

Usability Evaluation of Online Courses Service Platform Based on Extenics: Using "Machine Principle" Course as an Example

Ding Gang^{1,2,*}, Wei Lihong¹, Cheng Yanyu¹

¹Harbin Institute of Technology Office of Academic Affairs, Harbin City, China

²Harbin Institute of Technology, School of Mechatronics Engineering, Harbin City, China

Email address:

dinggang@hit.edu.cn (Ding Gang), weilihong@hit.edu.cn (Wei Lihong), chyy@hit.edu.cn (Cheng Yanyu)

*Corresponding author

To cite this article:

Ding Gang, Wei Lihong, Cheng Yanyu. Usability Evaluation of Online Courses Service Platform Based on Extenics: Using "Machine Principle" Course as an Example. *Education Journal*. Vol. 7, No. 2, 2018, pp. 43-50. doi: 10.11648/j.edu.20180702.13

Received: May 21, 2018; **Accepted:** July 20, 2018; **Published:** August 13, 2018

Abstract: In this paper, based on the usability evaluation system of online courses service platform, the content experience dimension is quantified by means of professional teachers' subjective scoring on the quality and arrangement of teaching content, and the interface experience dimension is quantified by means of performance measurement, the task completion of the subjects in the learning process is measured by making a series of learning tasks on the completion platform, the subjects who completed the performance measurement experiment were invited to participate in the self-report questionnaire survey, then the emotional experience dimension is quantified by means of self reporting measurement. On this basis, through the establishment of the matter element and the correlation function, an extension evaluation model of the service platform for online courses is developed based on Extenics. Using the quantitative data of each indicator as inputs, the proposed extension evaluation model is used to calculate the correlation degree of each indicator, and the usability of the service platform for online courses is evaluated. The result shows that the usability level of the service platform for online course which is using in Harbin Institute of Technology is in the third level, and it is at a medium level.

Keywords: Online Courses Service Platform, Quantification of Usability Evaluation Indicator, Extension Evaluation Model

1. Introduction

The online course platform and its MOOC (Massive Open Online Courses) and SPOC (Small Private Online Courses) and "flipped-class" teaching model based on the MOOC/SPOC have greatly promoted the health and rapid development of China's higher education [1-3].

In order to study the usability of online course service platform, the online course service platform which is running by Harbin Institute of Technology is taken as the research object [4], and the usability evaluation system of the online course service platform established by the analytic hierarchy process (AHP) is shown in Figure 1.

2. Quantitative of Usability Evaluation Indicators of Online Course Service Platform

According to the characteristics of the indicators in Figure 1, three corresponding methods are adopted to quantify the indicators. For the quantification of content experience dimension, professional teachers' subjective grading method will be used. The method of performance measurement is adopted to quantify the dimension of interface experience. A series of experiments will be conducted to obtain relevant index data by inviting qualified subjects. After the completion of the performance measurement test, participants will be invited to complete a self-report survey to quantify the indicators of emotional experience dimensions.

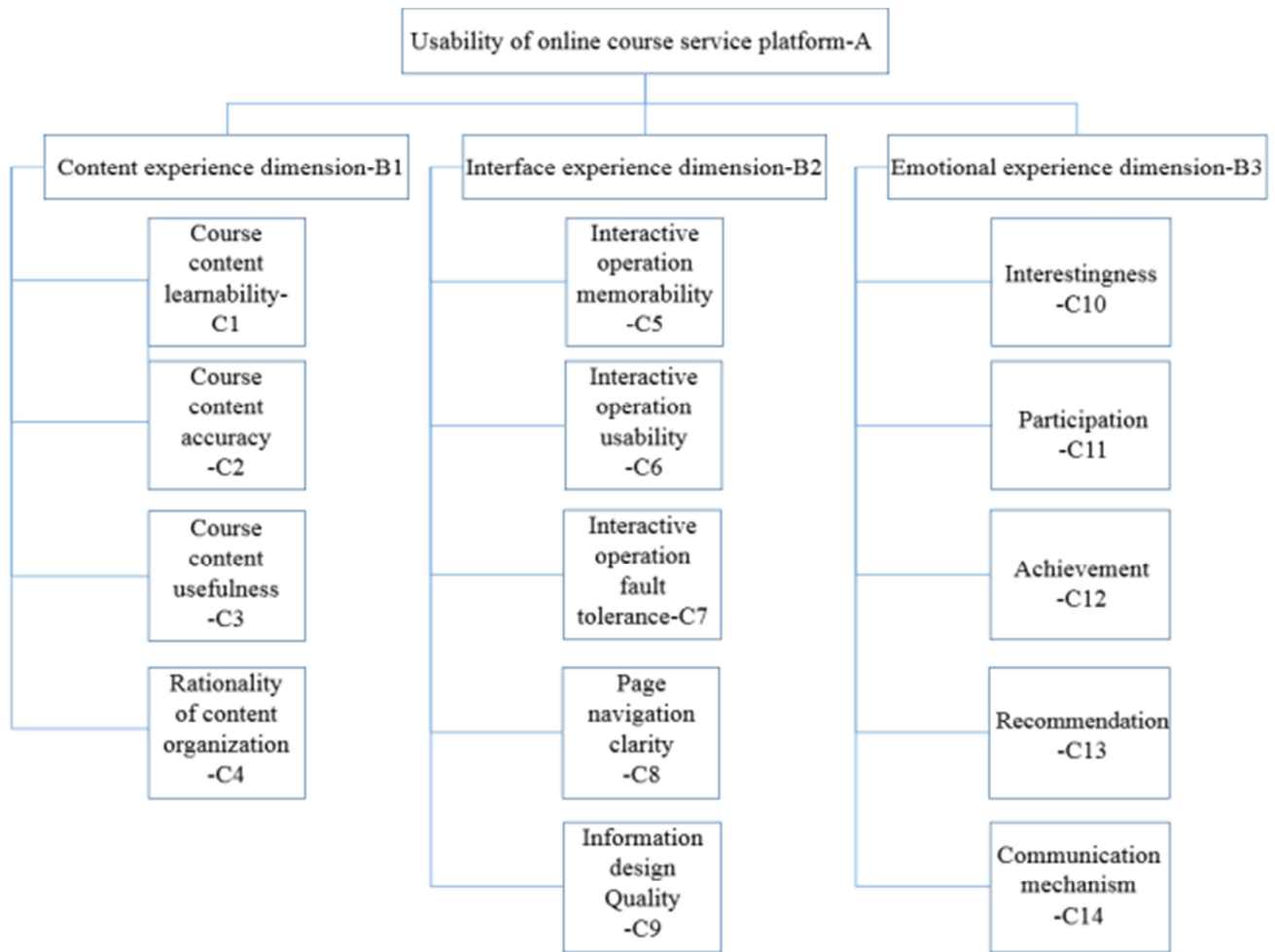


Figure 1. The usability evaluation system of online course service platform.

2.1. Quantifying the Content Experience Dimension Based on the Subjective Scoring Method

As the indicators of the content experience dimension are evaluated for the quality and arrangement of the teaching content, the quantification of the content experience dimension will be carried out by the subjective score of the professional teachers.

2.1.1. Experimental Design of Quantifying Subjective Scoring Method

Subjective scoring method is to use expert experience and other invisible knowledge to judge scoring indicators. In the

quantitative experiment of content experience dimension, we will invite 10~15 teachers or teaching assistants who have rich experience in teaching "Machine Principle" Course.

In the subjective scoring and quantifying experiment, the courseware of "gear transmission" of "Machine Principle" course of Harbin Institute of Technology will be taken as an example. The courseware will be sent to professional teachers, so that they can carefully check the content and structure of the related courseware. After reading all the teaching contents, they are required to complete the subjective evaluation questionnaire. The subjective evaluation questionnaire was shown in Table 1.

Table 1. The subjective evaluation questionnaire.

Problem Number	Problem Content
Q1	The content of the course is clear and easy to understand.
Q2	The course content is easy to learn and the mobility is good.
Q3	The contents and principles of the course are correct, and there is no pseudoscience.
Q4	There are no editing errors in text content, data and charts.
Q5	The course content is in line with the learning needs of the mechanical students.
Q6	The practical value of the course content is high.
Q7	The content and knowledge structure of the course are clear and complete.
Q8	The course content is clear and focused. Distribution of main and secondary content is reasonable.

After completing the test, the subjects were asked to score according to the subjective scoring method, and the 10 grade

scoring system was adopted. The teachers rated 0-9 points according to their own experience, 0 point were very

disapproval, and the 9 point representatives agreed very much. With the increase of scores, the degree of conformity increased gradually.

2.1.2. Quantitative Results and Analysis

In this quantitative experiment of content experience

dimension, 15 teachers and teaching assistants who are familiar with the course of "Machine Principle" have collected 120 data for the evaluation of the teaching content, and the average value of each score is obtained by preliminary processing. The average result of the subjective score is shown in Figure 2.

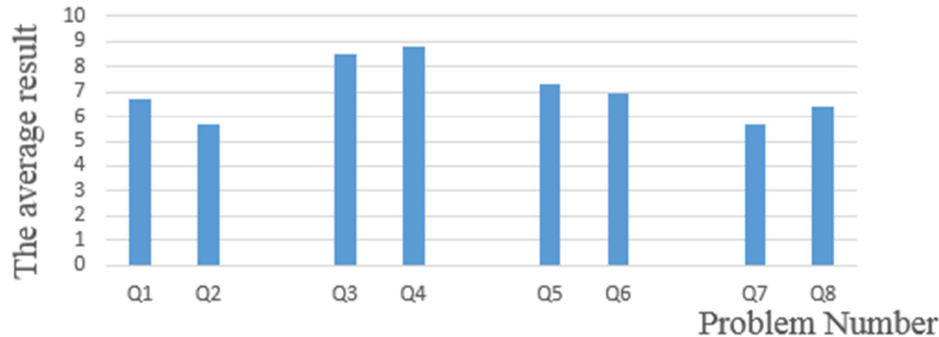


Figure 2. The average result of subjective score.

From the results of Figure 2, we can see that the results of subjective scoring are generally high, and the accuracy of teaching content is the highest, which indicates that the accuracy of the "machine principle" courseware is higher. Secondly, in view of the higher grade of teaching content usefulness, the content of teaching courseware is in accordance with the students' learning needs and has a high value of use. However, there is little gap between the learning and rationality of teaching content, which is lower than the

accuracy and usefulness of the score, indicating the relatively easy learning and combination of teaching courseware. Reason is not as accurate and useful as it needs to be strengthened in these two aspects.

The obtained data are calculated according to the four factors of the content experience dimension, the average value, the maximum value and the minimum value are obtained, and then the data is normalized to get the quantized data as shown in Table 2.

Table 2. Subjective score quantized data.

First-class index	Second-class index	Average value	Maximum value	Minimum value	Normalized data
Content experience dimension	Course content learn ability	6.200	8.000	5.500	0.280
	Course content accuracy	8.650	9.000	8.000	0.650
	Course content usefulness	7.100	9.000	6.000	0.367
	Rationality of content organization	6.050	8.000	4.500	0.443

2.2. Quantification of Interface Experience Dimension Based on Performance Measurement

Performance measurement is a commonly used measurement method in usability evaluation [5]. The performance measurement is based on the design of the measurement experiment, with the pre designed and established tasks as the measurement basis, and the completion instructions of the tasks are clearly defined. According to the success of the task, complete the task time, error number and completion efficiency data, quantify the dimension of the interface experience.

2.2.1. Experiment Design of Performance Measurement

The performance measurement experiment is to measure the usability of the interface experience dimension. By designing a series of tasks to study the course of machine principle in the network course service platform, the task completion of the subjects in the learning process is measured. The main measure is to complete the total time of the task, the

time to complete the tasks, and the time, and the time to complete the tasks. The number of errors and efficiency, and then get the quantitative value of usability evaluation of the interface experience dimension.

This trial recruited two groups of 40 subjects. Group A was used to measure the memorability of interaction, including 20 subjects who did not use the learning experience of online course service platform. The B group was used to measure the ease of interaction, including 20 subjects who had learning experience using online course service platform. Two groups of subjects were invited to experiment. The total time of completion of all tasks, the completion time of a single task, the number of errors and the efficiency of the completion of the task were collected and recorded by viewing the experimental video. This experiment takes the "gear transmission" section of the "machine principle" course on the online course service platform as an example to carry out the design of the experimental task of performance measurement, and the specific tasks are set as shown in Table 3.

Table 3. Performance measurement task setting.

Task number	Task statement
T1	Open the web page as required (http://jwcs.hit.edu.cn/)
T2	Entry into the account login interface
T3	Enter the password to login the specified account
T4	Browse all courses on the online courses service platform
T5	Search the course of machine principle
T6	Find the machine principle course. The course number is 13SD08000200, and the main teacher is Ding Gang.
T7	Look at the syllabus for the course and check it off.
T8	Return to "my course" column.
T9	Entering the course of machine principle.
T10	Open the course documents and find the relevant teaching resources.
T11	Learn (play) [test courseware] video of "gear transmission".
T12	Click on the full screen to play the learning course.
T13	Quit full screen after learning to complete.
T14	Close the teaching video.
T15	Download [test courseware] eighth chapter "gear transmission" PPT.
T16	Return to the first page of the course.
T17	Exit account.
T18	Click to close the web page.

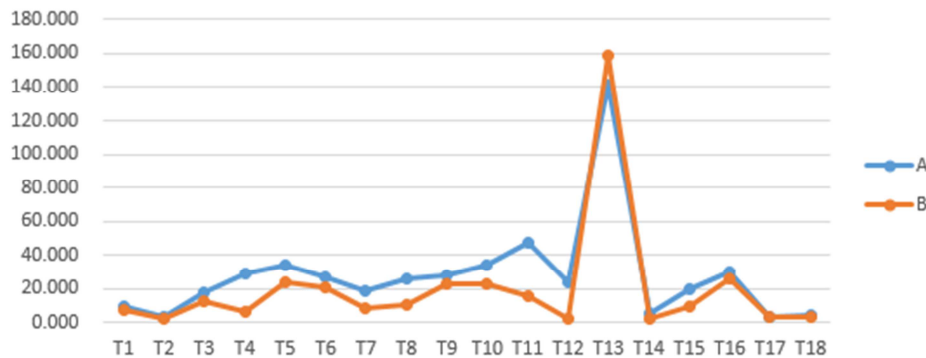
In order to reduce the interference of objective factors, such as network speed, equipment difference and the use of environment, the subjects are divided into 5 groups, and the same batch of equipment is used to connect the same wireless network signal to the experiment. The experiment time is carried out in the similar time period every day to ensure that the objective factors are the same as possible to ensure the objective. The degree of interference of factors was reduced to a minimum. Before the experiment, we first let the subjects know the task of performance measurement, and challenge the uncertain or undefined task steps. The subjects can explain the operation of the whole task to the subjects and start the experiment after the whole task is clear.

During the whole experiment, a professional recording

software was used to record the whole process of the experiment. The test showed that the subjects began to perform tasks. After completing all tasks, the subjects were asked to complete the task and the video recording was finished. Through playback video, we can record 40 participants' participation in performance measurement.

2.2.2. Quantitative Results and Analysis

In the quantitative experiments of the interface experience dimension, 800 data of 40 subjects were collected, and the average time for the completion of the tasks was obtained by preliminary processing. The average time for the performance measurement to complete the tasks was shown in Figure 3.

**Figure 3.** The average time for the performance measurement to complete the tasks.

As can be seen from the above picture, the average time for the A group to complete the tasks is basically longer than that of the B group. It can be seen that the subjects without the experience of the network service platform need more time to complete the tasks.

The average total time, the average task efficiency, the error number, the maximum and the minimum value of the completed task are obtained according to the collected data calculation and processing, and then the data is normalized to get the quantized data as shown in Table 4.

Table 4. The quantitative data for performance measurement.

First-class index	Second-class index	Average value	Maximum value	Minimum value	Normalized data
Interface experience dimension	Memorability (A group operation time)	504.751	567.143	415.280	0.589
	Usability (B group operation time)	359.742	392.385	320.800	0.544
	fault tolerance (Error number)	2.400	3.896	0.000	0.616
	Clarity (Average task efficiency)	24.014	27.262	20.488	0.520

2.3. Quantitative Analysis of Emotional Experience Based on Self Reporting

The index of emotional experience dimension is subjective evaluation index. Using self-report measurement method can transform the emotional experience of subjective indicators into specific quantitative values and facilitate concrete evaluation and calculation. At this stage, the 40 participants who participated in the performance measurement experiment obtained the specific quantitative value through

self-report.

2.3.1. Experiment Design of Self Reporting

This self-report questionnaire is designed to quantify the usability of information design quality indicators for emotional experience dimensions and interface experience dimensions. 40 participants who were invited to complete the performance measurement experiment participated in the self-report questionnaire survey. The self-reported problems are set as shown in Table 5.

Table 5. The self reporting problem setting.

Problem number	Problem content
Q1	I am willing to use the platform to learn the course.
Q2	I am willing to take part in all the learning activities related to the course.
Q3	I experienced a sense of achievement in progress in my studies.
Q4	I would like to recommend this way of learning to people around me.
Q6	Through operation, I think the message of online course service platform is very convenient.
Q6	I think the videos and courseware are clear and beautiful, with good color and fluency.

2.3.2. Quantitative Results and Analysis

A total of 40 participants were invited to participate in the self-report measurement experiment. 240 data were collected, and Figure 4 showed self-report scores.

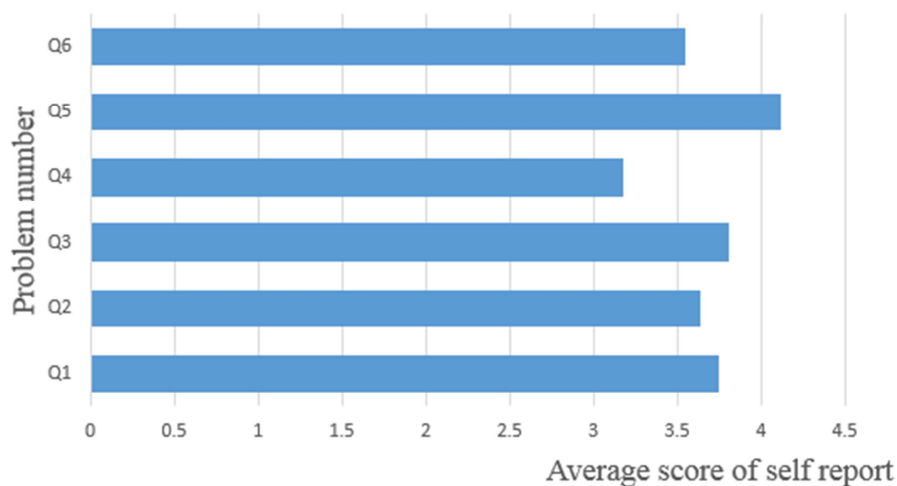


Figure 4. Self-report score.

From the average data of self-report scores, it can be seen that 40 subjects have a higher subjective impression of the online course service platform and a higher overall score. The subjects had the best impression on the communication mechanism of the online classroom and scored the highest score. The second is learning interest, sense of participation and sense of achievement. The lower score is the degree of

learning recommendation. Compared with the other four factors, the degree of recommendation is relatively insufficient. Besides, the scores of the quality of information design were also higher.

The average, maximum and minimum values of the obtained data are obtained, and then data normalization is processed to get the quantized data shown in Table 6.

Table 6. Self-report quantitative data.

First-class index	Second-class index	Average value	Maximum value	Minimum value
Interface experience dimension	Information design Quality	5.000	2.000	0.517
	Interestingness	5.000	3.000	0.373
	Participation	5.000	2.000	0.545
Emotional experience dimension	Achievement	5.000	1.000	0.703
	Recommendation	5.000	1.000	0.545
	Communication mechanism	5.000	2.000	0.706

3. Construction of Usability Evaluation Model for Online Course Service Platform Based on Extenics

Extenics is applicable to the comprehensive evaluation of the usability of online course service platform [6-8]. Based on the theory of extenics and the establishment of matter-element and correlation function, a usability extension evaluation model of online course service platform is developed. Through the normalization of all the index data obtained, the extension model is used to calculate the correlation of each index, and the availability of the network course service platform is evaluated.

$$R_j = (N_j, c_i, x_{ji}) = \begin{bmatrix} N_j & c_1 & x_{j1} \\ & c_2 & x_{j2} \\ & \vdots & \vdots \\ & c_n & x_{jn} \end{bmatrix} = \begin{bmatrix} N_j & c_1 < a_{j1}, b_{j1} > \\ & c_2 < a_{j2}, b_{j2} > \\ & \vdots & \vdots \\ & c_n < a_{jn}, b_{jn} > \end{bmatrix} \quad (1)$$

The matter element model formed by the comprehensive evaluation of the range of values of each index can be called the joint domain [10].

$$R_p = (P, c_i, x_{pi}) = \begin{bmatrix} P & c_1 & x_{p1} \\ & c_2 & x_{p2} \\ & \vdots & \vdots \\ & c_n & x_{pn} \end{bmatrix} = \begin{bmatrix} P & c_1 < a_{p1}, b_{p1} > \\ & c_2 < a_{p2}, b_{p2} > \\ & \vdots & \vdots \\ & c_n < a_{pn}, b_{pn} > \end{bmatrix} \quad (2)$$

In the evaluation of the usability level of the online course service platform, the evaluation indexes are divided into class I - V level, which correspond to Excellent, Good, Medium, Passed, Failed. The evaluation criteria of each level are: level I is $<0.80, 1>$, level II is $<0.60, 0.80>$, level III is $<0.40, 0.60>$, level IV is $<0.20, 0.40>$, level V is $<0, 0.20>$. Then, the joint domain and five classical domains can be determined respectively.

$$R_p = (P, c_i, x_{pi}) = \begin{bmatrix} I - V & c_1 < 0, 1 > \\ & c_2 < 0, 1 > \\ & \vdots & \vdots \\ & c_{14} < 0, 1 > \end{bmatrix} \quad (3)$$

$$R_1 = (I, c_i, x_{1i}) = \begin{bmatrix} I & c_1 < 0.8, 1 > \\ & c_2 < 0.8, 1 > \\ & \vdots & \vdots \\ & c_{14} < 0.8, 1 > \end{bmatrix} \quad (4)$$

$$R_2 = (II, c_i, x_{2i}) = \begin{bmatrix} II & c_1 < 0.6, 0.8 > \\ & c_2 < 0.6, 0.8 > \\ & \vdots & \vdots \\ & c_{14} < 0.6, 0.8 > \end{bmatrix} \quad (5)$$

$$R_3 = (III, c_i, x_{3i}) = \begin{bmatrix} III & c_1 < 0.4, 0.6 > \\ & c_2 < 0.4, 0.6 > \\ & \vdots & \vdots \\ & c_{14} < 0.4, 0.6 > \end{bmatrix} \quad (6)$$

3.1. Determining the Classical Domain and the Joint Domain

According to the definition of matter element, the usability level evaluation model of online course service platform can be established. Through the usability evaluation system of online course service platform, it can be found that the evaluation of usability level of this platform has n evaluation indicators, c_1, c_2, \dots, c_n . These indicators are used to quantitatively classify the j level of this platform, and a comprehensive evaluation matter-element model, namely the classical domain, is constructed [9].

$$R_4 = (IV, c_i, x_{4i}) = \begin{bmatrix} IV & c_1 < 0.2, 0.4 > \\ & c_2 < 0.2, 0.4 > \\ & \vdots & \vdots \\ & c_{14} < 0.2, 0.4 > \end{bmatrix} \quad (7)$$

$$R_5 = (V, c_i, x_{5i}) = \begin{bmatrix} V & c_1 < 0, 0.2 > \\ & c_2 < 0, 0.2 > \\ & \vdots & \vdots \\ & c_{14} < 0, 0.2 > \end{bmatrix} \quad (8)$$

3.2. Determining the Matter Element to Be Evaluated

For the objects to be evaluated, the evaluation information obtained through the inspection analysis and the evaluation indexes obtained through experiments is expressed by matter element R_0 .

$$R_0 = (P_0, c_i, x_i) = \begin{bmatrix} P_0 & c_1 & v_1 \\ & c_2 & v_2 \\ & \vdots & \vdots \\ & c_n & v_n \end{bmatrix} \quad (9)$$

P_0 indicates the level of the target to be evaluated, v_n represents the specific value of the n -th index of the unit required for evaluation.

The data of the 14 indicators obtained through quantitative experiments are normalized, and the matter-element matrix is expressed as:

$$R_0 = (P_0, c_i, x_i) = \begin{bmatrix} P_0 & c_1 & 0.280 \\ & c_2 & 0.650 \\ & c_3 & 0.367 \\ & c_4 & 0.443 \\ & c_5 & 0.589 \\ & c_6 & 0.544 \\ & c_7 & 0.616 \\ & c_8 & 0.520 \\ & c_9 & 0.517 \\ & c_{10} & 0.373 \\ & c_{11} & 0.545 \\ & c_{12} & 0.703 \\ & c_{13} & 0.545 \\ & c_{14} & 0.706 \end{bmatrix} \quad (10)$$

3.3. Determining the Weight Coefficient

Weight coefficient is assigned to the evaluation index of the online course service platform usability evaluation system in reference [4], and the comprehensive weight of the specific indicators is shown in Table 7.

Table 7. Comprehensive weight distribution of indicators at all levels of the evaluation system.

First-class index	First-class index weight	Second-class index	Second-class index weight	Comprehensive weight
Content experience dimension	0.2817	C ₁	0.3095	0.0872
		C ₂	0.2009	0.0566
		C ₃	0.2101	0.0592
		C ₄	0.2796	0.0788
		C ₅	0.2158	0.1078
Interface experience dimension	0.4995	C ₆	0.1976	0.0987
		C ₇	0.1711	0.0855
		C ₈	0.1460	0.0729
		C ₉	0.2696	0.1347
		C ₁₀	0.3120	0.0683
Emotional experience dimension	0.2188	C ₁₁	0.1586	0.0347
		C ₁₂	0.2699	0.0590
		C ₁₃	0.1694	0.0371
		C ₁₄	0.0902	0.0197

3.4. Correlation Calculation

Since the evaluation object is an evaluation system with two levels of indicators, multi-level extenics is used to evaluate the evaluation process. The first level evaluation is to calculate the correlation between the two level indicators for each grade. The correlation function of the objects that determined the target of evaluation is:

$$K_j(x_i) = \begin{cases} \rho(x_i, x_{ji}) / [\rho(x_i, x_{pi}) - \rho(x_i, x_{ji})], & x_i \neq x_{ji} \\ -\rho(x_i, x_{ji}) / |x_{ji}|, & x_i = x_{ji} \end{cases} \quad (11)$$

$$\rho(x_i, x_{ji}) = \left| x_i - \frac{a_{ji} + b_{ji}}{2} \right| - \frac{1}{2} (b_{ji} - a_{ji}) \quad (12)$$

$$\rho(x_i, x_{pi}) = \left| x_i - \frac{a_{pi} + b_{pi}}{2} \right| - \frac{1}{2} (b_{pi} - a_{pi}) \quad (13)$$

The formula for calculating the correlation is as follows:

$$K_j(P_0) = \sum_{i=1}^n \omega_{ij} K_j(x_i) \quad (14)$$

According to the formula (11) and formula (14), the relevance of two level index of usability of online course service platform can be calculated, as shown in Table 8-10.

Table 8. Correlation of content experience dimension index.

	K ₁ (x ₁)	K ₂ (x ₁)	K ₃ (x ₁)	K ₄ (x ₁)	K ₅ (x ₁)
C ₁	-0.201	-0.165	-0.093	0.124	-0.069
C ₂	-0.060	0.050	-0.025	-0.084	-0.113
C ₃	-0.114	-0.082	-0.018	0.035	-0.066
C ₄	-0.125	-0.073	0.060	-0.025	-0.099

Table 9. Correlation of interface experience dimension index.

	K ₁ (x ₁)	K ₂ (x ₁)	K ₃ (x ₁)	K ₄ (x ₁)	K ₅ (x ₁)
C ₅	-0.073	-0.006	0.012	-0.068	-0.105
C ₆	-0.071	-0.022	0.055	-0.047	-0.085
C ₇	-0.055	0.007	-0.014	-0.062	-0.089
C ₈	-0.054	-0.021	0.058	-0.029	-0.058
C ₉	-0.100	-0.040	0.112	-0.052	-0.107

Table 10. Correlation of emotional experience dimension index.

	$K_1(x_1)$	$K_2(x_1)$	$K_3(x_1)$	$K_4(x_1)$	$K_5(x_1)$
C_{10}	-0.167	-0.118	-0.021	0.043	-0.099
C_{11}	-0.057	-0.017	0.043	-0.038	-0.068
C_{12}	-0.067	0.131	-0.069	-0.136	-0.170
C_{13}	-0.061	-0.018	0.023	-0.041	-0.293
C_{14}	-0.022	0.042	-0.024	-0.046	-0.057

After the correlation of the two level index is obtained, the two level evaluation is carried out, that is, the correlation matrix of the first level index and the two level index for each usability grade is multiplied to determine the association matrix $K(N)$ for the usability level. The relationship between the first grade index and the system to be evaluated is obtained. The results of the specific extension evaluation are shown in Table 11.

Table 11. Evaluation system and first class index correlation.

	$K_1(x_1)$	$K_2(x_1)$	$K_3(x_1)$	$K_4(x_1)$	$K_5(x_1)$
B_1	-0.141	-0.076	-0.021	0.014	-0.098
B_2	-0.176	-0.040	0.112	-0.129	-0.222
B_3	-0.082	0.004	-0.011	-0.048	-0.150
A	-0.399	-0.112	0.080	-0.163	-0.470

Grade evaluation can be calculated by:

$$K_j = \max K_j(N) \quad (j = 1, 2, \dots, m) \quad (15)$$

By formula (15), it can be calculated $K_j = K_3(N)$. It shows that the usability of the online course service platform in Harbin Institute of Technology is level III and is at the middle level, and it needs to be improved gradually.

4. Conclusion

In this paper, three measures of subjective score, performance measurement and self-report are used to quantify the two level indicators of the online course service platform usability evaluation system. The subjective score method invites the teaching experts to carry on the subjective score of the learning courseware, and in the latter two quantitative experiments, the quantitative experiments are carried out by setting up the operation task and the questionnaire survey, and the data are statistically and normalized after the end of the experiment. The extenics evaluation model is constructed, and the quantitative data as the basic input is used to evaluate the online course service platform of Harbin Institute of Technology. The results show that the level of the platform usability is level III and is at the middle level, and it needs to be gradually improved to improve its usability.

Acknowledgements

This paper is supported by Key research projects of higher education reform in Heilongjiang (Research and practice of credit transfer mechanism oriented to the dissemination and sharing of high-quality educational resources, item No.: SJGZ20170068), General research projects on teaching reform of higher education in Heilongjiang (Problem analysis and countermeasure research on MOOC selection, item No.: SJGY20170663), Key projects of the online education research center of China's Ministry of Education (Research on the theory and practice of educational resource construction and gain propagation based on MOOC).

References

- [1] Xu Xiaofei, Fu Yuxi, Li Lian, etc. Thinking about the development of computer education MOOC in China [J]. China University Teaching, 2015, 11: 6-10+30.
- [2] Xu Xiaofei, Li Lian, Fu Yuxi. Developing the MOOC mode with Chinese characteristics, improving teaching reform and talent training quality [J]. China University Teaching, 2018, 1: 23-24.
- [3] Xu Xiaofei, Zhang Long. Actively respond to the MOOC wave and promote the reform of computer education in China [J]. Computer Education, 2016, 1: 8-9.
- [4] Ding Gang, Wei Lihong, Zhang Yangyang, etc. Usability Evaluation System of The Service Platform for Online Courses: Using Harbin Institute of Technology as An Example [R]. Harbin, 2018.
- [5] Ben Ammar Lassaad, Mahfoudhi Adel. Early usability evaluation in model driven framework [C]. 15th International Conference on Enterprise Information Systems, 2013:23-30.
- [6] Cai Wen, Yang Chunyan, Wang Guanghua. A new cross subject-Extenics [J]. Bulletin of National Natural Science Foundation of China, 2004, 5: 268-272.
- [7] Yang Chunyan, Cai Wen. Generating Creative Ideas for Production Based on Extenics [J]. Journal of Guangdong University of Technology, 2016, 33 (1): 12-16.
- [8] Yang Chunyan, Cai Wen. Extenics and the Intelligent Processing to Contradictory Problems [J]. Science & Technology Review, 2014, 32 (36): 15-20.
- [9] Yang Chunyan, Cai Wen, Tu Xuyan. Research, application and development on Extenics [J]. Journal of Systems Science and Mathematical Sciences, 2016, 36 (9): 1507-1512.
- [10] Cai Wen, Yang Chunyan. Basic theory and methodology on Extenics [J]. China Science Bulletin, 2013, 58 (13): 1190-1199.