Modeling of Relationships between Abilities, Skills, and Knowledge for Mechanical Designers and Its Application to University Curriculum

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Abstract

Many studies about mechanical design education have been reported. However, there is no study for the classification of them. This study constructs the relationship model between the abilities, skills, and knowledge which are required by designers and extracted from the conventional Japanese studies. The proposed model gives an idea for the improvement of a curriculum for university.

Keywords: design education, design skill, ISM, cluster analysis, correspondence analysis

1 Introduction

Mechanical design education as the basis of the product manufacture is important and advanced in an industrially-advanced country like Japan [1]. However, the design technique of designers is said to be decreased recently. For example, sodium leak at the Monju fast-breeder reactor (in 1995) was caused by the design mistake that the designer forgot the corner radius at the stepped thermo sensor casing. Additionally, the specialization and professionalization of design work associated with the diverse functions and complicated mechanisms of products expose the lack of the designers' communication ability [2]. For example, turbine wreck at the Hamaoka nuclear power station was occurred by the lack of the communication between the designer and the operator. Designers require diverse skills and abilities other than those above. Therefore, it is difficult to construct an appropriate education for them.

Mechanical design education has been studied by many researchers as follows. Kawaguchi *et al.* [3] offered a class in which students conduct design activities (design calculation, mechanical drawing, manufacturing, and presentation) in order to enable them to obtain "inspiration", "presentation skill", "leadership", "teamwork of project", and "knowledge of machining". Hattori *et al.* [4] provided a facility to make students free to do manufacturing and improved their "ability to solve problems" and "presentation / writing skill". Fujita *et al.* [5], [6] made students to construct mechanical drawings alternately by hand and 3DCAD in order to improve "spatial representation ability". Noguchi *et al.* [7] gave students design tasks (drawing using CAD, demonstration with a prototype, and cost evaluation) and made them to obtain "knowledge of production cost", "skill to operate CAD", and "material knowledge". Although there are many studies of the mechanical design education as stated above, there is no study for the classification of them. This causes the education institution, which has each aim of the mechanical design education, cannot use the achievements of the studies properly.

This study aims to construct a relationship model of the abilities, skills, and knowledge (hereinafter called ASKs) acquired by Japanese mechanical design education and helps educators to construct effective mechanical design education using it. This paper is organized as follows. Section 2 extracts the ASKs of mechanical design and groups and stratifies them to construct their relationship model. Section 3 illustrates an application of the proposed model to the curriculum of Tokai University, while Section 4 provides conclusions and the future research direction.

2 Relationship model between abilities, skills, and knowledge of mechanical design

This chapter indicates the extraction of the ASKs regarding mechanical design from the previous Japanese study [1], [3]-[32] and the construction of their relationship model using affinity diagram and Interpretive Structural Modeling (ISM).

2.1 Extraction of abilities, skills, and knowledge of mechanical design

This study employed "J Dream 2" (scientific and technical literature database) and selected articles published from 1989 to 2013, by the keyword of "design education". From the selected 514 articles, 31 articles were further selected by eliminating those of the other area (such as information design, electrical design and architectural design) and conference articles. The ASKs extracted from them are shown in the next session (see **Fig. 1**).

2.2 Modeling of the relationship between extracted abilities, skills, and knowledge

In order to combine extracted ASKs that express same thing, this study employed affinity diagram [33]. In this method, designers start by writing down the terms on a card one by one. The cards whose terms are similar are corrected; the designers decide the collective term of them. Repeating the process, the terms are grouped and stratified on the basis of their similarities. **Figure 1** shows the combined ASKs. In this figure,

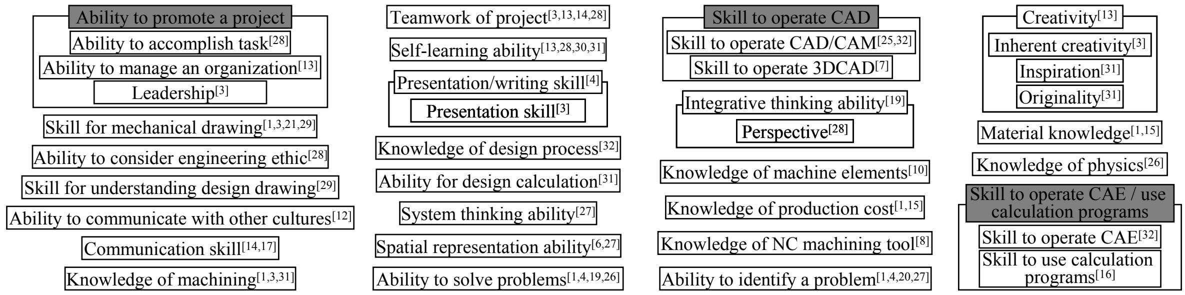

Fig. 1 Extracted abilities, skills, and knowledge

newly derived terms are gray-colored. This study finally chose 25 ASKs required for mechanical designers.

This study constructed the structural model expressing the relationship between the 25 ASKs by stratifying them via ISM [34]. In this method, designers start by making the direct affective matrix that expresses the relationships between terms. The matrix is transformed into the skeleton matrix that simplifies the relationships using computer program. On the basis of the matrix, the designers can depict the directed graph (structural model) in which the terms affecting others are located higher and are connected only to the directly affected elements by arrowed lines. In this study, professional mechanical designers made the direct affective matrix. The matrix and the structural model constructed using ISM are **Table 2** and **Fig. 2**, respectively. In **Fig. 2**, dash line means strong connection in which elements affect each other. The structural model shows they are classified into three parts which are the groups of the terms having at least one relationship with other element:

(a) Part 1 seems to be a group regarding "collective activity" because it is composed of the ASKs required when the designer works cooperatively in a project team or express his opinion clearly, such as "teamwork of project" and "presentation / writing skill";
(b) Part 2 is considered a group regarding "mechanical drawing" because it contains the ASKs for developing and understanding mechanical drawing, such as "spatial representation ability" and "skill for understanding design drawing";
(c) Part 3 is thought to be a group regarding "problem finding / solving" because the ASKs in the group are related to a design thinking or knowledge applicable to it, such as "integrative thinking ability" and "material knowledge".

Table 2 Direct affective matrix of abilities, skills, and knowledge

	Communication skill	Teamwork of project	Ability to promote a project	Presentation/writing skill	Ability to communicate with other cultures	Ability to identify a problem	Ability to solve problems	Skill for mechanical drawing	Knowledge of machining	Creativity	Spatial representation ability	Knowledge of machine elements	integrative thinking ability	System thinking ability	Knowledge of design process	Material knowledge	Knowledge of production cost	Skill to operate CAD	Skill for understanding the design drawing	Knowledge of NC machining tool	Knowledge of physics	Ability for design calculation	Skill to operate CAE/use calculation programs	Ability to consider engineering ethic	Self-learning ability
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1																								
2	1	1																						1	
3	1		1																						
4	1	1		1																				1	
5	1	1			1																			1	
6						1	1																		
7						1	1																		
8								1																	
9						1	1		1																
10						1				1															
11								1			1														
12						1	1					1													
13						1							1	1											
14						1							1	1											
15						1	1								1										
16						1	1									1									
17							1										1								
18								1										1							
19								1			1								1						
20									1											1					
21						1	1		1			1				1					1				
22						1	1									1						1			
23																						1	1		
24		1																						1	
25														1											1

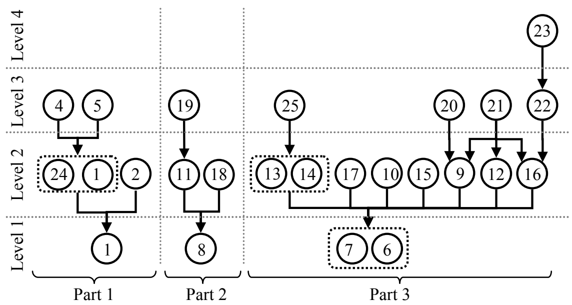

Fig. 2 Structural model of abilities, skills, and knowledge

3 Application of proposed model

This chapter describes the application of the proposed model in chapter 2 to the curriculum of Tokai University (Mechanical Engineering Department).

3.1 Curriculum evaluation

This study evaluated how the classes in the curriculum are effective to make the students to acquire the extracted ASKs. Therefore, the syllabuses of them are checked if the ASK are described. The result is shown as a matrix (**Table 3**) that expresses "the syllabus of a class refers a ASK " as "1".

3.2 Idea for improving curriculum

This study analyzed the evaluation result (**Table 3**) using correspondence analysis and clarified the relationships between classes and ASKs. Correspondence analysis is a multivariate statistical technique and displays or summarizes some types of data in two-dimensional graphical form on the basis of their relatedness. This study aggregated the data of **Table 3** with respect to the three parts ("collective activity", "mechanical drawing", and "problem finding / solving") described in Section 2.2 in order to prevent the outlier. Specifically, the evaluation values of each part are calculated as the average value of the ASKs belonging to the part and are listed in **Table 4**. The result of the corresponding analysis using the aggregated data is shown in **Fig. 3**. This study

Table 3 Curriculum evaluation result

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		Communication skill	Teamwork of project	Ability to promote a project	Presentation/writing skill	Ability to communicate with other cultures	Ability to identify a problem	Ability to solve problems	Skill for mechanical drawing	Knowledge of machining	Creativity	Spatial representation ability	Knowledge of machine elements	Integrative thinking ability	System thinking ability	Knowledge of design process	Material knowledge	Knowledge of production cost	Skill to operate CAD	Skill for understanding the design drawing	Knowledge of NC machining tool	Knowledge of physics	Ability for design calculation	Skill to operate CAE/use calculation programs	Ability to consider engineering ethic	Self-learning ability
1	Modern civilization 1						1	1			1			1											1	
2	Introductory seminar 1				1		1	1		1						1		1			1					1
3	Linear algebra for engineer 1																						1			
4	Differential and integral calculus for engineer 1																						1			
5	Physics A																					1				
6	Physics B																					1				
7	Computer literacy																							1		
8	Introduction to mechanical engineering				1					1				1	1		1					1			1	
9	Linear algebra for engineer 2																						1			
10	Differential and integral calculus for engineer 2																						1			
11	Introductory seminar 2	1			1			1						1											1	
12	Strength of materials 1																1					1				
13	Modern civilization 2							1						1												
14	Fundamental physics for mechanical engineering 1																					1				
15	Thermal engineering 1																					1				
16	Engineering drawing								1			1								1						
17	Differential equations for engineer 1																						1			
18	Applied mathematics 1																					1	1			
19	Seminar of mechanical engineering				1									1											1	
20	Fundamental physics for mechanical engineering 2																					1				
21	Strength of materials 2																1					1				
22	Fundamental of machine design								1	1		1	1							1			1			
23	Machining									1								1				1				
24	Differential equations for engineer 2																						1			
25	Applied mathematics 2																					1	1			
26	Introduction to fluid mechanics 1																					1				
27	Engineering materials								1	1		1	1				1			1		1				
28	Experiments on mechanical engineering 1				1		1	1									1					1				
29	Computer aided design /computer aided manufacturing								1	1		1							1	1	1					
30	Probability theory and statistics for engineering																						1			
31	Theory of structure																1					1				
32	Tribology													1								1				
33	Introduction to fluid mechanics 2																					1				
34	Advanced materials																1					1				
35	Control engineering 1																					1	1			
36	Machine design1						1	1	1			1	1			1			1	1			1			
37	English skills review course					1																				
38	Thermal engineering 2																					1				
39	Experiments on mechanical engineering 2	1	1	1	1		1	1						1								1	1			1
40	Control engineering 2																					1				
41	English for science and technology					1																				
42	Issue driven learning	1			1		1	1																		
43	Machine design2						1	1	1			1	1	1	1	1				1			1			
44	Fluid mechanics																					1				
45	Thesis research 1	1	1	1	1		1	1						1	1										1	1
46	Thesis research 2	1	1	1	1		1	1						1	1										1	1
47	Computer programming C																							1		
48	Computer programming F																							1		
49	Energy conversion engineering																					1				
50	Mechanical vibration																					1				
51	Health fitness practice	1																								1
52	English listening & speaking 1					1																				
53	English listening & speaking 2					1																				
54	English reading & writing 1					1																				
55	English reading & writing 2					1																				
56	Life long sports practice	1																								1

additionally employed cluster analysis to classify the classes into clusters, on the basis of the coordinate value in **Fig. 3**. This study applied Ward's method, which is one of the most popular methods in hierarchical cluster analysis and exhibits the ability to accurately construct the hierarchical structure in avoiding chain effect [35]. **Figures 3 and 4** show ellipses that express the groups and the dendrogram derived by the cluster analysis method, respectively. These figures show the classes are classified into four clusters. These clusters can be identified from **Table 4** as follows: cluster 1 relating to "collective activity" and "problem finding / solving"; cluster 2 relating to "mechanical drawing" and "problem finding / solving"; cluster 3 relating to "problem finding / solving"; cluster 4 relating to "collective activity" and "problem finding / solving".

Figure 3 shows the cluster 2, which includes all classes for mechanical design, locates far from the other

Table 4 Curriculum evaluation result (Average evaluation value of each group)

		1	2	3	4	5	24		8	11	18	19		6	7	9	10	12	13	14	15	16	17	20	21	22	23	25	
		Communication skill	Teamwork of project	Ability to promote a project	Presentation/writing skill	Ability to communicate with other cultures	Ability to consider engineering ethic	**Group regarding collective activity**	Skill for mechanical drawing	Spatial representation ability	Skill to operate CAD	Skill for understanding the design drawing	**Group regarding mechanical drawing**	Ability to identify a problem	Ability to solve problems	Knowledge of machining	Creativity	Knowledge of machine elements	Integrative thinking ability	System thinking ability	Knowledge of design process	Material knowledge	Knowledge of production cost	Knowledge of NC machining tool	Knowledge of physics	Ability for design calculation	Skill to operate CAE/use calculation programs	Self-learning ability	**Group regarding problem finding / solving**
1	Modern civilization 1						1	0.17					0.00	1	1		1		1										0.27
2	Introductory seminar 1				1			0.17					0.00	1	1	1					1		1	1				1	0.47
3	Linear algebra for engineer 1							0.00					0.00													1			0.07
4	Differential and integral calculus for engineer 1							0.00					0.00													1			0.07
5	Physics A							0.00					0.00												1				0.07
6	Physics B							0.00					0.00												1				0.07
7	Computer literacy							0.00					0.00														1		0.07
8	Introduction to mechanical engineering				1		1	0.33					0.00			1			1	1		1			1				0.33
9	Linear algebra for engineer 2							0.00					0.00													1			0.07
10	Differential and integral calculus for engineer 2							0.00					0.00													1			0.07
11	Introductory seminar 2	1			1		1	0.50					0.00		1				1										0.13
12	Strength of materials 1							0.00					0.00									1			1				0.13
13	Modern civilization 2							0.00					0.00		1				1										0.13
14	Fundamental physics for mechanical engineering 1							0.00					0.00												1				0.07
15	Thermal engineering 1							0.00					0.00												1				0.07
16	Engineering drawing							0.00	1	1		1	0.75																0.00
17	Differential equations for engineer 1							0.00					0.00													1			0.07
18	Applied mathematics 1							0.00					0.00												1	1			0.13
19	Seminar of mechanical engineering				1		1	0.33					0.00						1										0.07
20	Fundamental physics for mechanical engineering 2							0.00					0.00												1				0.07
21	Strength of materials 2							0.00					0.00									1			1				0.13
22	Fundamental of machine design							0.00	1	1		1	0.75			1		1								1			0.20
23	Machining							0.00					0.00			1							1		1				0.20
24	Differential equations for engineer 2							0.00					0.00													1			0.07
25	Applied mathematics 2							0.00					0.00												1	1			0.13
26	Introduction to fluid mechanics 1							0.00					0.00												1				0.07
27	Engineering materials							0.00	1	1		1	0.75			1		1				1			1				0.27
28	Experiments on mechanical engineering 1				1			0.17					0.00	1	1							1			1				0.27
29	Computer aided design /computer aided manufacturing							0.00	1	1	1	1	1.00			1								1					0.13
30	Probability theory and statistics for engineering							0.00					0.00													1			0.07
31	Theory of structure							0.00					0.00									1			1				0.13
32	Tribology							0.00					0.00						1						1				0.13
33	Introduction to fluid mechanics 2							0.00					0.00												1				0.07
34	Advanced materials							0.00					0.00									1			1				0.13
35	Control engineering 1							0.00					0.00												1	1			0.13
36	Machine design1							0.00	1	1	1	1	1.00	1	1			1			1					1			0.33
37	English skills review course					1		0.17					0.00																0.00
38	Thermal engineering 2							0.00					0.00												1				0.07
39	Experiments on mechanical engineering 2	1	1	1	1			0.67					0.00	1	1				1						1	1		1	0.40
40	Control engineering 2							0.00					0.00												1				0.07
41	English for science and technology					1		0.17					0.00																0.00
42	Issue driven learning	1			1			0.33					0.00	1	1														0.13
43	Machine design2							0.00	1	1		1	0.75	1	1			1	1	1	1					1			0.47
44	Fluid mechanics							0.00					0.00												1				0.07
45	Thesis research 1	1	1	1	1		1	0.83					0.00	1	1				1	1								1	0.33
46	Thesis research 2	1	1	1	1		1	0.83					0.00	1	1				1	1								1	0.33
47	Computer programming C							0.00					0.00														1		0.07
48	Computer programming F							0.00					0.00														1		0.07
49	Energy conversion engineering							0.00					0.00												1				0.07
50	Mechanical vibration							0.00					0.00												1				0.07
51	Health fitness practice	1						0.17					0.00															1	0.07
52	English listening & speaking 1					1		0.17					0.00																0.00
53	English listening & speaking 2					1		0.17					0.00																0.00
54	English reading & writing 1					1		0.17					0.00																0.00
55	English reading & writing 2					1		0.17					0.00																0.00
56	Life long sports practice	1						0.17					0.00															1	0.07

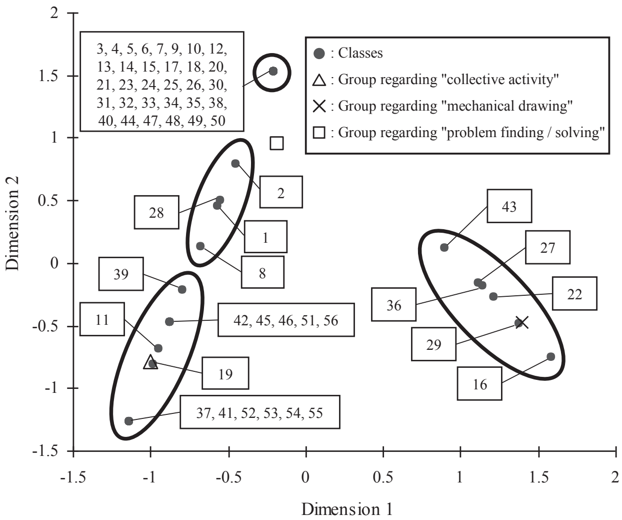

Fig. 3 Scatter graph by corresponding analysis

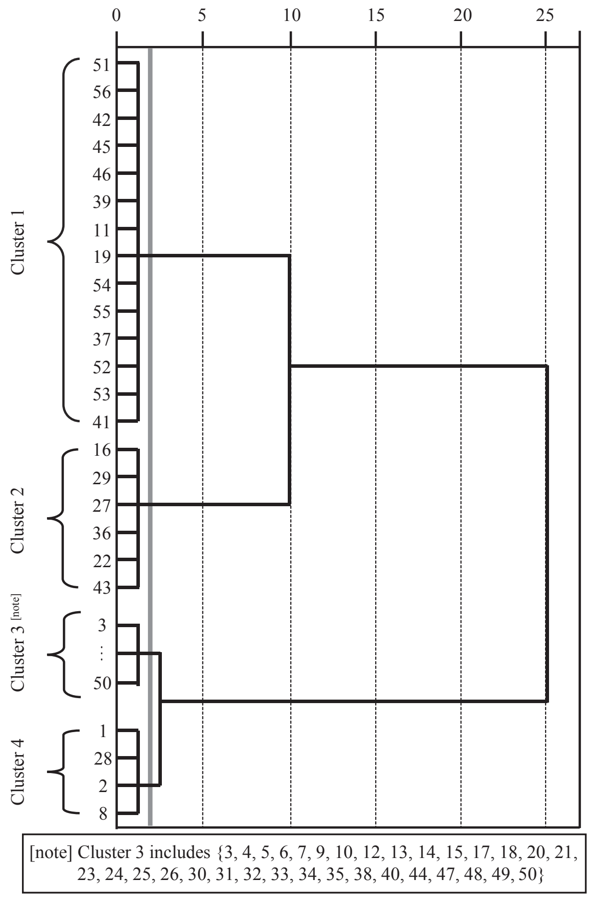

Fig. 4 Dendrogram by cluster analysis

clusters. The reason comes from the fact that all of the 6 classes, included in the cluster 2, do not relate to the ASKs of "collective activity" (i.e. most classes included in the clusters 1, 3, and 4 relate them) (see **Table 3**). This means the mechanical design classes of Tokai University are constructed on an individual work. Although, there is an idea to make the students acquire the ASKs of "collective activity" in non-mechanical design classes, it is better for them to learn the ASKs in mechanical design classes in order to foster industry-ready designers. In this case, "machine design 2" (No.43), which is located near the other clusters (**Fig. 3**), is favorable to be improved to include the ASKs of "collective activity".

Based on the suggestion, "machine design 2" was changed to be a group working style, and it has started. The effectiveness will be analyzed in the future.

4 Conclusions

This study constructed a relationship model between the abilities, skills, and knowledge which are required by mechanical designers and are extracted from the conventional studies using affinity diagram and interpretive structural modeling. Using the proposed model, the classes of Tokai University (Mechanical Engineering Department) were evaluated by correspondence and cluster analyses, and improvement plan of the classes were proposed. In the future, the proposed plan will be implemented to confirm the effectiveness of the proposed model.

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