Sensors and Materials, Vol. 35, No. 4 (2023) 1161–1170
MYU Tokyo

S & M 3237

Important Elements of Sensor Technology and Data Management and Related Education

Yung-Kuan Chan,[1] Jiin-chyuan Mark Lai,[2] Ming Yuan Hsieh,[3*] and Teen-Hang Meen[4**]

[1]Department of Management Information Systems, National Chung Hsing University, 145 Xingda Road, West District, Taichung City 40227, Taiwan
[2]Department of Applied Foreign Languages, TransWorld University, 1221 Zhenan Road, Douliu City, Yunlin County 640, Taiwan
[3]Department of International Business, National Taichung University of Education, 140 Minsheng Road, South District, Taichung City 40306, Taiwan
[4]Department of Electronic Engineering, National Formosa University, 64 Wunhua Road, Huwei Township, Yunlin County 632, Taiwan

(Received July 4, 2022; accepted March 14, 2023)

Keywords: sensor technology, problem analysis, analytical skill, problem-solving, decision-making

The demand for both sensors and a dedicated workforce has been increasing rapidly; an appropriate curriculum is needed to train this workforce. This study was conducted to identify elements that need to be included in the curriculum to teach sensor technology and the associated data management effectively. In this study, interviews with experts and a survey by questionnaire were conducted. The data were analyzed with an analytical network process (ANP), and statistical analysis including ANOVA, regression analysis, and factor analysis. As a result, four criteria (problem analysis, pattern recognition, abstraction of problems, and finding solutions) were defined with 12 subcriteria including faculty education in the curriculum, self-directed learning in the curriculum, committees and working groups to structure the curriculum, planning, organizing and managing the curriculum, learning outcomes, feedback from students and teaching staff, advice of experts, training assistants, appropriate assessment, appropriate education, appropriate evaluation, and recruiting students. Analytical skills, problem-solving, and decision-making were found to be alternatives (elements in education) in the analysis. The results of ANP and other statical analyses indicated that among the criteria, problem analysis is more important than the others in education for sensor technology and data management. Among alternatives (educational elements), analytical skills are more important than problem-solving and decision-making. Therefore, education in sensor-related subjects needs to be more focused on analyzing and detecting problems in sensor data. These results provide the basis for creating a curriculum for education in sensor-related technologies.

1. Introduction

Sensors are used to monitor and control the parameters of devices and machines, such as temperature, heat, speed, pressure, motions, vibrations, directions, and gases. Electrical signals

*Corresponding author: e-mail: uscpawisely@hotmail.com
**Corresponding author: e-mail: thmeen@gs.nfu.edu.tw
https://doi.org/10.18494/SAM4015

ISSN 0914-4935

are sent to sensing devices and processed by computers. With the rapid development of sensor technologies, the collection of sensor data is an inevitable part of industrial activities as well as in private lives.(1) Therefore, sensor technology has been integrated into higher education. Colleges and universities are introducing artificial intelligence in education (AIED), educational data mining (EDM), and learning analytics (LA) to enhance students' capabilities in dealing with numerous types of sensor data.(2) Subjects related to these topics include the training of students to exercise decision-making ability(3) based on game theory,(4) social learning theory,(5) and computational thinking,(6) as these are required to understand the diverse applications of sensor data. Therefore, it is necessary to discuss how to apply such subjects to higher education by developing an interesting and interdisciplinary curriculum in which the following capabilities are developed: critical thinking,(7) problem-solving, and decision-making.(6)

Critical thinking is required to solve a problem effectively in data science.(7) The four steps required for critical thinking include understanding and breaking down a complicated problem into simple problems to find the critical factors needed to solve the larger problem.(8,9) Critical thinking requires a model to handle faults and redundancy.(10) It is important in analyzing sensor data to identify problems and their solutions. Critical thinking is also important in problem-solving and decision-making.(11,12) Problem-solving is taught in problem-based learning (PBL) because in PBL courses, the course participants discuss and solve problems by constructing, sharing, and integrating the issues related to the problems in order to obtain more skills and knowledge with a higher learning performance. Problem-solving ability fosters problem-centered learning and is applied to self-learning by reinforcing interpersonal skills and teamwork. Social learning theory originated from social cognitive theory(5) and is based on the idea that people learn specific behaviors through observations. In order to analyze the data from sensor networks and individual/group behavior, an understanding of social learning theory is required because behavioral routines can be found in the sensor data.(13) Game theory is used to assay the outcomes or consequences of each choice in an entire decision-making procedure. Game theory was proposed to prove the concept of "taking the minimum in a negative situation" and to construct the "zero-sum game".(14) The theory applies to computing science, the biological sciences, electronics, military strategy, operations research, and economics. Game theory assumes that each decision-making step, each object of decision-making, and each subject of decision-making are rational.(15)

This study was carried out to identify the important factors that affect the education of students with respect to the effective use of sensor data. The results may be used to provide the basis for establishing an interdisciplinary curriculum for education in sensor-related topics. First, we defined the elements required for education in sensor data management through interviews with experts and the analytical hierarchy process (AHP). Then, the elements were grouped into criteria, subcriteria, and alternatives. Alternatives are proposed as important considerations for education in sensor technology and data management. The results offer a reference for use in education as well as in the development of sensors.

2. Methods

2.1 Interview

We interviewed 20 experts in related fields of science and education to define elements that need to be included in the education of students of sensor technology. The experts included five scholars with over ten years of research experience in relevant fields, five lecturers with over ten years of working experience, five professors with over ten years of research experience in higher education, and five managers with over ten years of experience in human resources management at companies.

2.2 Survey

A questionnaire to survey students was created based on the results of the interviews with experts. The questionnaire was distributed to 150 students at higher education institutions. A total of 113 valid questionnaires were collected for a recovery rate of 75.3%. This survey was carried out in the northern region (Chilung, Taipei, New Taipei, and Taoyuan), middle region (Hsinchu, Miaoli, Taichung, and Changhua), southern region (Yunlin, Chiayi, Tainan, and Kaohsiung), and eastern region (Yilan, Hualien, and Taitung) of Taiwan. The descriptive statistics of the survey results are listed in Table 1.

2.3 Analytical network process (ANP)

The use of ANP was proposed by Saaty for handling complex research questions that are not solved by the analytical hierarchy process (AHP), as it has limitations due to the independence of characteristics, criteria, subcriteria, and alternatives. Therefore, a positive reciprocal matrix and supermatrix were established for a precise hierarchical analysis by first collecting experts' opinions using the Delphi method.(16) In ANP, it is assumed that criteria and subcriteria are independent of each other. However, internal and external dependences on criteria and subcriteria can be found, which leads to an error in solving complicated problems. ANP is used

Table 1
Statistics of the survey.

Gender	67 males (59.3%) and 46 females (40.7%)
Number of respondents by region	43 (38.1%) from the northern region 38 (33.6%) from the middle region 21 (18.6%) from the southern region 11 (9.7%) from the eastern region
Number of interdisciplinary courses taken by respondents	None: 63 (55.8%), One: 39 (34.5%), Two: 8 (7.1%), Three: 2 (1.8%), Four: 1 (0.9%)
Learning experience in game theory	Yes: 53 (46.9%), No: 60 (53.1%)
Learning experience in problem-solving	Yes: 27 (23.9%), No: 86 (76.1%)
Learning experience in decision-making	Yes: 32 (28.3%), No: 81 (71.7%)

for setting priorities, generating alternatives, choosing the best policies, determining requirements, allocating resources, predicting outcomes, risk assessment, measuring performance, system design, ensuring system stability, optimization, planning, and conflict resolution.[17] The purpose of ANP is to analyze complex problems using hierarchical research to evaluate weights. A matrix of pairwise comparisons is given as

$$A = \begin{pmatrix} 1 & \dots a_{1j} & \dots a_{1n} \\ \dots & \dots & \dots \\ a_{i1} & \dots a_{ij} & \dots a_{in} \\ \dots & \dots & \dots \\ a_{n1} & \dots a_{nj} & \dots 1 \end{pmatrix} = \begin{pmatrix} \frac{w_1}{w_1} & \dots \frac{w_1}{w_j} & \dots \frac{w_1}{w_j} \\ \dots & \dots & \dots \\ \frac{w_i}{w_1} & \dots \frac{w_i}{w_j} & \dots \frac{w_i}{w_n} \\ \dots & \dots & \dots \\ \frac{w_n}{w_1} & \dots \frac{w_n}{w_j} & \dots \frac{w_n}{w_n} \end{pmatrix}. \tag{1}$$

The weight W_j and the pairwise ratio of W_i / W_j are decided by analyzing the data. There are three characteristic expressions:

$$A_{ij} = W_i / W_j,\ a_{ij} = 1 \text{ for } i = j, \text{ and } a_{ij} \times a_{ji} = 1, \tag{2}$$

where W is the matrix of relative pairwise weights and is calculated based on $AW = \lambda_{max}$. Then, the eigenvalue is calculated from the matrix of pairwise comparison. On the basis of this principle, the weights of each element are calculated for further analysis using factor analysis, regression analysis, or ANOVA.

3. Results and Discussion

3.1 ANP

Using information from the experts' interviews, the criteria, subcriteria, and alternatives that need to be included in the interdisciplinary curriculum were defined (Table 2). Four criteria are analysis, pattern recognition, abstraction of problem, and finding solutions. Two to four subcriteria belong to each criterion, as shown in Table 2. The alternatives are defined as analytical skills, problem-solving skills, and decision-making skills.

Table 3 shows the results of the Kaiser–Meyer–Olkin (KMO) test, which determined that the sampling adequacy was 0.726 at a significance level of 0.000. This result indicates that factor analysis is appropriate for analyzing the data from the questionnaire. Table 4 shows the consistency index and consistency ratio, both of which are less than 0.1. This indicates that there was consistency in the survey results.

The consistency ratio and consistency index for criteria and subcriteria are less than 0.1. This implies that the criteria and subcriteria are independent of each other (Table 4).

Table 2
Criteria, subcriteria, and alternatives in ANP based on the results of the experts' interviews.

Criteria	Subcriteria	Alternatives
Problem analysis	Faculty education in the curriculum Self-directed learning in the curriculum	Analytical skills Problem-solving Decision-making
Pattern recognition	Committee and working group for building the curriculum Planning, organizing and managing the curriculum Outcomes Feedback from students and teaching staff	
Abstraction of problem	Advice of experts Training assistants Appropriate assessment	
Finding solutions	Appropriate education Appropriate evaluation Recruiting students	

Table 3
KMO and Bartlett's test for factor analysis.

Sampling adequacy		0.726
Bartlett test of sphericity	Chi-squared test	540.121
	df	171
	Significance	0.000

Table 4
Consistency of the ANP model.

	Variables	Consistency index	Consistency ratio
Criteria	Problem analysis	0.0431	0.0743
	Pattern recognition	0.0364	0.0628
	Abstraction of problem	0.0380	0.0655
	Finding solutions	0.0336	0.058
Subcriteria	Faculty education in the curriculum	0.0263	0.0454
	Self-directed learning in the curriculum	0.0239	0.0412
	Committee and working group for building the curriculum	0.0203	0.035
	Planning, organizing, and managing the curriculum	0.0216	0.0372
	Outcomes	0.0304	0.0523
	Feedback from students and teaching staff	0.0329	0.0568
	Advice of experts	0.0289	0.0499
	Training assistants	0.0236	0.0407
	Appropriate assessment	0.0251	0.0432
	Appropriate education	0.0144	0.0248
	Appropriate evaluation	0.0198	0.0341
	Recruiting students	0.0171	0.0295

From the result of the questionnaire based on the above elements, the weights and scores of the elements were calculated as shown in Table 5. Among the criteria, the weight of problem analysis is the largest (0.457), followed by pattern recognition (0.2795), abstraction of problems (0.1691), and finding solutions (0.0944). The total weights of the alternatives are 0.5803 (analytical skill), 0.2902 (problem-solving), and 0.1296 (decision-making). Thus, analytical skill is the most important alternative for the ANP model of this study. Among

Table 5
Weight of the elements in the ANP model.

Criteria	Weight	Subcriteria	Alternatives					
			Analytical skill		Problem-solving		Decision-making	
			Weight	Score	Weight	Score	Weight	Score
Problem analysis	0.457	Faculty education in the curriculum	0.5786	0.1668	0.2936	0.0846	0.1279	0.0369
		Self-directed learning in the curriculum	0.5811	0.1622	0.2894	0.0808	0.1295	0.0361
Pattern recognition	0.2795	Committee and working group for building the curriculum	0.5765	0.0793	0.2871	0.0395	0.1364	0.0188
		Planning, organizing and managing curriculum	0.5735	0.0661	0.2871	0.0331	0.1350	0.0156
		Outcomes	0.5855	0.0644	0.2902	0.0319	0.1243	0.0137
		Feedback from students and teaching staff	0.5820	0.0635	0.2910	0.0318	0.1269	0.0139
Abstraction of problem	0.1691	Advice of experts	0.5847	0.0401	0.2872	0.0197	0.1281	0.0088
		Training assistants	0.5876	0.0474	0.2867	0.0231	0.1257	0.0101
		Appropriate assessment	0.5847	0.0468	0.2898	0.0232	0.1255	0.010
Finding solution	0.0944	Appropriate education	0.5777	0.0319	0.2932	0.0162	0.1291	0.0071
		Appropriate evaluation	0.5780	0.0309	0.2885	0.0154	0.1334	0.007
		Recruiting students	0.5695	0.0259	0.2939	0.0134	0.1366	0.0062
Total weight			0.5803		0.2902		0.1296	

the alternatives, analytical skill shows similar weights ranging from 0.5735 to 0.5876 for the criteria. The weights of problem-solving are in the range of 0.2871−0.2939, and those of decision-making range from 0.1243 to 0.1366. Although the weights are similar, analytical skill has higher weights in the abstraction of problems. Problem-solving and decision-making have higher weights in finding solutions and in pattern recognition, especially in committees and working groups for building, planning, organizing, and managing the curriculum.

Through factor analysis, we calculated the communality values of the criteria, subcriteria, and alternatives. All values are close to 0.7, which means that there are high dependences and correlations between the variables (Table 6).

3.2. Regression analysis

Regression analysis was conducted to understand the relationship between the criteria, subcriteria, and goals. The weights of the criteria, subcriteria and goals were used for the analysis of the three models with the dependent variable of each goal (analytical skill, problem-solving, and decision-making) and the independent variables of the criteria and subcriteria. Table 7 shows the results of the regression analysis.

The R^2 of model A (with problem-solving as the dependent variable) is 0.625, which means that 62.5% of problem-solving is explained by the criteria and subcriteria in the regression model. The R^2 of models B (with analytical skill as the dependent variable) and C (with decision-making as the dependent variable) are 0.5402 and 0.6905, implying that 54 and 69% of analytical skill and decision-making are contributed by the criteria and subcriteria (Table 7).

Table 6
Communality values of criteria, subcriteria, and alternatives.

Variable		Communality
Criteria	Problem analysis	0.776
	Pattern recognition	0.619
	Abstraction of problem	0.608
	Finding solution	0.719
Subcriteria	Faculty education in the curriculum	0.787
	Self-directed learning in the curriculum	0.795
	Committee and working group for building the curriculum	0.666
	Planning, organizing, and managing curriculum	0.636
	Outcomes	0.631
	Feedback from students and teaching staff	0.667
	Advice of experts	0.785
	Training assistants	0.779
	Appropriate assessment	0.814
	Appropriate education	0.787
	Appropriate evaluation	0.671
	Recruiting students	0.776
Alternatives	Analytical skill	0.625
	Problem-solving	0.790
	Decision-making	0.786

Table 7
Result of regression analysis with the criteria, subcriteria, and goals.

Model	R	R^2	Adjusted R^2	Estimated standard error
A (Problem-solving)	0.791	0.625	−0.068	0.823
B (Analytical skills)	0.735	0.5402	−0.003	0.771
C (Decision-making)	0.831	0.6905	−0.039	0.744

Table 8
ANOVA analysis in RA of qualitative analysis.

Model	Items	Sum of square	Degree of freedom	Sum of average square	F-test	Significance
A (Problem-solving)	Regression	6.011	16	0.376	0.754	0.041
	Residual	65.086	96	0.678	—	—
	Sum	71.097	112	—	—	—
B (Analytical skill)	Regression	9.326	16	0.583	0.979	0.0485
	Residual	57.134	96	0.595	—	—
	Sum	66.46	112	—	—	—
C (Decision-making)	Regression	6.532	16	0.408	0.737	0.038
	Residual	53.185	96	0.554	—	—
	Sum	59.717	112	—	—	—

3.3 ANOVA

Table 8 shows the results of the ANOVA of the models. The F values are 0.754, 0.979, and 0.737 at significance levels of 0.041, 0.049, and 0.038. These results mean that the regression models are appropriately established by the significant correlation of the elements.

3.4 Factor analysis

Table 9 presents the results of the factor analysis of the data from the questionnaires. Problem analysis shows the largest weight (0.457) among the criteria in this study. For problem analysis, faculty education in the curriculum and self-directed learning are important, both of which affect the analytical skills of students the most. The weights of the analytical skills for faculty education in the curriculum and self-directed learning are higher than those of problem-solving and decision-making. For pattern recognition, forming a committee and working group to build

Table 9
Results of factor analysis.

Criteria	Communalities	Weight	Subcriteria	Communalities	Analytical skills		Problem-solving		Decision-making	
					Weight	Score	Weight	Score	Weight	Score
Problem analysis	0.776	0.457	Faculty education in the curriculum	0.813	0.5786	0.1668	0.2936	0.0846	0.1279	0.0369
			Self-directed learning in the curriculum	0.787	0.5811	0.1622	0.2894	0.0808	0.1295	0.0361
Pattern recognition	0.619	0.2795	Committee and working groups for building the curriculum	0.795	0.5765	0.0793	0.2871	0.0395	0.1364	0.0188
			Planning, organizing, and managing the curriculum	0.666	0.5735	0.0661	0.2871	0.0331	0.135	0.0156
			Outcomes	0.636	0.5855	0.0644	0.2902	0.0319	0.1243	0.0137
			Feedback from students and teaching staff	0.631	0.582	0.0635	0.291	0.0318	0.1269	0.0139
Abstraction of problem	0.608	0.1691	Advice of experts	0.667	0.5847	0.0401	0.2872	0.0197	0.1281	0.0088
			Training assistants	0.785	0.5876	0.0474	0.2867	0.0231	0.1257	0.0101
			Appropriate assessment	0.779	0.5847	0.0468	0.2898	0.0232	0.1255	0.01
Finding solution	0.719	0.0944	Appropriate education	0.814	0.5777	0.0319	0.2932	0.0162	0.1291	0.0071
			Appropriate evaluation	0.787	0.578	0.0309	0.2885	0.0154	0.1334	0.007
			Recruiting students	0.671	0.5695	0.0259	0.2939	0.0134	0.1366	0.0062
Standardized comprehensive weight scales					0.5803		0.2902		0.1296	

the curriculum; planning, organizing, and managing the curriculum; outcomes from education; and feedback from students and teaching staff are important and most influence analytical skills. The advice of experts, training assistants, and appropriate assessment are important for education in the abstraction of problems and affect analytical skills more than problem-solving and decision-making. Analytical skills are also important for education in finding solutions, for which appropriate education, appropriate evaluation, and recruiting students are regarded as important criteria.

4. Conclusion and Recommendations

Sensors are used in most electronic devices in both industry and everyday life. Consequently, it is becoming more important to establish an appropriate curriculum in colleges for educating students about sensors. As there are numerous sensors and huge amounts of sensor data, it is almost impossible to provide instruction on every sensor technology. Instead, it is worth knowing which elements need to be included in the curriculum related to the education of sensor technology and its data management. Therefore, we identified important elements in education using interviews with experts and surveys of students and analyzed the results using ANP and statistical analysis based on critical thinking, problem-solving, and game theory.

The results of the survey and ANP analysis enabled us to identify four important criteria (problem analysis, pattern recognition, abstraction of problems, and finding solutions), and 12 subcriteria (faculty education in the curriculum; self-directed learning in the curriculum; committee and working groups for building the curriculum; planning, organizing and managing the curriculum; outcomes; feedback from students and teaching staff; advice of experts; training assistants; appropriate assessment; appropriate education; appropriate evaluation; and recruiting students). The alternatives used in the ANP in this study were analytical skills, problem-solving, and decision-making.

The results of statistical analysis using ANOVA, regression analysis, and factor analysis showed that problem analysis is more important than pattern recognition, abstraction of problems, and finding solutions in the education of students in sensor technology and data management. For all criteria, analytical skills are more important than problem-solving and decision-making. Such results imply that education in sensor-related topics needs more focus on the analysis of the problems that sensors detect and the types of problems that are detected with sensor technology. The results provide the basis for setting up a curriculum for a college education related to sensors and the development of sensor technology.

Acknowledgments

This research was supported by grants from the National Taichung University of Education (NTCU111103) and of the National Science and Technology Council in Taiwan (MOST 110-2420-H-002-003-MY3-Y11209).

References

1 M. Javaid, A. Haleem, S. Rab, R. P. S.ingh, and R. Suman: Sens. Int. **2** (2021) 100121. https://doi.org/10.1016/j.sintl.2021.100121
2 J. A. Ruipérez-Valiente, R. Martínez-Maldonado, D. D. Mitri, and J. Schneider: Sensors **22** (2022) 8556. https://doi.org/10.3390/s22218556
3 K. Leyton-Brown and Y. Shoham: Synthesis Lectures on Artificial Intelligence and Machine Learning 2 (Springer, 2008) 1. https://doi.org/10.2200/S00108ED1V01Y200802AIM003
4 K. Chatterjee and G. L. Lilien: Int. J. Res. Mark. **3** (1986) 79. https://doi.org/10.1016/0167-8116(86)90012-1
5 Britannica: https://www.britannica.com/topic/Social-Learning-and-Imitation (accessed February 2023).
6 R. Selten: Games. Econ. Behav. **3** (1991) 3. https://EconPapers.repec.org/RePEc:eee:gamebe:v:3:y:1991:i:1:p:3-24
7 A. R. Basawapatna, K. H. Koh, and A. Repenning: Proc. 15th Annu. Conf. Innovation and Technology in Computer Science (ITiCSE, 2010) 224–228. https://doi.org/10.1145/1822090.1822154
8 L. English: Math. Think Learn. **20** (2018) 1. https://doi.org/10.1080/10986065.2018.1405615
9 S. Grover and R. Pea: Educ. Res. **42** (2013) 38. https://doi.org/10.3102/0013189X12463051
10 S. Basu, G. Biswas, and J. S. Kinnebrew: User Model User-adapt Interact. **27** (2017) 5. https://link.springer.com/article/10.1007/s11257-017-9187-0
11 G. Chen, J. Shen, L. Barth-Cohen, S. Jiang, X. Huang, and M. Eltoukhy: Comput. Educ. **109** (2017) 162. https://doi.org/10.1016/j.compedu.2017.03.001
12 H. Y. Durak and M. Saritepeci: Comput. Educ. **116** (2018) 191. https://doi.org/10.1016/j.compedu.2017.09.004
13 B. Lin and D. J. Cook: Sensors **20** (2020) 5207. https://doi.org/10.3390/s20185207
14 J. Von Neumann and M. Oskar: Theory of Games and Economic Behavior: 60th Anniversary Commemorative Edition (Princeton University Press, 2007) p. 220. https://press.princeton.edu/books/paperback/9780691130613/theory-of-games-and-economic-behavior
15 M. Esmaeili, G. Allameh, and T. Tajvidi: Int. J. Prod. Res. **54** (2016) 2152. https://doi.org/10.1080/00207543.2015.1115907
16 T. L. Saaty: The Analytic Hierarchy Process (McGraw-Hill, New York, 1980).
17 T.-L. Wu, M.-Y Hsieh, K.-W. Min, M.-T. Yu, and C-.T. Ho: Sens. Mater. **33** (2021) 2045. https://doi.org/10.18494/SAM.2021.3287