visualization that is easy to grasp at a glance'' appeared frequently in all menus in the following order: main screen, AT information, quick menu and idea suggestions, My Page, and news and information. These codes are related to the need for intuitiveness and convenience of use and converge on the main themes of design, usability issues, and information structure improvement. As a result of the task analysis, the idea proposers tasked with the lowest level of performance were moved to another menu, and the tasks performed by developers and makers with the lowest levels of performance were finding or communicating the idea proposal.

In the case of an assistive device open platform, the menus used in the research and development process of assistive devices are divided (idea suggestion, assistive device information, and news and information), and each of the stakeholders, such as the idea proposer, developer, and makers, need to interact with each other in the research and development process. Therefore, this platform requires frequent movements between menus and must enable interactions during the research and development process. Even now, the assistive device open platform has buttons that allow users to link and access the related content of each menu and provides images and explanations. However, it seemingly lacks the intuitiveness to grasp the relationships between users at first. To avoid complicating the movement between menus and communications with multiple stakeholders, it is necessary to improve the information structure of the parts that must be linked between menus and to reduce the steps of use.

Additionally, as related codes for the intuitiveness and convenience of the method of use, 35 codes of ''difficulty in finding menus'' appeared in the quick menu, and 17 codes of ''need of relocating the registration button'' appeared in the idea suggestion menu. As a necessary new and improved function, participants frequently mentioned the need to visualize the position and information of the button so that it could be seen intuitively. In a study by Microsoft, nine out of ten users requested existing features of a product [47] because the product was too complex for the user to understand all the product features. Assistive device open-source platforms also need to focus on simplicity so that users can easily identify and use the necessary functions.

D. DEFINING DETAILED FUNCTIONS FOR EACH OF THE STAKEHOLDER PERSONAS

For an assistive device open platform, it is necessary to define personas for various stakeholders and provide only the core menus desired by the persona. The assistive device open platform supports the continuous and step-by-step interactions of various stakeholders. It can provide options for services and methods of use according to the characteristics of each stakeholder and the process of use, and supports selecting and changing these options to be used. In a study on interface design for people with Down syndrome, such simplification and personalization were also suggested as design directions [48]. In this study, open-platform stakeholders of assistive devices were divided into idea proposers (AT users), developers, and makers. Depending on the use of the AT open platform by the three stakeholders, appropriate menus, information, and methods of interaction should be provided.

What should be avoided in this assistive device open platform is to increase the number of functions to provide more functions to various stakeholders. More functions could increase the complexity of the interface and hinder the usability of the homepage. Determining which core features should be included, rather than simply adding them, can improve product usage [49]. To derive core functions, it is necessary to clearly define groups for each stakeholder and materialize their personas through participatory stakeholder workshops to gain a deeper understanding and empathy for each stakeholder [50].

VI. CONCLUSION

This study evaluated the usability of an open platform for assistive devices and suggested points for improvement. We evaluated the effectiveness, efficiency, and satisfaction of the platform to fully assess its usability. We used task analysis, thematic analysis, SUS, and E-Government Website UI·UX quality evaluation scoreboard for this.

The AT open-source platform is a new concept that plays relatively unfamiliar roles, such as the co-creation and sharing of assistive device open sources. This study is significant because it examines how each stakeholder understands and accepts new and unfamiliar concepts and because it derived the improvements required for stakeholders who have a common interest in AT to perform different roles on a single platform. This study conducted evaluations by dividing stakeholders into idea proposers, developers, and makers, and analyzed what aspects should be improved for each page and stakeholder.

The main screen was the most common issue identified through thinking aloud, followed by idea suggestions and assistive device information. The thematic analysis based on this data yielded 32 codes, with the most common comments being ''difficult to understand the service content,'' ''need to improve the ease of operation,'' ''need to improve the visualization,'' and ''need for visualization that is easy to understand at a glance.'' These 32 codes were reorganized

into nine main themes, including design and usability issues, information structure improvement, and service identity. In the task analysis, we compared the average times of the 20 participants and three experts. The results showed that the participants performed the tasks 38.1 seconds slower than the experts. Among the tasks that deviated from the average, those with the greatest deviations were ''uploading open sources of assistive devices,'' ''uploading use stories,'' and ''recruiting open people.'' These tasks were interpreted as reflecting a lower understanding of platform services than experienced users. However, the tasks with the smallest time difference were relatively simple. These included ''downloading open sources,'' ''contacting idea proponents,'' and ''finding assistive devices.'' On the SUS, the average scores were acceptable, at B−, and good, and on the website UIUI evaluation, the average score was 75, which is generally good.

The study suggests that when multiple stakeholders need to interact in a complex and continuous manner, it is important to define clear personas for each stakeholder; define usage scenarios accordingly; provide a more intuitive service identity, language, and information structure; and provide visualized information as well as text. **Web standards specified by the W3C also provide considerations for understanding the challenges of people with visual, mobility, hearing, and cognitive disabilities and complying with web accessibility requirements for them [20]. In this study, only people with mobility disabilities were examined, so in the future, usability evaluations for people with visual, hearing, and cognitive disabilities should be conducted to ensure that the homepage can be used smoothly by everyone.**

REFERENCES

[1] World Health Organization (WHO). *Global Report on Assistive Technology*. [Online]. Available: https://www.unicef.org/reports/global-report-assistive-technology

[2] United Nations (UN). *Disability-Inclusive Communications Guidelines*. [Online]. Available: https://www.un.org/sites/un2.un.org/files/un_disability-inclusive_communication_guidelines.pdf

[3] C. Khasnabis, Z. Mirza, and M. MacLachlan, ''Opening the GATE to inclusion for people with disabilities,'' *Lancet*, vol. 386, no. 10010, pp. 2229–2230, Dec. 2015.

[4] D. Kim, K. Kim, S. Jung, J. Nam, and S. Baek, ''Learning experiences of students participating in course-based assistive technology development,'' *J. Spec. Educ. Rehabil. Sci.*, vol. 52, no. 4, pp. 391–409, 2013.

[5] J.-Y. Kong and N.-Y. An, ''Analysis of the actual conditions and demands of 3D printers for customized remodeling and manufacturing of assistive devices for the disabled: Focusing on assistive technology centers,'' *J. Digit. Contents Soc.*, vol. 22, no. 2, pp. 301–306, Feb. 2021.

[6] N. Gallup, J. Bow, and J. Pearce, ''Economic potential for distributed manufacturing of adaptive aids for arthritis patients in the U.S.,'' *Geriatrics*, vol. 3, no. 4, p. 89, Dec. 2018.

[7] J. Á. Ariza and J. M. Pearce, ''Low-cost assistive technologies for disabled people using open-source hardware and software: A systematic literature review,'' *IEEE Access*, vol. 10, pp. 124894–124927, 2022.

[8] F. Hamidi, P. M. Owuor, M. Hynie, M. Baljko, and S. McGrath, ''Potentials of digital assistive technology and special education in Kenya,'' in *Sustainable ICT Adoption and Integration for Socio-Economic Development*. Hershey, PA, USA: IGI Global, 2017, pp. 125–151.

[9] E. Buehler, S. Branham, A. Ali, J. J. Chang, M. K. Hofmann, A. Hurst, and S. K. Kane, ''Sharing is caring: Assistive technology designs on thingiverse,'' in *Proc. 33rd Annu. ACM Conf. Human Factors Comput. Syst.*, Apr. 2015, pp. 525–534.

[10] S. McDonald, N. Comrie, E. Buehler, N. Carter, B. Dubin, K. Gordes, S. McCombe-Waller, and A. Hurst, ''Uncovering challenges and opportunities for 3D printing assistive technology with physical therapists,'' in *Proc. 18th Int. ACM SIGACCESS Conf. Comput. Accessibility*, Oct. 2016, pp. 131–139.

[11] J. Okerlund and D. Wilson, ''DIY assistive technology for others: Considering social impacts and opportunities to leverage HCI techniques,'' in *Proc. FabLearn*, Mar. 2019, pp. 152–155.

[12] Y. I. Degerli, F. Dogu, and C. Oksuz, ''Manufacturing an assistive device with 3D printing technology—A case report,'' *Assistive Technol.*, vol. 34, no. 1, pp. 121–125, Jan. 2022.

[13] S. Abdi, I. Kitsara, M. S. Hawley, and L. P. de Witte, ''Emerging technologies and their potential for generating new assistive technologies,'' *Assistive Technol.*, vol. 33, pp. 17–26, Dec. 2021.

[14] A. Hurst and J. Tobias, ''Empowering individuals with do-it-yourself assistive technology,'' in *Proc. 13th Int. ACM SIGACCESS Conf. Comput. Accessibility*, Oct. 2011, pp. 11–18.

[15] M. D. Corry, T. W. Frick, and L. Hansen, ''User-centered design and usability testing of a web site: An illustrative case study,'' *Educ. Technol. Res. Develop.*, vol. 45, no. 4, pp. 65–76, Dec. 1997.

[16] *Ergonomics of Human-System Interaction—Part 11: Usability: Definitions and Concepts*, Standard ISO 9241-11:2018, 2018.

[17] B. Shneiderman, *Designing the User Interface*. Reading, MA, USA: Addison-Wesley, 1998.

[18] J. Nielsen, *Usability Engineering*. San Diego, CA, USA: Morgan Kaufmann, 1993.

[19] A. Dix, G. Abowd, R. Beale, and J. Finlay. *Human-Computer Interaction*. [Online]. Available: http://www.ebrary.com/corp/techReader.jsp

[20] W3C WAI. *Making the Web Accessible*. [Online]. Available: https://www.w3.org/WAI/

[21] C. Lim et al., ''Development and implementation of a digital textbook platform usability evaluation tool,'' in *Proc. Assoc. Advancement Comput. Educ. (AACE)*, 2010, pp. 84–89.

[22] B. K. Kang, ''A study on GUI design elements to promote usability for potential users: Used on MTS (mobile trading system),'' M.S. thesis, Hongik Univ. Graduate School, Seoul, South Korea, 2018.

[23] J. W. Kim, *Human Computer Interaction*. Seoul, South Korea: Ahn Graphics, 2012.

[24] Q. Liu and K. Kim, ''Research on the usability test of interface design in e-government—Focused on Qingdao e-government website,'' *Arch. Design Res.*, vol. 36, no. 1, pp. 59–73, Feb. 2023.

[25] A. Manoharan and T. J. Carrizales, ''Recent trends in e-government: States' and local governments' utilisation of websites,'' *Int. J. Electron. Governance*, vol. 4, no. 4, p. 283, 2011.

[26] D. L. Baker, ''Advancing e-government performance in the United States through enhanced usability benchmarks,'' *Government Inf. Quart.*, vol. 26, no. 1, pp. 82–88, Jan. 2009.

[27] S. W. Son, ''Development of usability evaluation method for online product customization,'' *Design Converg. Study*, vol. 17, no. 5, pp. 93–111, Oct. 2018, doi: 10.31678/SDC.72.7.

[28] K. Namkoong, *Research Methods for Public Administration*, 6th ed. 2021.

[29] H. Lee and J. H. Kim, ''A study on improvement plans for National Archives of Korea website's search service through its usability evaluation,'' *J. Korean Soc. Arch. Records Manag.*, vol. 21, no. 3, pp. 187–215, 2021, doi: 10.14404/JKSARM.2021.21.3.187.

[30] Y.-S. Jeong, ''Development of evaluation criteria on digital text-book,'' *J. Korean Assoc. Comput. Educ.*, vol. 11, no. 3, pp. 13–20, 2008.

[31] B. Baxley, ''Universal model of a user interface,'' in *Proc. Conf. Designing User Experiences*, Jun. 2003, pp. 1–14, doi: 10.1145/997078.997090.

[32] J. C. Nesbit, K. Belfer, and T. L. Leacock. 2004. *LORI 1.5: Learning Object Review Instrument*. [Online]. Available: http://www.elera.net

[33] L. Benson, D. Elliott, M. Grant, D. Holschuh, B. Kim, H. Kim, and T. C. Reeves, ''Usability and instructional design heuristics for e-learning evaluation,'' in *Proc. Assoc. Advancement Comput. Educ. (AACE)*, 2002, pp. 1615–1621.

[34] V. Clarke, V. Braun, and N. Hayfield, ''Thematic analysis,'' in *Qualitative Psychology: A Practical Guide To Research Methods*, 2015, pp. 222–248.

[35] American Psychological Association (APA), ''Ethical principles of psychologists and code of conduct,'' *Amer. Psychologist*, vol. 57, no. 12, pp. 1060–1073, 2002.

[36] T. Boren and J. Ramey, ''Thinking aloud: Reconciling theory and practice,'' *IEEE Trans. Prof. Commun.*, vol. 43, no. 3, pp. 261–278, Oct. 2000.

[37] B. Albert, T. Tullis, and D. Tedesco, *Beyond the Usability Lab: Conducting Large-Scale Online User Experience Studies*. San Mateo, CA, USA: Morgan Kaufmann, 2009.
[38] J. Brooke, "SUS: A quick and dirty usability scale," *Usability Eval. Ind.*, vol. 189, no. 194, 1996.
[39] A. Bangor, P. Kortum, and J. Miller, "Determining what individual SUS scores mean: Adding an adjective rating scale," *J. Usability Stud.*, vol. 4, no. 3, pp. 114–123, 2009.
[40] *Ministry of Public Administration and Security E-Government Website UI [UX Guidelines]*, 2019, pp. 154–157.
[41] M. Fan, S. Shi, and K. N. Truong, "Practices and challenges of using think-aloud protocols in industry: An international survey," *J. Usability Stud.*, vol. 15, no. 2, pp. 85–102, 2020.
[42] J. R. Lewis and J. Sauro, "Item benchmarks for the system usability scale," *J. Usability Stud.*, vol. 13, no. 3, pp. 158–167, 2018.
[43] *E-Government User Experience Application Guidelines*, Ministry of Security and Public Administration, Seoul, South Korea, 2016, p. 56.
[44] J. G. Redish, *Letting Go of the Words: Writing Web Content That Works*. San Mateo, CA, USA: Morgan Kaufmann, 2007.
[45] M. R. de Azevedo, F. M. Bóia, and Ó. Mealha, "Corporate relevance of UX writing contributions for a design language system," in *Proc. 17th Iberian Conf. Inf. Syst. Technol. (CISTI)*, Jun. 2022, pp. 1–6.
[46] J. J. Hyeon, "A study on the development of process and workshop toolkit for UX writing," The Graduate School of Seoul Women's University, 2023.
[47] C. Capossella, "Key note address at Microsoft professional developers conference 2005 (13, Sep. 2005—Part of Bill Gates' keynote address)," Tech. Rep., 2005.
[48] J. Lazar, C. Woglom, J. Chung, A. Schwartz, Y. G. Hsieh, R. Moore, and B. Skotko, "Co-design process of a smart phone app to help people with down syndrome manage their nutritional habits," *J. Usability Stud.*, vol. 13, no. 2, pp. 73–93, 2018.
[49] University of Cambridge. [Online]. Available: http://www.inclusivedesigntoolkit.com/why/why.html
[50] R. M. Schumacher, "Gran got tech: Inclusivity and older adults," *J. User Exper.*, vol. 18, no. 2, pp. 62–67, 2023.

EUN RAE RO received the master's degree in service-integrated design. Her research interests include service design, UX evaluation methods, assistive technology, older adults, and persons with disabilities.

KWANG OK AN received the Ph.D. degree from the Department of Electrical and Computer Engineering, Seoul National University. Her research interests include assistive technology and biosignal processing.

AGNES JIHAE KIM received the Ph.D. degree in industrial design, with a focus on deriving design guidelines through research on the interaction between people with disabilities, older adults, and artifacts, such as products, services, and spaces.

SUNG UK JANG received the B.S., M.S., and Ph.D. degrees in computer science and engineering from the Korea University of Technology and Education. His current research interests include extended reality (XR), virtual simulations with medical digital twins, and human augmentation.

EUN JOO KIM received the Ph.D. degree from the Department of Occupational Therapy, Inje University. Her research interests include social participation, assistive technology, older adults, and persons with disabilities.

SEON DEOK EUN received the Ph.D. degree. He has been the Leader of the Assistive Technology Research Team for Independent Living, National Rehabilitation Research Institute, since 2021. His primary research interests include the development of assistive technology and rehabilitation exercise programs for people with disabilities.