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A Novel Curriculum Visualization Method Using a Combination of Competencies, Cosine Similarity, Multidimensional Scaling Methods, and Scatter Plotting

Kunihiko Takamatsu [*], Katsuhiko Murakami [†], Yasuhiro Kozaki [‡], Kenya Bannaka [*], Ikuhiro Noda [*], Mayumi Yamasaki [*], Kenichiro Mitsunari [*], Tadashi Nakamura [*], Yasuo Nakata [*]

Abstract

This article outlines a new way of visualizing curricula (sets of courses for students) using competencies via a combination of cosine similarity, multidimensional scaling methods, and scatter plotting. We have already published a report analyzing syllabi (summary texts that explain the main points of courses or the contents of curricula) with the same methods. In this report, we show that using competencies is more useful than using syllabi. Usually, students are only interested in the course content when they select courses; this new visualization of curricula using competencies gives students a new perspective on their courses.
Keywords: competency, cosine similarity, multidimensional scaling methods, scatter plotting, visualizing curricula

1 Introduction

Over the past decade, the circumstances in which Japanese universities find themselves have changed significantly. During the 2016 International Conference on Data Science and Institutional Research (DSIR 2016), we reported on enhanced collaboration between faculty and staff at Kobe Tokiwa University, using a strength, weaknesses, opportunities, and threats (SWOT) framework, as well as complex network analysis methods [1]. Our results led to the creation of a team at the university. In this article, we report on the team's activities and data, which we analyze using information gathered by the team.

1.1 Preparation for Reform in Higher Education

[*] Kobe Tokiwa University, Hyogo, Japan
[†] The University of Tokyo, Tokyo, Japan
[‡] Osaka Kyoiku University, Osaka, Japan

Table 1: Kobe Tokiwa University competencies (cited from [7])

Abbreviated name of competency	*Competency*
1. Culture	Ability to use liberal arts as the foundation of human nature, which can involve a variety of people.
2. Common Sense	Ability to behave sensibly and show sound judgment in practical matters.
3. Professional Expertise	Having the necessary knowledge and skills to perform the duties of each profession
4. Media Literacy	Ability to collect, organize, and analyze necessary information from various media sources for proper thinking and judgment.
5. Logical Thinking	Ability to consider situations logically based on evidence.
6. Critical Thinking	Ability to have a multilateral, critical perspective that can grasp and consider various ideas.
7. Intellectual Curiosity	Ability to be curious, to learn and remember things, and to have fun and take pleasure in learning.
8. Exploration	Ability to think deeply about things and methods.
9. Continuity	Ability to maintain a consistent stance on issues and act knowledgeably and thoughtfully.
10. Self-Management	Ability to manage one's physical and mental health appropriately.
11. Reflection	Ability to continually seek ways to improve oneself by reflecting on one's thinking and behavior.
12. Design Thinking	Ability to design solutions and develop comprehensive knowledge.
13. Presentation	Ability to appropriately communicate one's personal feelings and thoughts to others.
14. Judgment	Ability to make appropriate decisions given the circumstances, based on valid information and sound thinking.
15. Implementation	Ability to take specific actions based on one's feelings and thoughts and without fear of failure.
16. Responsibility	Ability to behave and face things responsibly as a member of society.
17. Contribution	Ability to feel happy for others and take actions that are useful for others.
18. Communication	Ability to listen to others' opinions, without which it is impossible to have a creative dialogue.
19. Cooperation & Collaboration	Ability to set aside personal and individual interests to work together harmoniously.

1.2 Curriculum Mapping

Table 2: The relationships between 40 courses and the 19 competencies at Kobe Tokiwa University

course name / competency	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	total
01.Pleasant & Deep Learning I	0	0	0	0	0	0	0	20	0	10	25	10	15	0	0	0	0	0	20	100
02.Pleasant & Deep Learning II	0	0	0	0	0	0	0	20	0	10	25	10	15	0	0	0	0	0	20	100
03.Freshman Seminar I	0	0	0	0	0	0	25	35	0	0	20	0	0	0	0	0	0	20	0	100
04.Freshman Seminar II	0	0	0	0	0	0	25	35	0	0	20	0	0	0	0	0	0	20	0	100
05.Leadership & Facilitation	0	0	0	0	0	0	0	0	0	0	40	15	0	0	0	10	10	5	20	100
06.Information Technology Basic	35	0	0	35	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
07.Health & Sports Science II	0	0	0	0	0	0	0	0	0	30	0	0	30	0	0	20	0	0	20	100
08.Academic writing	0	0	0	15	25	15	25	0	0	0	0	0	15	5	0	0	0	0	0	100
09.English Communication I	0	0	0	19	30	23	15	0	0	0	0	0	13	0	0	0	0	0	0	100
10.English Communication II	0	0	0	10	35	35	10	0	0	0	0	0	10	0	0	0	0	0	0	100
11.Communicative English Basic	0	0	0	0	0	0	20	0	0	0	0	0	60	0	0	0	0	20	0	100
12.Communicative English Intermediate	0	0	0	0	0	0	25	0	0	0	0	0	60	0	0	0	0	15	0	100
13.Sign Language	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	10	100
14.Life & Symbiosis	20	0	5	25	0	10	0	40	0	0	0	0	0	0	0	0	0	0	0	100
15.Global Environment	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	100
16.Mathematics	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	50	100
17.Statistics	0	0	0	25	25	0	0	0	0	0	0	0	0	0	0	0	0	0	50	100
18.Physics	35	0	0	0	35	0	0	0	0	0	0	0	0	0	0	0	0	0	30	100
19.Chemistry	28.5	0	0	0	21	0	28.5	8	0	0	0	0	8	0	3	0	3	0	0	100
20.Mystery of the Human Body	30	0	0	10	0	0	20	0	0	10	10	0	10	0	0	0	0	10	0	100
21.Life science	40	0	0	0	20	15	0	0	0	0	0	0	20	0	0	0	5	0	0	100
22.Safety Science	20	20	0	20	0	0	0	0	0	0	0	0	0	0	0	20	0	0	20	100
23.Agriculture	20	25	0	0	0	5	10	17.5	0	0	0	0	5	0	0	12.5	5	0	0	100
24.Introduction to Programming	0	0	0	0	30	0	0	0	0	0	0	45	0	0	0	0	25	0	0	100
25.Philosophy	0	0	0	0	25	50	0	0	0	0	0	0	25	0	0	0	0	0	0	100
26.Theory of Arts and Culture	35	0	0	0	0	0	40	0	0	0	25	0	0	0	0	0	0	0	0	100
27.Literature	10	0	0	0	20	0	0	0	0	0	10	0	40	0	0	10	0	10	0	100
28.Current Events in the World	35	0	0	0	0	0	25	20	0	0	0	20	0	0	0	0	0	0	0	100
29.Modern Sociology	20	0	0	20	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	100
30.Economics	0	30	0	0	30	0	20	0	0	0	0	0	20	0	0	0	0	0	0	100
31.Clinical Psychology	0	0	24	0	0	24	0	0	0	0	0	0	24	0	0	0	0	24	4	100
32.Human Relations Theory	0	0	24	0	0	24	0	0	0	0	0	0	23	0	0	0	0	24	5	100
33.Education & Human	60	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	20	0	100
34.Collaboration with the Community I	0	10	0	0	0	0	0	0	0	0	50	0	0	0	10	10	10	0	10	100
35.Disaster and Community Development	0	0	0	0	0	0	0	25	25	0	0	0	0	0	0	25	25	0	0	100
36.Community Design	0	0	0	15	15	15	0	10	0	0	0	25	20	0	0	0	0	0	0	100
37.Life Design	0	0	0	15	15	0	10	10	0	0	0	35	15	0	0	0	0	0	0	100
38.The Constitution of Japan	35	0	0	0	20	0	0	0	0	0	20	0	10	0	0	10	0	5	0	100
39.Life & Ethics	0	60	0	0	0	20	0	0	0	0	0	0	10	0	0	0	10	0	0	100
40.Japanese History	20	0	20	0	20	15	0	0	0	0	0	0	25	0	0	0	0	0	0	100

In 1991, MEXT recommended a self-review, self-evaluation system to improve the quality of higher education and research in Japan [19]. In a 2008 report by MEXT's CCE, ongoing efforts to enhance the general quality of higher education in Japan, including the use of curriculum maps

that they should achieve in the course in the context of all the possible competencies. The rubric revealing relationships between all the courses and competencies is displayed in Table 2.

2 Methods

Cosine similarity can be used to measure similarities and detect differences between vectors. The cosine similarity of vectors $\vec{a}$ and $\vec{b}$ is defined as:

$$\cos(\vec{a}, \vec{b}) := \frac{\vec{a} \cdot \vec{b}}{|\vec{a}||\vec{b}|} = \frac{\sum_{i=1}^{|V|} a_i b_i}{\sqrt{\sum_{i=1}^{|V|} a_i^2} \cdot \sqrt{\sum_{i=1}^{|V|} b_i^2}}$$

In this paper, a *vector* is a syllabus or a course's pattern of 19 competencies. Thus, herein, cosine similarity measures the similarity between two syllabi or courses (Table 2) and a course can be regarded as a vector with 19 dimensions; we can therefore calculate total cosine similarity between two courses. The maximum value of cosine similarity is 1 and the minimum is -1.

When two syllabi or competencies are the same, their cosine similarity is 1. The number of possible relationships between two courses is ${}_{40}C_2$=780. We therefore obtain cosine similarity metrics in 780 dimensions, meaning that for visualization purposes, we also needed to reduce the dimensionality of this analysis method.

Methods of reducing dimensions can generally be classified into two types: linear and nonlinear. Linear methods involve methods such as Random Projection [28], PCA [29], Linear Discriminant Analysis [30], and MDS [31]. Nonlinear methods include Isomap [32], Locally Linear Embedding [33], Modified Locally Linear Embedding (MLLE) [34], Hessian Eigenmapping [35], local tangent space alignment [36], and t-distributed stochastic neighbor embedding (t-SNE) [37]. In this study, we opted for the MDS method to visualize the cosine similarity matrix, because it is perhaps the easiest to understand.

The conventional way of visualizing a cosine similarity matrix is to map it onto distance space, thereby reducing this high dimensionality to low dimensionality (two dimensions). Unfortunately, the cosine similarity of the two vectors in the vector space is unlikely to involve distance axioms in a general mathematical sense (e.g., based on non-negativity, non-degradability, symmetry, triangular inequality), because cosine similarity can be negative. When any x, y, z belonging to the set X satisfy these four arbitrary guidelines against two real variable functions d: $X \times X \rightarrow \mathbf{R}$, defined on the set X, d represents their distance, and (X, d) represents their distance space in a general mathematical sense.

(1) non-negativity: $d(x, y) \geq 0$

(2) non-degradability: $x = y \Rightarrow d(x, y) = 0$

(3) symmetry: $d(x, y) = d(y, x)$,

(4) triangular inequality: $d(x, y) + d(y, z) \geq d(x, z)$

Therefore, when using the visualization method described above, for practical purposes, it is necessary to subtract from 1. This way, non-negativity can be guaranteed and mapped onto the distance space. After this mapping, the maximum value of cosine similarity becomes 2 and the minimum value becomes 0. This mapping also satisfies the principles of non-degradability, symmetry, and triangular inequality.

When trying to visualize the (x, y) components obtained by dimensional reduction, a scatter plot may be of use; however, it may be difficult to understand the meaning of the x and y axes. For simplicity, in this study, the x-axis and the y-axis are images corresponding to the first axis and the second axis of the principal component analysis. That is, the x and y axes are derived by calculations that mathematically reduce dimensions.

To calculate the cosine similarity of syllabi, we prepared a vector space in which each vector represented the syllabus of a course offered by Kobe Tokiwa University in 2017. Each syllabus is freely available on the institution's official homepage [18]. We prepared each syllabus in portable document format (PDF), and then converted these files to plain text using an open-source UNIX command-line tool called pdftotext, which encodes the text using UTF-8 [38]. We then

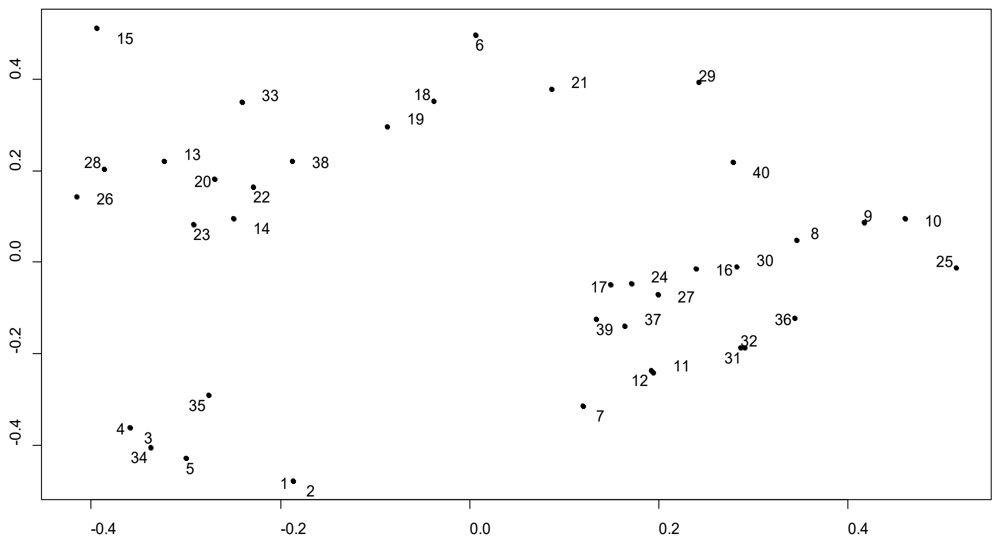

Figure 1: Visualizing curricula using syllabi: using 19 competencies for 40 courses, we visualized MDS via scatter plotting.

performed a morphological analysis of the Japanese language in each file using MeCab [39]. Finally, we calculated cosine similarity using files produced with MeCab.

We visualized the resulting cosine similarity matrix with MDS, using the R package "lsa" (latent semantic analysis) [40], as well as by using scatter plotting with R's "maptools" package [41][42]. We also used Cytoscape [43], a network visualization tool developed for the analysis of protein-protein interactions (PPI), to visualize the interrelationships between courses and competencies (Figure 1). Network visualization is underpinned by graph theory.

3 Results

To visualize curricula using competencies, we calculate cosine similarity, MDS, and scatter plotting (Figure 1). There are three groups in Figure 1. The first group took Pleasant & Deep Learning I, Pleasant & Deep Learning II, Freshman Seminar I, Freshman Seminar II, Leadership & Facilitation, Collaboration with the Community I, and Disaster and Community Development. The second group took Sign Language, Life & Symbiosis, Global Environment, Mystery of the Human Body, Safety Science, Agriculture, Theory of Arts and Culture, Current Events in the World, Education & Human, and The Constitution of Japan. The third group took Health & Sports Science II, Academic writing, English Communication I, English Communication II,

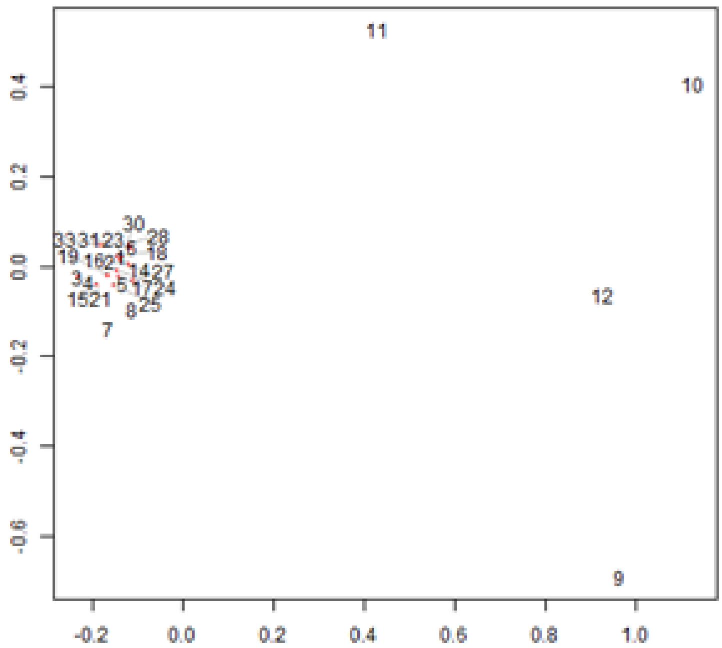

Figure 2: Curricula, visualized by employing syllabi; using syllabi from 39 courses, we visualized MDS via a scatter plotting (cited from [39]).

Communicative English Basic, Communicative English Intermediate, Mathematics, Statistics, Introduction to Programming, Philosophy, Literature, Economics, Community Design, Life Design, and Life & Ethics.

These different groups' different courses do not superficially appear to be related, but the visualized curricula in fact show some overlap in the competencies that they cover. This finding is very important, as it may provide students with more helpful guidance in selecting their courses. For example, if students want to obtain a wide range of competencies, they will see that they have to choose courses from different groups. Note that scatter plotting of MDS is relative, so it will

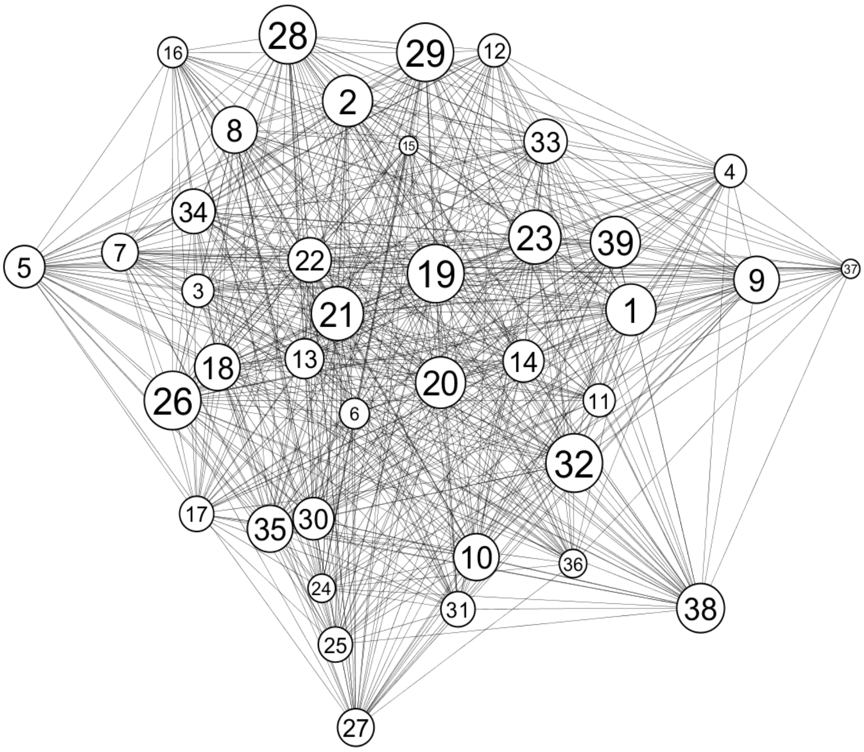

Figure 3: A network, visualized; using 19 competencies from 39 courses, we visualized this network with Cytoscape (cited from [39]).

change if courses are added or deleted. However, scatter plots of MDS may be useful for advising students, regardless of whether these plots change or not.

We visualized curricula by employing syllabi from 39 courses, instead of competencies (Figure 2, cited from [44]). As there is only one big group, it is possible to understand that this map is not useful in comparison with both curriculum maps, which were developed by humans; it is also possible to visualize curricula using competencies.

For visualizing curricula using network analysis, we obtained the symmetric matrix of cosine similarity. This matrix-vector is known as an adjacency matrix in network analysis. Next, we transformed the adjacency matrix into an adjacency list using the igraph library [45]. We visualized these data using the open-source software Cytoscape [43] (Figure 3, cited from [44]). Since this figure shows too many connections, it is difficult to clearly understand the relationships among courses.

4 Discussion and Implications

We believe that using MDS to visualize curricula is the best way for students to understand course competencies and select their courses. These methods work better using syllabi or network visualization.

Global competency here refers to the knowledge and skills that people need to understand today's "flat world" and to integrate across disciplines, so that they can comprehend global events and create possibilities to address them. Global competencies also include the attitudinal and ethical dispositions that make it possible to interact peacefully, respectfully, and productively with fellow human beings from diverse geographies [46].

Thus, competency-based education, which is an approach to teaching and learning more often used in learning concrete skills than in abstract learning, has become a hot topic in higher education circles. However, the competency-based education approach has just been initiated in Japan. The Organization for Economic Co-operation and Development (OECD) has defined core competencies [47]. The Programme for International Student Assessment (PISA), which is conducted by OECD, was developed based on these core competencies.

At present, Kobe Tokiwa University is undergoing reforms, one of which is a move to competency-based education. As discussed above, our university developed a common evaluation indicator called "Tokiwa competencies," which students should acquire through regular, quasi-regular (or remedial), and extracurricular (or club) activities. We believe 19 Tokiwa competencies is too many in number. Therefore, we aim to re-define Tokiwa competencies and reduce the number of competencies.

While most students previously selected their courses based solely on content, these competencies will provide students with an expanded perspective to assist them in course selection. We developed an Information and Communication Technology-based support system to help students select university-level courses. Since 2017, the syllabi of Kobe Tokiwa University display the relationships between courses and the Tokiwa competencies (Table 2).

As such, students can now calculate the theoretical competencies when selecting their courses. We developed a web-based system to facilitate the calculation of competencies. Students first select their preferred courses and enter them on the webpage; the competencies are then illustrated as a radar chart reflecting the 19 categories. While this radar chart is theoretical and represents ideal competency values, it is useful for understanding the types of competencies that may be obtained from the courses (Figure 4).

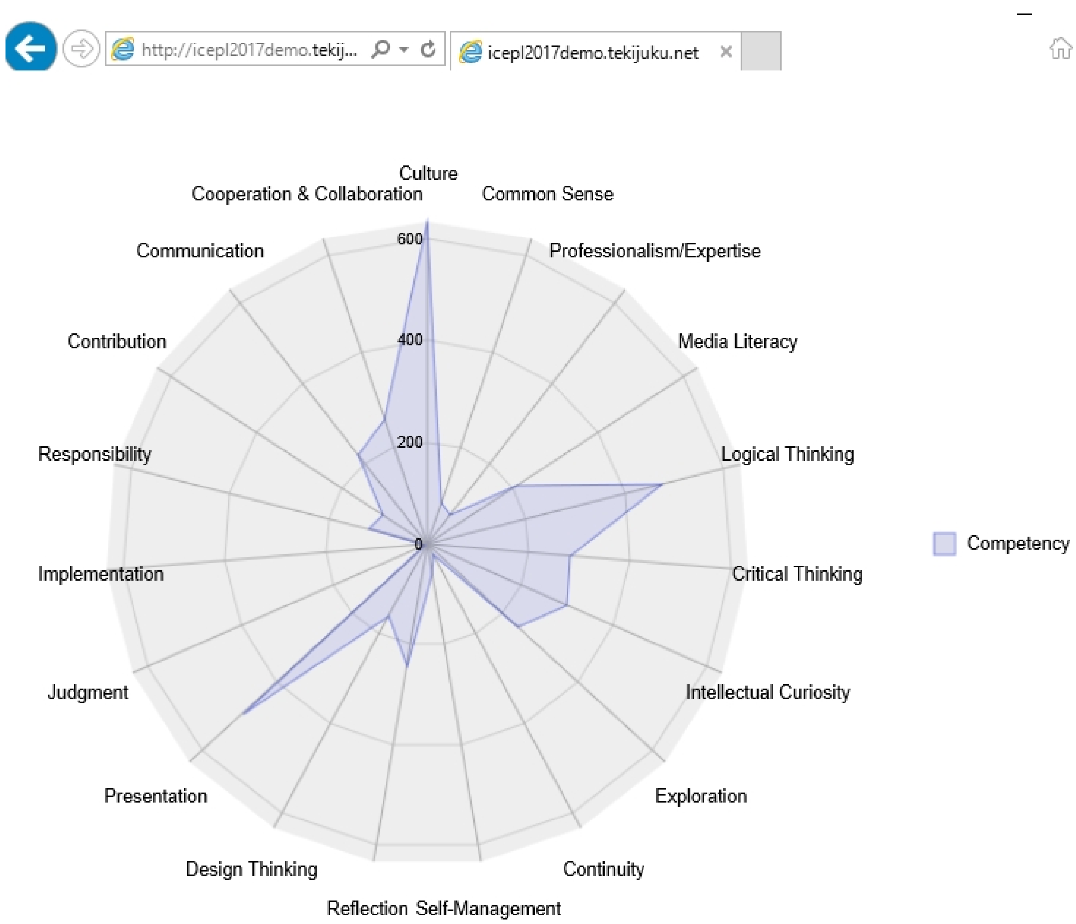

Figure 4. Rader Chart of Competencies Corresponding to Academic Skills and Deep Learning I, Academic Skills and Deep Learning II, Information Technology Basics, Academic Writing, English Communication I, English Communication II, and Life and Ethics. Source: Takamatsu et al. [48]. Web-based Support System for Students to Select Courses using Tokiwa Competencies. International Conference on Education, Psychology, and Learning (ICEPL 2017).

We further developed a web-based radar chart system of Tokiwa competencies to help students understand their competency level by themselves. Students first select their current competency level on the webpage; the competencies are then illustrated as a radar chart showing the 19 categories (Figure 5). This system is compatible with both computers and smartphones, which is necessary given that most students use a smartphone instead of a computer. This feature has been created with the hope that students understand each competency easily, and that this would reflect in their behavior in regular and quasi-regular curricula, as well as extracurricular activities in university.

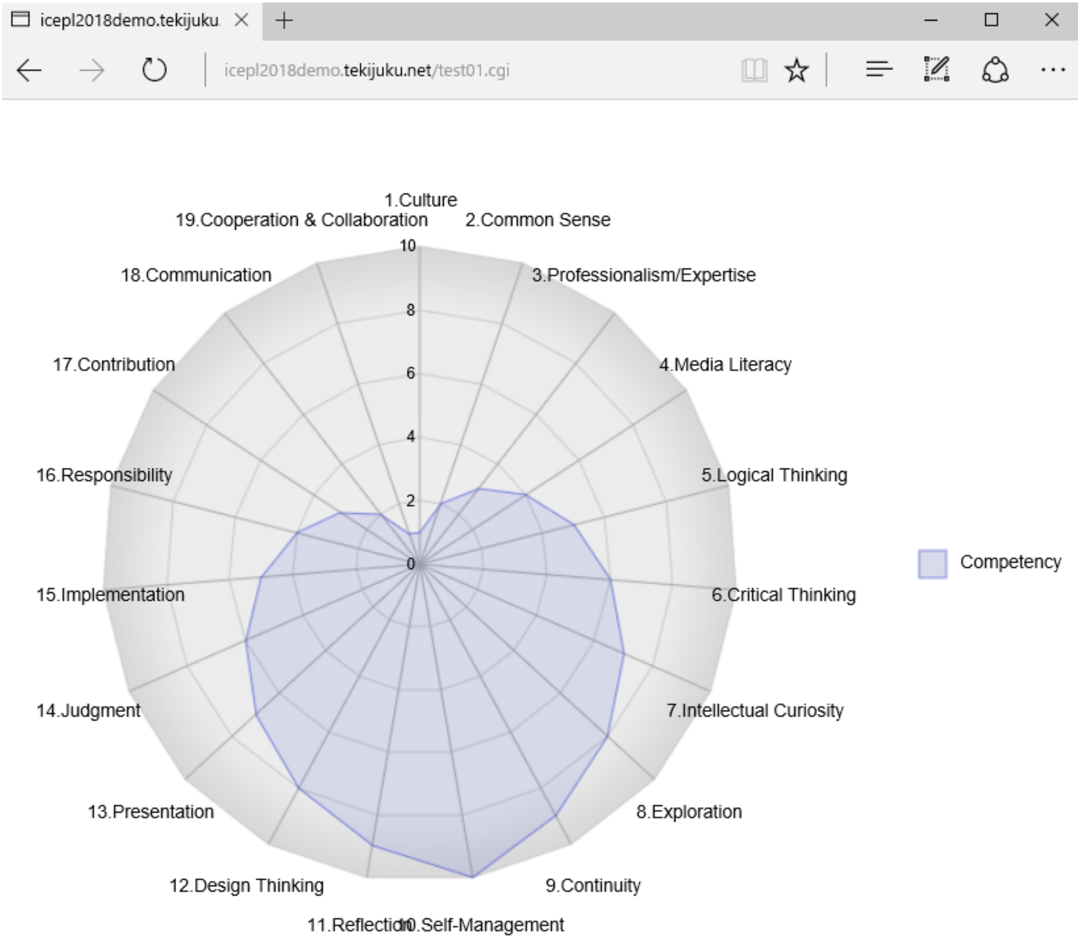

Figure 5. Example of a radar chart. Source: Takamatsu et al. [7]. Web-based Radar Chart System of Tokiwa Competencies, International Conference on Education, Psychology, and Learning (ICEPL 2018).

In this study, we visualized curricula using competencies via a combination of cosine similarity, MDS, and scatter plotting. Using this study, we have already initiated the attempt to advise students based on their desired competencies. A detailed analysis of the results and impact will be reported in another article.

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