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COLLABORATION SUPPORT SYSTEM FOR ANALYZING INDIVIDUAL DIFFERENCES BASED ON DESIGNERS' IDEA EVALUATION

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ABSTRACT
In our previous research, we focused on the creative aspects of collaboration and proposed an analytical method of ideas created by designers during collaborative design projects. This method analyses created ideas using DEA (Data Envelopment Analysis) and reveals their characteristics, overall effectiveness, relationships from the various viewpoints and potentially fruitful directions for improving them or exploring new ideas. By following these indications, designers can explore sophisticated ideas more efficiently and effectively. To provide further support for creative collaboration, this paper now focuses on individual differences, especially the differences in designers' idea evaluation. In our previous method, although designers individually evaluate created ideas, the results of their evaluation are summed up in order to carry out DEA. Therefore, the differences in designers' evaluation are averaged and can't be revealed to the result of DEA. However, in most cases, the differences in designers' evaluation exist because of various reasons and such differences or diversities themselves are worth being focused and analyzed for further idea exploration. Therefore, this paper proposes a new analytical method for revealing such differences by analyzing the results of designers' idea evaluation from various viewpoints.

Keywords: Design engineering, Creative design, Collaboration, Creativity support, and Evaluation of differences in designers' evaluation

1. INTRODUCTION
Collaboration is a process where the efforts of a group of participants are facilitated by sharing information, expertise, ideas, resources or responsibilities [1]. The advantage of collaboration is the increased ability to achieve complex large-scale and multidisciplinary problems, which no man can achieve alone. In addition to such advantage, collaboration offers an additional potential benefit in terms of enhancing group members' creativity. During the collaboration processes, group members cooperate by exchanging ideas, opinions and various information, which can stimulate their creativity and increase their chances of generating new ideas [2]. The importance of collaboration is gradually recognized in these days and we often here the word "collaboration" in a variety of places.
Collaboration has been a research subject for many years and various support methods or systems for smooth collaboration were developed and sold as commercial products. They can be roughly organized into several areas such as (1) communication support [3][4], (2) knowledge management [5][6] and (3) distributed design environments [7][8]. However, there are few researches that focus on the creative side of collaboration and support designers' creativity with a few exceptions such as Brainstorming and KJ-method, which are the famous and traditional group creativity techniques.
Against these backgrounds, we focused on the creative side of collaboration and developed support methods for enhancing designers' creativity during collaborative design activities. In our previous researches [9][10], we proposed a support system that consists of following two visualization procedures. The first procedure makes visible the flow of interactive communication among designers, which enables smooth interactive communication. The second one makes visible the relationships between ideas, design concepts and design goals, which enables sharing of exploration space and wide range of idea exploration. In another previous research [11], we proposed an analytical method of created ideas during collaboration. This method analyzes the results of designers' evaluation of created ideas using DEA (Data Envelopment Analysis) for revealing the overall effectiveness of each idea, the

relationships between ideas from the various viewpoints, and the potentially fruitful directions for improving the existing ideas or exploring of new ideas. By following these indications, designers can efficiently and effectively create or find out more sophisticated ideas.

To provide further support for creative collaboration, this paper now focuses on individual differences among designers, especially the differences in designers' evaluation. In our previous method, although designers individually evaluate created ideas, the results of their evaluation are summed up in order to carry out DEA. Therefore, the differences in designers' evaluation are averaged and can't be revealed to the result of DEA. However, in most cases, the differences in designers' evaluation exist because of various reasons. For example, there are often or always the differences in what designers concretely imagine in their mind when they hear an idea proposed by a designer using several words or a short sentence, or the differences in how designers evaluate effect and performance of the presented ideas. Such differences or diversities tend to be considered undesirable, but they have a huge potential for leading new ideas during divergent processes of exploring ideas. Therefore, the method proposed in this paper reveals such differences by analyzing the results of designers' idea evaluation and encourages their further idea explanations.

The rest of this paper is organized as follows. Section 2 describes the proposed method and section 3 describes the computerized support system that facilitates designers using the proposed method. To confirm the effectiveness of the proposed method, an experiment for undergraduate students is carried out in Section 4, and finally, Section 5 summarizes the accomplishments of this paper.

2. COLLABORATION SUPPORT METHOD BASED ON ANALYSIS OF DIFFERENCES IN DESIGNERS' IDEA EVALUATION

In this paper, we focus on the differences in designers' evaluation and propose a new analytical method for enhancing the effect of creative collaboration by revealing such differences. Before describing the details of the proposed method, intended process and ideas are first described. As for the intended process, the proposed method supports the one where designers cooperatively explore new ideas for achieving given target goals or solving problems occurred during design activities. Such process can be occurred on all fronts of design processes. As for the ideas, the proposed method supports the ones represented by several words or a short sentence. Since the ideas are generated for achieving goals or solving problems, the degree of their achievement can be numerically evaluated.

The proposed method consists of following four stages.

Stage1: Exploration of ideas
Stage2: Evaluation of ideas by designers
Stage3: Analysis of differences in designers' evaluation
Stage4: Discussion of ideas by designers

Stage1 is conventional collaborative activity itself and Stage2 to 4 are analytical tasks. Fig.1 shows the overview of the proposed method. The following sections explain the details of each stage.

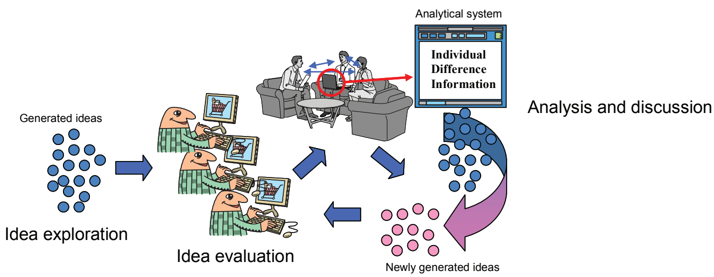


Figure 1. Overview of the proposed method

2.1 Stage1: Exploration of ideas

In the first stage, designers cooperatively explore as many ideas as possible. This stage is usual collaborative activity and communication support method developed in our previous researches [9]

[10] can be utilized. Since support of idea exploration processes is not the purpose of this paper, please see our previous researches for details.

2.2 Stage2: Evaluation of ideas by designers

In the second stage, designers individually evaluate the ideas explored in the first stage from the following two viewpoints.

(1) Numerical performance evaluation

In this paper, the performance of an idea is defined as the degree of contribution to the achievement of the given design goal when it is practically adopted to the design object. Designers individually grade all ideas on a scale of 1 to 10 from the viewpoint of how each idea can achieve each design goal. An idea that doesn't have any contribution is graded 1, whereas an idea that has considerable contribution is graded 10. The degree of contribution is evaluated in each goal, so the number of evaluations that needs to be executed by each designer equals to the total number of ideas multiplied by the total number of given design goals.

(2) Semantic interpretation

When a designer presents a new idea using several words or a short sentence, the others imagine the concrete image of the idea, such as a new technology, mechanism, structure, material, etc., from the presented words in their mind. However, there is no guarantee that what designers imagine in their mind is identical because of the differences in their experiences, knowledge, skills, etc.
To reveal such difference, the proposed method asks designers to individually interpret ideas freely described by several words to formulaic representations. If what designers imagine is different, the results of semantic interpretation are not identical. In the proposed method, list of selectable verbs and objectives are prepared and designers interpret an idea to the combination of a verb and an objective by selecting from the list. By comparing verbs and objectives selected by designers, the degree of the difference in semantic interpretation can be revealed. Fig.2 shows the concept of formulaic semantic interpretation.

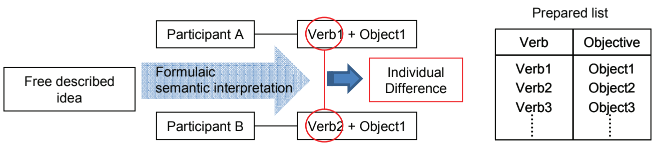


Figure 2. Concept of formulaic semantic interpretation

For appropriate semantic interpretation, it is important to prepare the list of verbs and objectives that are closely matched for the design object. These lists should be prepared in each case. In the experiment described in Section 4, we prepare the list based on references [12] and [13].

2.3 Stage3: Analysis of differences in designers' evaluation

In the third stage, individual differences are analyzed based on the results of designers' evaluation carried out in the second stage. In this stage, the results of numerical performance evaluations and semantic interpretations are individually analyzed and then these analytical results are combined into a single scatter diagram.

2.3.1 Analysis and visualization of numerical performance evaluation

Under the condition where n design goals are given, the results of numerical performance evaluations can be plotted on a n-dimensional space. Fig.3 shows the case of n = 3. This graph is drawn for each idea. Each vector shows the result of each designer's evaluation. The coordinate of each vector equals to its values.

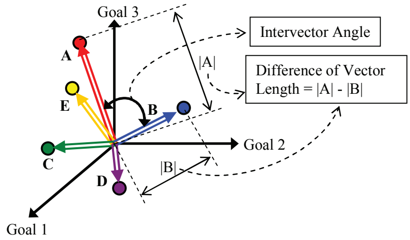


Figure 3. Two types of differences in numerical performance data

Using this graph, the differences in designers' numerical performance evaluations can be represented by the combination of (1) the angular differences between vectors and (2) the differences in the length of vectors. This paper takes the meanings of these differences as follows. The former ones show the individual differences concerning evaluation viewpoints. In other word, which design goals a designer estimates that the idea can improve. The latter ones show the individual differences concerning estimation of the total performance of the idea. The length of a vector shows that how effective a designer estimates the idea is. Two types of differences are calculated for each pair of designers.

For practical use, since it is impossible to make graphs under the condition where more than three design goals are given and only the values of angular and length differences are necessary information for further discussions, a table shown in table1 is drawn for each idea and displayed to designers instead of displaying the graph itself. This table contains both angular and length differences. The values displayed in the upper triangular show the angular differences between two designers, whereas the ones in the lower triangular show the differences in length between two designers.

Table 1. Presentation of two types of differences in a table form

	Participant A	Participant B	Participant C	Participant D	Participant E
Participant A		22.9	0.8	13.9	16.3
Participant B	3.9		22.3	18.5	17.7
Participant C	2.0	1.9		13.1	15.5
Participant D	0.5	4.3	2.4		2.6
Participant E	0.5	3.4	1.5	1.0	

Angular difference
(Differences in evaluation viewpoints)

Difference of vector length
(Differences in estimation of total performance)

2.3.2 Visualization of semantic interpretation

For the results of semantic interpretation, all combinations of verbs and objectives selected by designers are visualized by directed graph form for each idea, as shown in Fig.4. In the proposed method, same verbs or objectives selected by several designers are merged into one node and arrows show which verbs and objectives are selected by designers. In the case of Fig.4, verb1 and objective1 are connected by two arrows, which indicate that two designers selected same verb and object.

The results of semantic interpretation

Participant A	Verb1	Object1
Participant B	Verb2	Object2
Participant C	Verb1	Object1
Participant D	Verb2	Object2
Participant E	Verb3	Object2

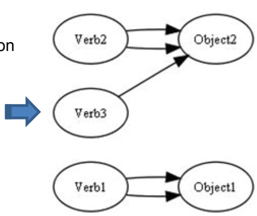


Figure 4. Visualization of semantic interpretation by directed graph form

2.3.3 Scatter diagram for designers' discussion

Based on the above analyses, consistency indexes of both numerical performance evaluation and semantic interpretation are calculated and a scatter diagram shown in Fig.5 is then drawn. The scatter diagram is used for the further discussion in the next stage and helps designers to understand the relationships between the idea being focused now and the others. The detailed procedure of drawing the scatter diagram is as follows.

(1) Consistency index of numerical performance evaluation

In this paper, consistency means the degree of the difference in designers' evaluation for an idea. Concerning the consistency of numerical performance evaluation, the index is calculated for each idea according to the following procedure.

Step1: Variance of designers' evaluated value is calculated for each design goal and for each idea.

Step2: Variances are then summed up for each idea

Step3: Maximum value of summed variances is found.

Step4: Uncompensated index of each idea is calculated by subtracting summed variance of each idea from the largest summed variance.

Step5: The deviation of each uncompensated index is calculated and defined as the compensated index.

(2) Consistency index of semantic interpretation

Concerning the consistency of semantic interpretation, the index is also calculated for each idea. When interpretation results of two designers are randomly selected and compared, the pair can be classified into the following four patterns: (a) Both the verbs and the objectives selected by two designers are identical, (b) Only the verbs are identical, (c) Only the objectives are identical and (d) Neither the verbs nor the objectives are identical. Therefore, the index is calculated according the following procedure, based on the above classification.

Step1: If the pair is classified into pattern (a), it is scored 1 and if classified into pattern (b), (c) or (d), it is scored 0.8, 0.4 or 0 respectively. These comparisons and scorings need to be done for each pair of designers for each idea.

Step2: After scoring for all pairs for all ideas, scores are summed up for each idea, which is defined as an uncompensated index. And finally, the deviation of each uncompensated index is calculated and defined as the compensated index.

(3) Scatter diagram

The scatter diagram is then drawn by plotting ideas based on the consistency index of performance evaluation as coordinated value of Y axis and the consistency index of semantic interpretation as coordinated value of X axis. Both indexes are deviation scores, so their averages equal to 50. Fig.5 shows an example of the scatter diagram. In this example, idea ID is drawn on the diagram instead of a dot.

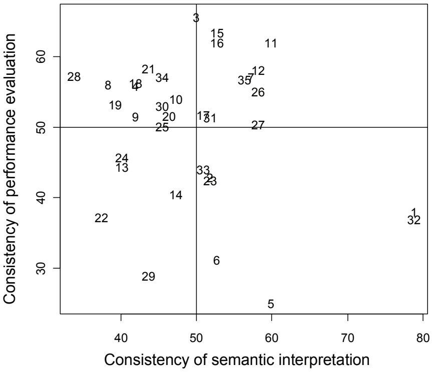


Figure 5. Scatter diagram

2.3.4 Priority of discussion

The priority of further discussion in the next stage is finally calculated by summing two indexes for each idea. Note that the priority of an idea with little difference in designers' evaluation becomes low, whereas the one's priority with a great difference becomes high, regardless of the evaluated values. It's just conceivable that the ideas with a great difference have more information about the differences in designers' viewpoints and chances of further idea generations than ones with little difference. In the case of Fig.5, further discussion in the next stage start from the ID 29 or 22.

2.4 Stage4: Discussion of ideas

Fig.6 shows the overview of the results of analysis carried out in the previous stage. In this figure, the upper half shows information of all ideas, whereas the lower half shows information of one idea which designers focus on now. Base on the results of analysis, designers discuss ideas and individual differences. During this stage, the computerized support system displays these results like Fig.6 for facilitating designers' discussion. See the details of the support system in Section 3. The procedure of this stage is as follows.

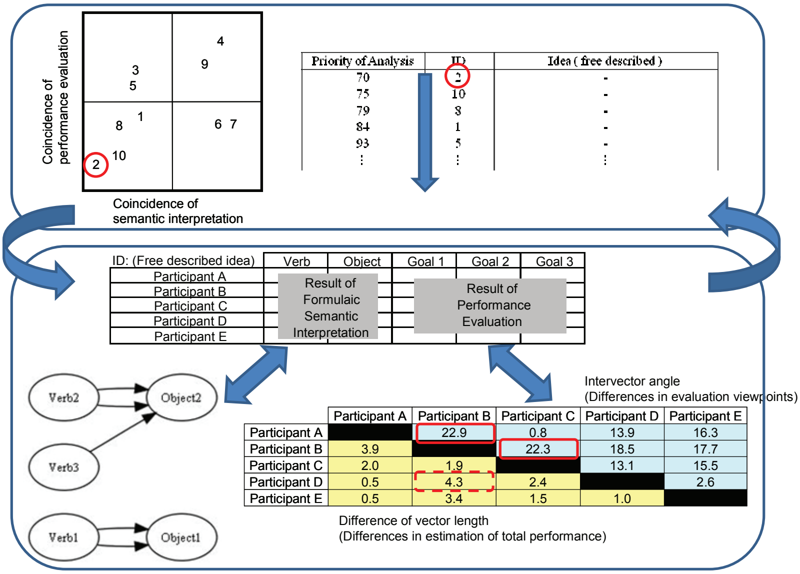


Figure 6. Overview of the results of analysis in the third stage

Step1: Based on the priority calculated in the previous stage, designers decide from which idea they start discussion. In the case of Fig.6, analysis and discussion start from the idea ID 2.

Step2: Next, designers focus on the individual differences in the focused idea displayed at the lower half of Fig.6. Raw data of numerical performance evaluation and semantic interpretation and their visualized data are displayed here. Designers start to discuss the idea and individual differences using these information. Detailed procedure is as follows.

(a) Concerning the individual differences in performance evaluation, discussions are carried out in order from the pair of designers whose angular difference is largest. Angular difference shows the differences in the viewpoint of performance evaluation, as described in the previous section. Each pair discusses why and what their evaluation viewpoint is so different. In the case of Fig.6, since the angular difference of the pair of designer A and B is 22.9, which is largest, they start 1st discussion and next, the pair of designer B and C whose angular value is 22.3 that is the second largest starts 2nd discussion. During the discussion between the pair, it is advisable for the other designers to actively join in their discussion. Concerning the differences in length, which show the differences in estimation of total performance, discussions are carried out in the same fashion.

(b) Concerning the individual differences in semantic interpretation, designers discuss why they select different words and what they think during interpretation using the directed graphs. Designers can intuitively understand the different viewpoint of semantic interpretation from the directed graphs. In the case of Fig.6, since two different objectives are selected to represent this idea, designers can understand that they took the idea as two different meanings during interpretation stages.

Step3: When new ideas are generated in the course of above discussions, newly generated ideas are recorded with the information about the source idea of them.

Step4: When designers agree that the focused idea has been well discussed, they go back to step1 and select the next target. In the case of Fig.6, the idea ID10 is selected as the next target.

Four steps described above are the procedure for effective and efficient discussion. When designers agree that discussions are well carried out, the force stage is terminated at any given point in time and they get back to the second stage to analyze generated ideas during the stage or to the first stage for further idea exploration.

3. COMPUTERIZED SUPPORT SYSTEM

To facilitate the use of the proposed method in experiments or practical collaborations, a computerized support system is developed. The system stores created ideas, supports designers' evaluation, analyze their results and display the results of difference analyses in the easily viewable form. Most of the system is programmed using Microsoft Excel and Visual Basic for Applications (VBA), except for the generation of directed graphs that show the results of semantic representations and a scatter diagram that shows the relationships between two calculated indexes. A directed graph is drawn by Graphviz [14], whereas a scatter diagram is dawn by R [15]. Fig.7 shows the overview of the computerized support system and the dataflow in the system.

Figs.8 to 11 show screenshots of the system. Fig.8 shows a window for a semantic interpretation where an evaluator selects a verb and an objective from dropdown lists for each idea. Fig.9 shows a window for a numerical performance evaluation where an evaluator grades on a scale of 1 to 10 by evaluating how each idea can achieve or improve each design goal. Fig.10 shows a screenshot of Excel that displays a priority list for further discussions and a scatter diagram. Fig.11 also shows a screenshot of Excel that displays analyzed individual differences information. During the fourth stage, designers make further discussions using these screens.

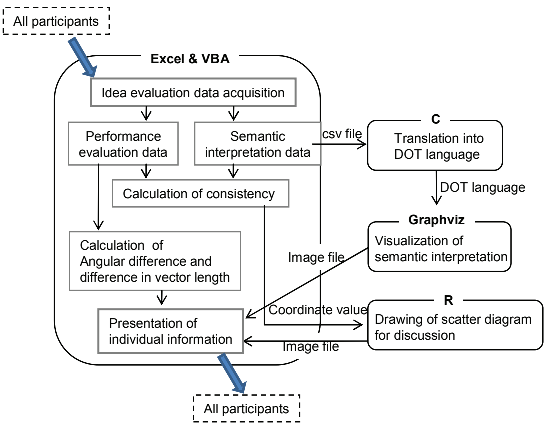
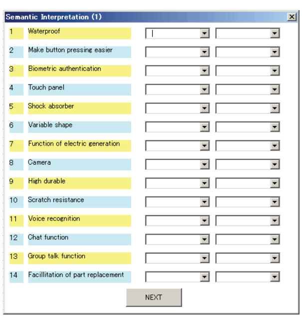


Figure 7. Data processing flow of computerized support system



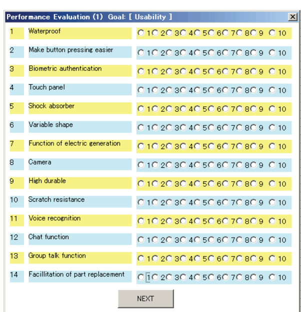


Figure 8. Window of semantic interpretation / Figure 9. Window of performance evaluation

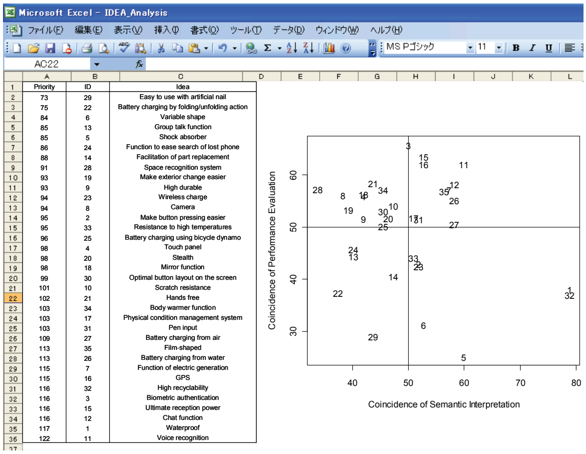


Figure 10. Screenshot of Excel that displays priority of discussion and scatter diagram

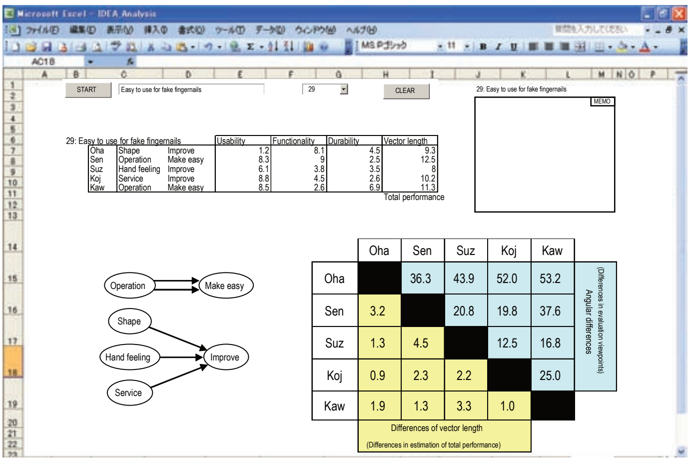


Figure 11. Screenshot of Excel that displays analyzed individual differences information

4. EXPERIMENT WITH UNDERGRADUATES

To confirm the effectiveness of the proposed method, we conduct an experiment with undergraduates and discuss its results.

4.1 Experimental conditions

In this experiment, five undergraduate students participate. All of them belong to engineering department in our institute. One of students operates the computerized support system and chairs this experimental collaboration. We select a cellular phone as a target design object and improvement of usability, functionality and durability as design goals of this experiment. Since students don't have enough engineering knowledge and skill, we ask students to describe ideas using simple expressions during. The duration of each stage is as follows. The duration of idea exploration, which corresponds to the first stage, is 30 minutes. The duration of students' evaluation, which corresponds to the second stage, is not limited. The duration of analysis and discussion, which corresponds to the third and fourth stages, is 90 minutes. All processes are recorded with a voice recorder and a digital camcorder for detailed analysis after the experiment. Fig.12 is a snapshot of the experiment.

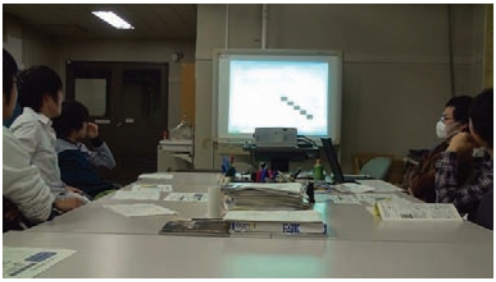


Figure 12. snapshot of the experiment

4.2 Experimental results

(1) Stage1

In the first stage, students generate 35 ideas in 30 minutes. Table2 shows the list of generated ideas.

(2) Stage2 and stage3

In the second stage, students make numerical performance evaluations and semantic interpretations for 35 ideas. Table3 shows the lists of verbs and objectives used in the experiment.

In the third stage, the computerized support system analyzes the results of students' evaluations and displays individual difference information. Fig.13 shows the priority list and the scatter diagram displayed in the experiment.

Table 2. Ideas generated in the first stage / Table 3. List of verbs and objectives

ID	Generated ideas	ID	Generated ideas
1	Woterproof	19	Make exterior change easier
2	Make button pressing easier	20	Stealth function
3	Biometric authentication	21	Hands free
4	Touch panel	22	Bttery charging by folding/unfolding action
5	Shock absorber	23	Wireless charge
6	Variable shape	24	Function to ease search of lost phone
7	Function of electric generation	25	Battery charging using bicycle dynamo
8	Camera	26	Battery charging from water
9	High durable	27	Battery charging from air
10	Scratch resistance	28	Space recognition system
11	Voice recognition	29	Easy to use with artificial nail
12	Chat function	30	Optimal button layout on the screen
13	Group talk function	31	Pen input
14	Facilitation of part replacement	32	High recyclability
15	Ultimate reception power	33	Resistance to high temperatures
16	GPS	34	Body warmer function
17	Physical condition management system	35	Film-shaped
18	Mirror function	-	-

Object		Verb	
Shape	Force	Translate	Insulate
Signal	Temperature	Generate	Store
Sound	Pressure	Remove	Fix
Output	Number of components	Gain	Hold
Eelectromagnetic wave	Water	Extract	Support
Electric current	Oil	Increase	Maintain
Voltage	Gass	Decrease	Activate
Electric power	Sound noise	Increment	Control
Frequency	Noise	Decrement	Form
Circuit	Heat	Magnify	Decide
Resistance	Hand feeling	Connect	Reinforce
Vibration	Display	Transfer	Protect
Position	Exterior	Supply	Improve
Direction	Service	Convect	Make easy
Speed	Operation	Guide	-Unselectable-
Sound Volume	Transport	Capture	-
Friction	-Unselectable-	Receive	-
Torque	-	Cut	-

Priority	ID	Idea
73	29	Easy to use with artificial nail
75	22	Battery charging by folding/unfolding action
84	6	Variable shape
85	13	Group talk function
85	5	Shock absorber
86	24	Function to ease search of lost phone
88	14	Facilitation of part replacement
91	28	Space recognition system
93	19	Make exterior change easier
93	9	High durable
94	23	Wireless charge
94	8	Camera
95	2	Make button pressing easier
95	33	Resistance to high temperatures
96	25	Battery charging using bicycle dynamo
98	4	Touch panel
98	20	Stealth
98	18	Mirror function
99	30	Optimal button layout on the screen
101	10	Scratch resistance
102	21	Hands free
103	34	Body warmer function
103	17	Physical condition management system
103	31	Pen input
109	27	Battery charging from air
113	35	Film-shaped
113	26	Battery charging from water
115	7	Function of electric generation
115	16	GPS
116	32	High recyclability
116	3	Biometric authentication
116	15	Ultimate reception power
116	12	Chat function
117	1	Waterproof
122	11	Voice recognition

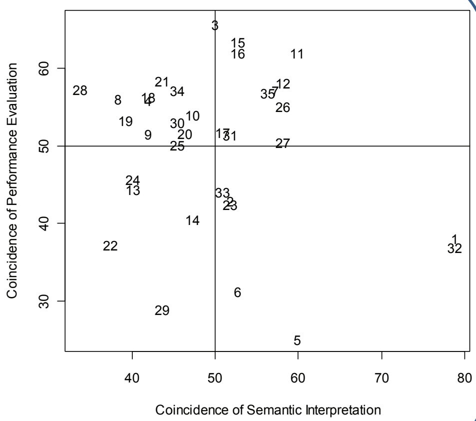


Figure 13. Priority list and scatter diagram presented in the experiment

(3) Stage4

In the fourth stage, students discuss ideas based on the visualized individual difference information for 90 minutes. When the 22nd idea has been discussed, students agree that discussions are well carried out, so this stage is finished. During the fourth stage, 22 ideas are newly generated. Table4 shows the list. The second column of the table is ID of the original idea of newly generated one.

Table 4. Newly generated ideas in the fourth stage

ID	ID of original idea	New idea
36	29	Button made of soft material
37	29	Operation using spatial position
38	6	All cmponents are made by soft material
39	6	Transformable to Rubik's Cube shape
40	5	Shoch absorber like Alpha-GEL
41	5	Shoch absorber using springs
42	24	Signal the location using sound
43	24	Signal the location using GPS
44	28	Space recognition system based on image processing
45	19	Exterior can be changed like a retractable top of open car
46	19	All exterior parts have display function
47	2	Simplify button layout
48	33	Heat insulation from circuit
49	33	Improve radiation performance of body material
50	4	Combination of button and touch panel
51	20	Stealth for blocking a neighbors' view
52	20	Function of destruction of evidence
53	18	Add a real mirror
54	18	Add a mirror function to display panel
55	17	Function of clinical thermometer
56	17	Function of body fat scale
57	17	Function of pedometer

4.3 Discussion

The main purpose of the proposed method is to provide designers useful hints for further idea explorations by revealing differences in designers' evaluation. 22 additional ideas are obtained during the fourth stage. As shown in Table 4, all of them are derived from the first 35 ideas. A detailed analysis of the process where each idea is obtained shows that students make further discussions by well utilizing the computerized support system. From these results, we can say that the proposed method achieves some positive results.

Another purpose is to reduce the differences in designers' evaluation by discussing revealed individual differences. To analyze changes in individual differences through the discussions, we ask students to evaluate ideas obtained during the fourth stage after the experiment in a same way as they evaluate in the second stage and compare two evaluation results. Table5 shows the consistencies of designers' evaluations in the second stage and after the experiment. The values shown in the table are the average of uncompensated consistency indexes in numerical performance evaluations and semantic interpretations. See the details of consistency index in the secsion2.3.3 (1) and (2). The reason for using uncompensated indexes is that compensated indexes are normalized.

Table 5. Comparison of consistency indexes in numerical performance evaluation and semantic interpretation

	Consistency of performance evaluation	Consystency of semantic interpretation
Evaluation in stage2	9.9	3.6
Evaluation after experiment	10.8	4.8

Table5 shows that consistency indexes of designers' evaluation are improved through the discussions. The degree of improvement is 9.1% in the numerical performance evaluation, 33.3% in the semantic interpretation. This comparison shows that the proposed method also achieves some positive results for the second purpose.

5. CONCLUSION

To provide further support for creative collaboration, this paper focuses on individual differences and proposes a new analytical method for revealing such differences. The following points are addressed.

(1) When a designer presents a new idea, which is represented by several words in most cases, the other designers imagine concrete something in their mind from the words and then evaluate it from various viewpoints. This paper focuses on designers' semantic interpretation and numerical performance evaluation and proposes the method for analyzing such activities.

(2) To reveal individual differences among designers based on the results of numerical performance evaluation and semantic interpretation, this paper proposes the method for analyzing these results and calculating indexes that show the degree of individual differences.
(3) Using analytical results of individual differences, designers discuss ideas and explore new ideas. To support this process, this paper proposes discussion procedure and several guidelines for discussion.
(4) To enable smooth operation of the proposed method, the computerized support system is developed. This system stores created ideas, supports designers' evaluation, analyze their results and display the analytical results of individual differences in the easily viewable form.
(5) To confirm the effectiveness of the proposed method, an experiment with undergraduate students is conducted and some positive results are achieved.

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