科技與工程教育學刊

Journal of Technology and Engineering Education

2020年12月 第50卷第1/2期

ISSN：1025-7578
DOI：10.6232/JTEE

國立臺灣師範大學科技應用與人力資源發展學系　主編

科技與工程教育學刊 2020，50(1/2)，1-13
DOI: 10.6232/JTEE.202012_50(1/2).0001

科學-科技-工程-數學相關學科的問題解決能力量表之發展

摘要

STEM 教育在日本廣受重視，但評估其有效程度的方法卻為數不多。在本研究中，我們發展量表來釐清對問題解決的興趣與對使用各科目概念和技巧兩者之間的關係。我們為公立學校三年級學生發展了對 STEM 教育中的問題解決能力的知覺量表，量表包括四個因素：針對問題解決技巧的自我知覺、解決科技問題的興趣、解決科學問題的興趣、解決數學問題的興趣。量表的信度亦得到分析結果證實。

關鍵詞：STEM 教育、問題能力、知覺量表

DOI: 10.6232/JTEE.202012_50(1/2).0001

Developing a Cognitive Scale for Ability to Solve Problems in STEM Related Subjects

Issei KOJIMA 1, Hiroyuki MURAMATSU 2*, Mitsunori YATSUKA 3*
Nishinadai Junior Highschool, Graduate School of Education, Shinshu University
** Shinshu University*

Abstract

STEM education has been attracting attention in Japan, but there are few methods to measure its effectiveness. In this study, we developed a scale to clarify the relationship between interest in problem solving and using the concepts and skills of each subject. We developed a scale of awareness of problem-solving skills in STEM education for third-year public school students. which consists of four factors: self-perception of problem-solving skills, interest in technological problem solving, interest in scientific problem solving, and interest in mathematical problem solving. The reliability of the scale was also confirmed by the results of the analysis.

Keywords: STEM Education, Problem Ability, Scale of Consciousness

1. Introduction

According to Bybee (2010), the primary purpose of STEM education is to promote the understanding of science and technology for all and to spread and improve science and technology literacy among all citizens.

In Japan, STEM education is also attracting attention, and the linkage between subjects such as mathematics, science, and technology is also being emphasized; STEM provides not only problem-solving skills but also motivation to learn science and mathematics. At meetings to discuss future educational policies, it is hoped that STEM will increase interest in learning, deepen student learning, and foster the development of future human resources with the ability to solve real-world problems by integrating multiple disciplines. (Ministry of Education, Culture, Sports, Science and Technology, 2020)

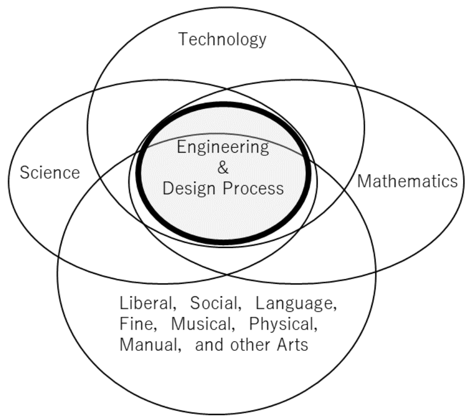


Fig. 1 Relationship of each discipline in STEAM education (Yamazaki 2020)

As a framework for STEM, Todd R. et al (2016) links situated learning, engineering design, scientific investigation, technological literacy, and mathematical thinking as an integrated system.

STEM in Japan, on the other hand, differs from that in other countries in some ways. Most significantly, the distinction between technology and engineering is blurred in Japan (Munegumi, 2019). Based on this, Yamazaki (2020) refers to STEM and STEAM based on the Japanese school

DOI: 10.6232/JTEE.202012_50(1/2).0001
system, tradition, and culture as "STEAM education from Japan. Figure 1 shows the relationship between the various academic fields in STEAM. In "STEAM Education from Japan", problem solving that overlaps mathematics, science, and technology is positioned as engineering and design strategies. Based on this framework, T and E are included in the technical field of technology and home economics (hereinafter referred to as "technology"), which is a subject in which Japanese technology is studied. In this study, we will proceed based on this Yamazaki framework.

Next, we will examine the qualitative abilities to be fostered in STEM. Matsubara and Kousaka (2017) organize the qualities and abilities to be fostered into three categories: (1) subject-specific concepts and individual skills, (2) cross-curricular concepts and general-purpose skills, and (3) the ability to solve real-world problems, and correspond to the degree of integration of STEM and the Japanese curriculum.

In this study, we focused on (2) cross-curricular concepts and generic skills. These skills are thought to bridge the gap between learning in subjects that are systematic but lack realistic contexts and learning in "integrated learning time" that involves realistic problem solving but lacks systematization. In other words, it is the most necessary perspective for the current Japanese curriculum.

However, there are challenges in doing so. One of the challenges is the lack of objective research on the educational benefits of STEM. In particular, we need to know what relationship exists between problem solving and concepts and skills in order to evaluate and improve STEM subjects. However, this has yet to be developed.

The relationships among the domains that make up STEM are becoming clearer. Yamamori et al. (2019) reported on third-grade students' perceptions of content relationships among the subjects of mathematics, science, and technology. It is likely that the aforementioned issues will be resolved if the relevance of problem solving in real-life contexts to the subjects is also clarified. Therefore, based on the framework of "STEAM education from Japan," this study decided to examine a scale of awareness to understand the actual state of problem-solving skills in STEM in Japan.

The purpose of this study was to develop a subject-specific problem-solving awareness scale in order to understand the actual state of problem-solving skills in STEM education in Japan.

2. Method

Learning strategies for subjects related to each of the domains that make up STEM (mathematics, science, and technology in Japan) were cited and organized from Japanese Courses of Study and textbooks.

For example, in science, the statement "compare and classify observed contents, focusing on similarities and differences" frequently appears in the objectives of the Courses of Study. (MEXT,

DOI: 10.6232/JTEE.202012_50(1/2).0001
2017) This includes the strategies of "comparison" and "classification. (MEXT, 2017) This includes the strategies of "comparison" and "categorization". Similarly, for each subject, the researcher and a teacher with 10 years of experience teaching both science and technology in middle school discussed and extracted subject-specific learning strategies.

In addition, in order to clarify the relevance of these strategies to problem solving in real-life contexts, three categories of interest in problem solving using subject strategies, perception of one's own level of proficiency in problem solving, and perception of the usefulness of subject strategies in problem solving were identified. The three perspectives are a more detailed version of the human nature toward learning in the Japanese teaching guidelines. Finally, we added a question on self-regulation, which refers to the ability to work persistently.

The questions thus prepared are assumed to have four factors: problem solving in the real world context and problem solving in each of the three Japanese subjects related to each of the STEM domains. The reason for this is that Japanese academic education to date has not included much problem solving in realistic contexts. Therefore, the use of strategies for learning subjects and the use of strategies for solving problems in real contexts are not the same, and differences are expected to occur. Therefore, we thought that by measuring the degree of the gap, we could clarify the relationship between problem solving in the real context and the subject matter.

We developed a questionnaire that asks about these questions. Each item was rated on a 5-point scale: 1: not at all, 2: not much, 3: undecided, 4: fairly much, 5: fairly much.

The first set of questions we devised were the 30 questions in Table 1.

3. Results

The survey was conducted on 108 third-year public school students in November 2020. A total of 89 students (41 boys and 48 girls) responded to the survey (82.4% valid response rate).

To examine the factor structure of the items, factor analysis was conducted. The results are shown in Table 2. Responses to each item were scored on a scale of 1-5. Factor analysis using the principal factor method and Promax rotation (κ=7) was conducted on a total of 30 items. According to Kaiser, H. F. (1960), when the sample size is small, the factor loadings are 0.40 or less. Based on the suggestion that items with factor loadings of 0.40 or less could not be sufficiently discriminated, items for which an inappropriate solution occurred in the process of identifying the factor, items for which high factor loadings were found on several items (0.38 or more on several), and items with low factor loadings (0.40 or less) were removed by trial and error. As a result, 12 items were excluded, and a four-factor solution with 18 items was adopted.

Table.1
Questionnaire Items

DOI: 10.6232/JTEE.202012_50(1/2).0001

Mathematics	Q1 I am interested in quantifying things.
	Q2 I am good at quantifying things
	Q3 Quantifying things will help me in my future
	Q4 I am interested in expressing the relationship in mathematical form.
	Q5 I'm good at expressing relationships mathematically
	Q6 Expressing relationships in mathematical formulas will help me in my future
	Q7 I am interested in organizing information with tables and graphs.
	Q8 I am good at organizing information with tables and graphs.
	Q9 Organizing information with tables and graphs will help me in my future
Science	Q10 I am interested in predicting and experimenting with solutions to problems.
	Q11 I am good at predicting and testing solutions to problems
	Q12 Anticipating, experimenting and verifying solutions to problems will help me in my future
	Q13: I am interested in finding common ground and differentiating among friends.
	Q14 I am good at finding commonalities and differentiating between people
	Q15: Finding common ground and grouping together will help me in my future.
	Q16 I am interested in comparing two different conditions
	Q17 I'm good at comparing two different conditions
	Q18 Comparing two different conditions will help me in my future
Technology and Engineering	Q19 I am interested in finding the best solution to a problem in a given condition.
	Q20 I am good at thinking of the best solution to a problem in a given condition.
	Q21 Figuring out the best solution to a problem in the given conditions will help me in my future.
	Q22 I am interested in actually making and testing
	Q23 I am good at actually making and testing things
	Q24 Actually making and experimenting will help me in my future
	Q25 I am interested in improving and modifying the method to become a better solution.
	Q26 I am good at improving and modifying methods for better solutions.
	Q27 Improving and modifying the method to become a better solution will help me in my future
Adjustment	Q28 I can persevere in my field of interest, even if it is difficult
	Q29 I can persevere in my studies, even if they are difficult
	Q30 I can persevere in studies that I feel will be useful for my future, even if they are difficult.

DOI: 10.6232/JTEE.202012_50(1/2).0001

The first factor was chosen as "self-awareness of problem-solving skills" because it contained many items related to self-awareness of problem-solving skills across subjects, such as "Q23: I am good at actually making and testing things". The second and subsequent factors included many self-perceptions about subject-specific strategies in mathematics, science, and technology. For example, "Q21 Figuring out the best solution to a problem in the given conditions will help me in my future." was selected as "interest in technical problem solving" if it included interest in problem solving related to technology. Similarly, those that included an interest in problem solving related to science, such as " Q13: I am interested in finding common ground and differentiating among friends," were classified as "interest in scientific problem solving," and those that included an interest in problem solving related to mathematics, such as "Q3 Quantifying things will help me in my future," were classified as "interest in mathematical problem solving".

The Cronbach's alpha coefficient for each factor were greater than 0.80, which was judged to be sufficiently consistent.

Based on the results, we were able to construct a scale of awareness of problem-solving skills in STEM consisting of four factors: "F1: Self-awareness of problem-solving skills," "F2: Interest in technological problem-solving," "F3: Interest in scientific problem-solving," and "F4: Interest in mathematical problem-solving. Regarding the inter-factor correlations, the third factor, Interest in scientific problem solving, was relatively independent in terms of correlation between factors while the others were moderately correlated.

3.(1) Distribution of each factor

In order to explore the tendency of the students' self-awareness and interest, the results of tabulating the mean scores and distributions of each factor are shown in Table 3. Considering the criterion of "3: Neutral", the mean score of the first factor, "self-awareness of problem solving" was 3.11, which was slightly lower than the other factors. The second factor, "Interest in technological problem solving," had a slightly higher mean score of 3.80. The distribution of the scores of each factor also increased around the mean score.

3.(2) Examining discrimination power by G-P analysis

In order to examine the discrimination ability of each item of this consciousness scale, G-P analysis was conducted based on the total score of the scale, with the top 50% (24 participants) as the G group and the bottom 50% (25 participants) as the P group. welch's t-test was conducted for items that showed significant differences in variance between the G and P groups.

DOI: 10.6232/JTEE.202012_50(1/2).0001

The results of the G-P analysis are shown in Table 4. It was confirmed that the mean score of the G group was significantly higher than that of the P group at the 1% level for all items. This suggests that the items in this awareness scale have adequate discrimination power.

3.(3) Validity review

The validity of the four factors obtained as a result of the factor analysis is discussed. The validity of the factors was examined from the perspective of construct validity by comparing the frameworks that were set when the questionnaire items were created and after the factors were determined.

When examining the questionnaire items, we assumed that the perceptions of the use of strategies in learning subjects and the perceptions of problem solving in real-life contexts would not be the same, and that differences would arise, given the characteristics of subject education in Japan to date. In fact, the four independent factors obtained from the factor analysis included the perceptions of problem solving in addition to the perceptions of subject matter strategies.

Of the four factors, "F1: Self-perception of problem-solving ability" consisted of items investigating the perception of one's level of proficiency in problem-solving, regardless of subject. It can be seen that students consider that being able to actually solve a problem and having a sense of interest and usefulness are two different things. In addition, as indicated in (1), the mean of the scale scores was lower than that of the other items.

DOI: 10.6232/JTEE.202012_50(1/2).0001

Table.2
Results of Factor Analysis

Question Items	Factor Loadings				Average	SD
	Self-awareness of problem-solving skills	Interest in technological problem solving	Interest in scientific problem solving	Interest in mathematical problem solving		
Q23 I am good at actually making and testing things	**0.95**	0.32	-0.31	-0.21	3.48	1.13
Q11 I am good at predicting and testing solutions to problems	**0.81**	-0.05	0.19	-0.16	3.29	1.02
Q20 I am good at thinking of the best solution to a problem in a given condition.	**0.75**	0.04	0.09	0.03	3.96	1.03
Q8 I am good at organizing information with tables and graphs.	**0.74**	-0.15	0.08	0.11	3.1	1.07
Q26 I am good at improving and modifying methods for better solutions.	**0.65**	0.11	-0.07	0.24	3.07	1.09
Q5 I'm good at expressing relationships mathematically	**0.62**	-0.24	0.19	0.22	2.69	1.22
Q21 Figuring out the best solution to a problem in the given conditions will help me in my future.	-0.19	**0.81**	0.21	0.02	3.78	0.98
Q25 I am interested in improving and modifying the method to become a better solution.	0.13	**0.78**	-0.03	-0.07	3.85	0.94
Q24 Actually making and experimenting will help me in my future	0.14	**0.77**	-0.1	0.07	3.82	0.91
Q27 Improving and modifying the method to become a better solution will help me in my future	-0.08	**0.71**	0.05	0.15	3.75	0.97
Q13: I am interested in finding common ground and differentiating among friends.	-0.13	-0.09	**0.96**	0.01	3.43	1
Q16 I am interested in comparing two different conditions	0.08	0.04	**0.89**	-0.19	3.36	1.11
Q19 I am interested in finding the best solution to a problem in a given condition.	0.08	0.22	**0.57**	-0.05	3.36	1.02
Q10 I am interested in predicting and experimenting with solutions to problems.	0.11	0.24	**0.54**	-0.03	3.55	1.1
Q15: Finding common ground and grouping together will help me in my future.	-0.01	0.34	**0.47**	0.12	3.54	0.87
Q7 I am interested in organizing information with tables and graphs.	0.26	0.07	**0.42**	0.17	3.15	1.18
Q3 Quantifying things will help me in my future	-0.15	0.15	-0.18	**0.97**	3.49	0.97
Q6 Expressing relationships in mathematical formulas will help me in my future	0.15	0.12	0.06	**0.59**	3.38	1.03
Q1 I am interested in quantifying things.	0.23	-0.17	0.11	**0.56**	3.07	1.27
Cronbach's alpha	0.91	0.88	0.894	0.801		
Interfactor correlation：Self-awareness of problem-solving skills		0.542	0.642	0.633		
Interest in technological problem solving			0.539	0.468		
Interest in scientific problem solving				0.688		

Table.3
Frequency distribution of scores

	Average	SD	Frequency distribution of scores				
			Under 1.5	1.5-2.5	2.5-3.5	3.5-4.5	Over 4.5
F1: Self-awareness of problem-solving skills	3.11	0.91	4	21	38	18	7
F2: Interest in technological problem solving	3.8	0.82	1	6	29	34	19
F3 Interest in scientific problem solving	3.4	0.85	5	8	39	31	6
F4 Interest in mathematical problem solving	3.31	0.93	3	14	38	20	13

DOI: 10.6232/JTEE.202012_50(1/2).0001

Table 4

Results of G-P analysis of the developed scales

	Question Items	G group Mean	G group SD	P group Mean	P group SD	T-Values
F1	Q23 I am good at actually making and testing things	4.54	0.59	3.76	1.01	3.29 **
	Q11 I am good at predicting and testing solutions to problems	4.38	0.71	3.16	0.90	5.24 **
	Q20 I am good at thinking of the best solution to a problem in a given condition.	4.33	1.01	3.40	0.71	3.77 **
	Q8 I am good at organizing information with tables and graphs.	4.17	0.96	3.12	0.88	3.97 **
	Q26 I am good at improving and modifying methods for better solutions.	4.38	0.88	3.68	0.80	2.90 **
	Q5 I'm good at expressing relationships mathematically	4.46	0.59	2.88	0.97	6.85 **
F2	Q21 Figuring out the best solution to a problem in the given conditions will help me in my future.	4.29	0.91	3.24	0.83	4.23 **
	Q25 I am interested in improving and modifying the method to become a better solution.	4.42	0.93	3.56	0.65	4.23 **
	Q24 Actually making and experimenting will help me in my future	4.54	0.72	3.64	0.95	3.73 **
	Q27 Improving and modifying the method to become a better solution will help me in my future	4.75	0.44	3.52	0.96	5.71 **
F3	Q13: I am interested in finding common ground and differentiating among friends.	4.54	0.59	3.56	0.71	5.25 **
	Q16 I am interested in comparing two different conditions	4.29	0.95	3.60	0.71	2.89 **
	Q19 I am interested in finding the best solution to a problem in a given condition.	4.50	0.78	3.60	0.65	4.41 **
	Q10 I am interested in predicting and experimenting with solutions to problems.	4.25	0.68	3.16	0.80	5.14 **
	Q15: Finding common ground and grouping together will help me in my future.	4.42	0.78	3.32	0.85	4.71 **
	Q7 I am interested in organizing information with tables and graphs.	4.50	0.51	3.60	0.71	5.09 **
F4	Q3 Quantifying things will help me in my future	4.54	0.51	2.96	0.93	7.31 **
	Q6 Expressing relationships in mathematical formulas will help me in my future	4.25	0.79	2.64	0.91	6.60 **
	Q1 I am interested in quantifying things.	4.63	0.49	3.44	0.96	5.39 **

** p.<01

DOI: 10.6232/JTEE.202012_50(1/2).0001

Table 5

Self-awareness by domain of problem-solving ability

Q23 I am good at actually making and testing things					
	Negative		Positive		
Factor	Mean	SD	Mean	SD	T-Values
F1: Self-awareness of problem-solving skills	2.52	0.64	3.65	0.78	7.47 **
F2: Interest in technological problem solving	3.39	0.76	4.16	0.70	4.97 **
F3: Interest in scientific problem solving	3.12	0.80	3.65	0.84	3.08 **
F4: Interest in mathematical problem solving	3.02	0.72	3.58	1.02	3.03 **
	n=42		n=47		

Q5 I'm good at expressing relationships mathematically					
	Negative		Positive		
Factor	Mean	SD	Mean	SD	T-Values
F1: Self-awareness of problem-solving skills	2.71	0.71	4.04	0.62	8.85 **
F2: Interest in technological problem solving	3.60	0.83	4.27	0.58	4.36 **
F3: Interest in scientific problem solving	3.10	0.81	4.07	0.51	6.82 **
F4: Interest in mathematical problem solving	3.03	0.86	3.98	0.74	5.25 **
	n=62		n=27		

Q11 I am good at predicting and testing solutions to problems					
	Negative		Positive		
Factor	Mean	SD	Mean	SD	T-Values
F1: Self-awareness of problem-solving skills	2.55	0.66	3.78	0.70	8.52 **
F2: Interest in technological problem solving	3.55	0.83	4.09	0.71	3.30 **
F3: Interest in scientific problem solving	3.01	0.84	3.85	0.63	5.44 **
F4: Interest in mathematical problem solving	3.02	0.78	3.66	0.99	3.33 **
	n=48		n=41		

** p<.01

The "F2: Interest in Technical Problem Solving" was constructed only by the technical department's strategy when reviewing the questionnaire. Similarly, "F4: Interest in Mathematical Problem Solving" was constructed only with the strategies of the mathematics department. In the case of "F3: Interest in scientific problem solving," all the strategies except Q7 "I am interested in organizing information using tables and graphs" were based on science strategies. It is thought that the students strongly recognized the connection with science problem solving.

Although the self-perception items regarding self-regulation of learning were constructed separately from the STEM framework, the results of the analysis showed that they were not related

DOI: 10.6232/JTEE.202012_50(1/2).0001
to any subject or problem solving. This can be judged to support the fact that it is different from the framework of the scale constructed in this study.

As can be seen, there is a great deal of similarity between the classification of each domain that was initially assumed and the results of the factor analysis. These similarities are assumed to support the current situation where the content of education to date in Japan is not sufficient to solve problems in the real context, and thus the factor structure was judged to have a certain degree of validity.

3.(4) Self-awareness analysis of problem-solving skills by domain

The first factor, "self-perception of problem-solving ability," was analyzed by dividing it into 4 or more " Positive" and 3 or less "Negative" factors in order to understand the relationship between the problem-solving ability and each subject. The first factor, "Q5: I'm good at expressing relationships mathematically," was used as a representative of mathematical problem solving. Q11: " I am good at predicting and testing solutions to problems " is representative of problem solving in science. Q23: " I am good at actually making and testing things " was taken as a representative of technological problem solving, and the relationship between these factors was examined. As shown in Table 5, the positive and negative groups were significantly higher in each subject at the 1% level of the positive factor.

4. Discussion

As a result of the survey, we were able to develop an awareness scale with four factors. In (1), we were able to confirm the consistency of the developed scale. In (2), it was confirmed that the developed scale had appropriate discriminatory power. In (3), the structure of each factor is consistent with the results expected from the past trend of subject education in Japan, and therefore, it was judged to have a certain degree of validity.

These procedures confirmed the reliability and discriminative validity of the survey, and it can be said that the survey can be used as a measurement scale to understand junior high school students' awareness of problem solving.

In the previous section (4), it can be seen that students who perceive themselves to be good at actually using the learning strategies of their subjects differ from those who perceive themselves to be poor at it in the way they perceive the importance and usefulness of individual subjects. It is necessary to take measures to increase interest in individual subjects at the stage of acquiring skills and concepts. In addition, it is assumed that the importance and usefulness of these subjects may be enhanced by engaging in problem solving. This may be a point of view for devising the arrangement of learning subjects in the future when creating a curriculum.

DOI: 10.6232/JTEE.202012_50(1/2).0001

5. Conclusion

In this study, the concepts and general-purpose skills that cut across subjects were considered to be widely transferred from subject-specific concepts and skills. The purpose of this study was to develop a scale to measure the degree to which subject-specific concepts and skills are related to the learning of other subjects and to the level of interest in problem solving in one's surroundings.

We developed a scale of awareness of problem-solving skills in STEM education, which consists of four factors: self-awareness of problem-solving skills, interest in technological problem solving, interest in scientific problem solving, and interest in mathematical problem solving. The validity of the scale was also confirmed.

The results of the analysis of students' attitudes clearly showed that students lack confidence in their problem-solving abilities and that there was a tendency between students who were good at STEM and those who were not so good at STEM, probably because they did not have much experience with STEM at this stage. We will analyze the details of these results and report on them in the future.

In the future, we will continue to develop and examine the curriculum and issues of STEM education. Further research will be conducted using this report as a preliminary study, and the educational effectiveness of each practice will be examined using the developed awareness scale.

Future issues include analyzing the effects of STEM practices and the changes that can be seen as they accumulate, and examining the placement and content of more effective STEM education materials.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Numbers JP 18H01014 and JP 19H01735

References

Bybee, R. (2010): What is STEM Education? *Science*, *329*(5955), 996.

Kaiser, H. F. (1960). The application of electronic computers to factor analysis. *Educational and Psychological Measurement*, 20,141-151

Matsubara K, Kousaka M. (2017), STEM education and questions as cross-curricular learning that emphasizes the development of qualities and abilities, *Journal of Science Education 41*(2)

Ministry of Education, Culture, Sports, Science and Technology (2020) Special Committee on Elementary and Secondary Education in the New Era (18th Meeting) Reference Material 1-2 p.45

Ministry of Education, Culture, Sports, Science and Technology (2017) Courses of Study for Junior High School

DOI: 10.6232/JTEE.202012_50(1/2).0001
Munegumi T. (2019) STEM Education and STEAM Education: History, Definition, and Disciplinary Integration, *Journal of Naruto University of Education, 34.*

Todd R. Kelley & J. Geoff Knowles. (2016) A conceptual framework for integrated STEM education,International *Journal of STEM education 3*,11

Yamamori, T., Ogura, M., and Moriyama, J. (2019), Understanding the actual situation of junior high school students' awareness of the relationship between mathematics, science, and technology, The 62nd National Conference of the Japanese Society for Industrial Technology Education

Yamazaki, S and Isobe, S. (2020): Relationship between Engineering, Design and other academic disciplines in STEAM education from Japan and conditions for continuous professional development of teachers, *Journal of Joetsu University of Education, 40*(1), 295-305

科技與工程教育學刊 2020，50(1/2)，14-26
DOI: 10.6232/JTEE.202012_50(1/2).0002

應用問題解決教學策略於小學程式設計教育

摘要

本研究的目的是檢視小學階段的程式設計教育實務情形，透過問題解決策略幫助學生運用程式設計思維，更深入地了解身心障礙者。在日本，小學階段已全面實行程式設計教育，因此目前教學現場迫切需要發展程式設計相關的學習活動，以促進「程式設計思考教育」的實踐。日本小學階段的程式設計教育目標是在未來為所有人創造安全的社會。我們相信了解身心障礙人士的相關實務活動，有助於學生運用資訊科技與程式設計以協助視障／聽障人士消除障礙，並提升學生重視視障／聽障人士的需求。本研究設計了一個小學四年級學生實作活動，讓他們利用 Micro:bit 和 MakeCode 為視障／聽障人士開發安全到校的工具。在開始進行設計前，學生透過模擬視障／聽障人士的思考體驗，與檢視學校的平面圖來發現可能的問題，而每位學生皆成功利用 Micro:bit 開發出工具來解決各自發現的問題。本研究結果為：（一）利用 MakeCode 和 Micro:bit 學習程式設計可提升小學四年級學生對程式設計的興趣；（二）事先理解身心障礙者的經驗，有助釐清所需要運用程式設計來解決的問題；（三）透過設計程式來消除障礙可產生對程式設計的正面感覺。

關鍵詞：小學程式設計教育、綜合領域學習時間、輔助科技

科技與工程教育學刊 2020，50(1/2)，14-26
DOI: 10.6232/JTEE.202012_50(1/2).0002

Trial practices of programming education using problem-solving strategy in elementary school

Tetsuya BANDO[1], Shunsuke TOMINAGA[2], Hitoshi CHONO[2], Naoto SONE[1], Nobuhiko FUJIHARA[1], Tetsuya YAMADA[3] & Yosuke ITO[1]
Naruto University of Education[1]
Fuzoku Elementary School Attached to Naruto University of Education[2]
Fuzoku Middle School Attached to Naruto University of Education[3]

Abstract

The purpose of this research is to examine programming education practices in elementary schools to help pupils notice the programming thinking process by problem-solving to better understand disabilities. Japan has fully implemented programming education in elementary schools. There is an urgent need to develop practices to foster "Programmatic thinking" through learning activities that incorporate programming. A goal of programming education for elementary schools in Japan is aimed at creating a safe society in the future for everyone. We believe that practices associated with the understanding of disabilities will lead to increased awareness of the use of information technology and programming to remove barriers for people with vison/hearing impairment. We planned practices for fourth-grade pupils to develop tools useful for inviting vision/hearing impaired persons to school by utilizing "Micro:bit" and "MakeCode." The pupils discovered problems by performing a simulated experience of thinking as the vision/hearing impaired persons and checking the floor plan in the school before working on the programming. Each of them was able to develop tools utilizing Micro:bit to solve the problems that they found. As a result of the trial practices, 1) Learning programming with MakeCode and Micro:bit raises interest in programming for fourth graders, 2) Incorporating the experience of understanding disabilities in advance helped clarify the problems to be solved using programming, 3)Working on programming to remove barriers creates positive feelings toward programming.

Keywords: Elementary Programming Education, Period for Integrated Study, Assistive Technology

DOI: 10.6232/JTEE.202012_50(1/2).0002

1. Introduction

The purpose of this research is to examine the practices of programming education in elementary school to help pupils notice the programming thinking process by problem-solving to better understand disabilities.

In recent years, computer science has become increasingly important. From PISA2021, OECD's Education Today (2019) has announced that it will set up the framework of computational thinking. Moreover, since the latter half of the 2010s, some countries have made computer science compulsory, starting from elementary courses. In response to this trend, Japan has fully implemented programming education in elementary schools (elementary programming education) since 2020. In Japan, it is recognized that it is important to develop problem-solving skills using information technology in the future society, and elementary school programming education has been implemented in schools for this purpose. The Japanese Cabinet Office (2016) uses the "Society 5.0" framework as its Science and Technology Guideline. Society 5.0 utilizes IoT, big data, and AI, which are the technologies that represent the Fourth Industrial Revolution, aiming to provide a safe place to live for men and women of all ages and disabilities toward the realization of "Society 5.0," there are high expectations for systematic information education, including programming education, from elementary to high schools in Japan.

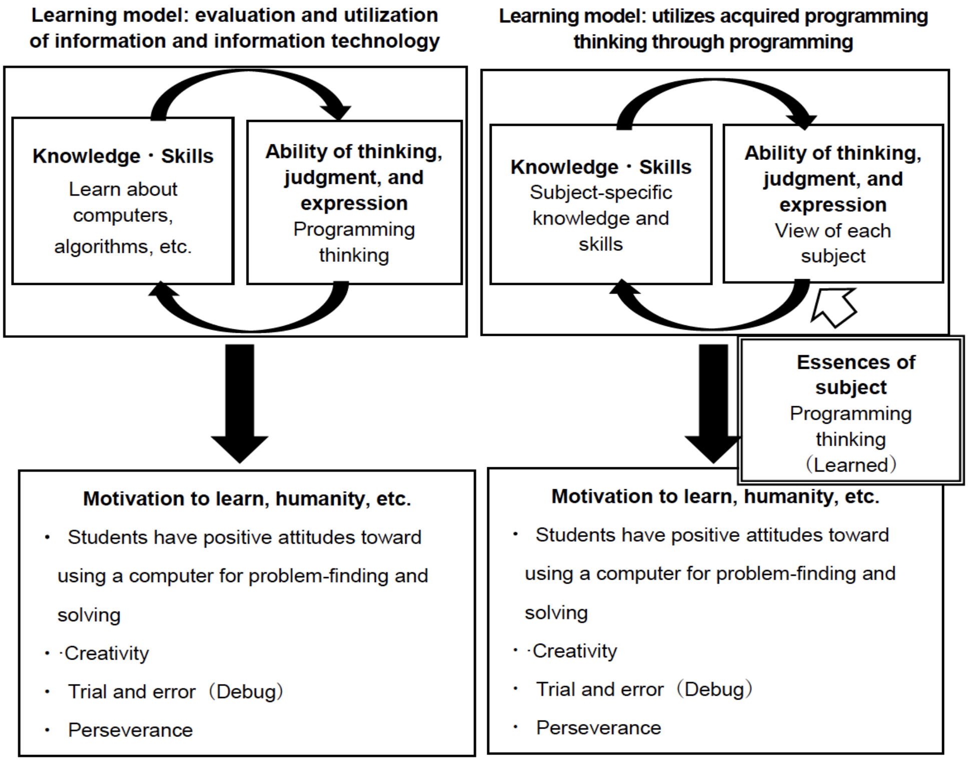
In Japan's National Curriculum Standards (Japanese course of study), the Ministry of Education, Culture, Sports, Science and Technology (MEXT) organized the goals of programming education into three pillars: "knowledge/skills"; "ability of thinking, judgment, and expression"; and "motivation to learn, humanities, etc." Among these, the core of programming education was shown to be the development of "programming thinking," which is positioned as the "ability of thinking, judgment, and expression." Programming thinking is a phrase coined based on the premise of logical and computational thinking. "Programming thinking," is defined as the ability to think logically about "what kind of movement combination is necessary, how to combine symbols corresponding to each movement, and how to improve combinations of symbols in order to realize the series of activities intended by you (MEXT, 2018)." Elementary programming education in Japan does not aim to acquire skills that enable programming in a specific programming language, but to develop problem-solving abilities that utilize information technology such as computers.

In Japan, there are no subjects related to computer science, including programming. This will be conducted within the existing subjects. In the course of study for elementary school, examples of learning content were presented in specific subjects such as mathematics, science, and the period for integrated study (MEXT, 2018). Two examples of programming-related learning content are drawing

DOI: 10.6232/JTEE.202012_50(1/2).0002

regular polygons in mathematics and using electricity in science. On the other hand, although the theme is not decided in the period for integrated study, it is shown that it is positioned as an inquiry-based study. Thus, there is concern that the subject-related lesson goals may be confused with the programming-related lesson goals because computer science-related subjects, including programming, have not been established for elementary schools in Japan (Ozaki & Ito, 2017).

To address this concern, two learning models of elementary programming education have been proposed so that the learning goals that incorporate programming become clearer. Figure 1 shows the proposed learning model. The first learning model is the "Phase 1: training model" for learning the concept of programming. The second is the "Phase 2: utilization model" of problem-based learning through programming (Bando et al., 2018). The "training model" mainly aims to develop programming thinking through learning activities related to information and information technology among the learning contents of each subject. On the other hand, the "utilization model" aims to deepen the content of the subject by utilizing the programming thinking cultivated in the "training model." The "utilization model" can be viewed as engaging in learning activities that incorporate programming in order to deepen subject area content learning. There is an urgent need to develop the



Phase1 training model Phase 2 utilization model

Figure 1. Two learning models in elementary programming education.

Note. From "Proposal of a primary programming education curriculum and management based on fostering information literacy" by Bando, T., Fujihara, N., Sone, N., Chono, H., Yamada, T., & Ito, Y, 2019, *Journal of Information Education in Naruto University of Education*, *16*, 27-36. Copyright 2019 by Center of Information Technology Service, Naruto University of Education.

DOI: 10.6232/JTEE.202012_50(1/2).0002

learning content of the model to foster programming thinking in order to implement the utilization model. Therefore, we decided to plan learning activities for pupils to find problems in their daily lives and solve them by programming, and to investigate their effects. In this research, we focused on a learning model – “training model” – that aims to foster programming thinking and developed learning content that incorporates problem-solving in the period for integrated study.

2. Learning that incorporates programming based on understanding disabilities

Regarding how to proceed with elementary programming education, MEXT (2020) has published the “Guide for Elementary Programming Education (3rd Edition).” As an example of learning content in the period for integrated study, a lesson to solve local community matters by programming was introduced. Given the local community matters, it is assumed that these are mainly related to agriculture, and currently they are trying to solve the problems of harvesting and crop transportation. As another study, it was reported that programming a robot vacuum cleaner and engaging in learning activities that make pupils think about how to interact with computers. This practice was said to foster an awareness of the desire to make effective use of computers in response to the declining birthrate and aging population (Ito & Hasegawa, 2019). In addition, at the elementary school level in Japan, there have been reports of practical examples of physical computing using Wedo2.0 (Kuroda & Moriyama, 2019) and Shpero (Yamamoto et al, 2017). The purpose of all of these is to make students aware of how programming is used in society.

As mentioned above, elementary programming education is positioned as an education that contributes to the development of qualities and abilities corresponding to Society 5.0. However, it is also necessary to be able to solve local issues and improve the environment. In light of the recent requirement of a better understanding of diversity, it is possible to assist people with disabilities in leading a safe and secure life through understanding their disabilities. In primary and secondary education, the importance of promoting understanding of persons with disabilities has been shown as a step toward the realization of an inclusive society (Central Board of Education, Primary and Secondary Education Section, 2012). Few studies have focused on problem-based learning that incorporates programming with the theme of understanding disabilities at the elementary school stages.

It is expected that children will deepen their understanding of programming as well as their understanding of disabilities by learning about the problems of people with disabilities and working on problem-solving using technology. Regarding education for understanding disability, it has been shown that understanding of disabilities can be deepened through pre-learning, wherein disabilities

DOI: 10.6232/JTEE.202012_50(1/2).0002

are understood by how they interact with the environment and how they can do more by devising ways (Takano & Kataoka, 2014). The problem-solving technology used by people with disabilities is called assistive technology. The Individuals with Disabilities Education Act defines assistive technology (AT) devices as any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of a child with a disability (20 U.S.C. 1401(1)).

From this aspect, in order to engage with people with disabilities, we decided to develop learning content through this research that can develop students' problem-solving abilities using technology from the perspective of AT and investigate its educational impact. The results showed that the children's interest in programming increased and their understanding of disabilities deepened. The findings of this study will be useful not only in promoting understanding of diversity, but also in developing technological literacy, which is the goal of technology education as general education.

3. Method

3.1 Participants

The participants were 27 fourth-grade students of a national elementary school in Japan (14 males and 13 females; valid rate 93.1%). They have never experienced programming in 4th grade learning activities.

3.2 Overview of learning activities

It was set around the mastery of basic operation methods related to programming and the design to solve problems. In the fourth grade, students will deepen their learning about relationships with people with disabilities, such as the vision/hearing impaired (Table 1). The unit goals of this lesson were set as follows.

1) By finding issues through encounters with people with disabilities and simulated experiences, reviewing the surrounding environment from various standpoints, and investigating tools and mechanisms that are easy for everyone to use, it is possible to deepen the perspective and way of thinking about things.

2) Based on your experiences and research, you can think from various standpoints, consider what you can do as a member of society, and try to act.

DOI: 10.6232/JTEE.202012_50(1/2).0002

Table 1
Unit planning

Period	Outline of learning activities
1st ~ 4th Period	Think about universal and barrier-free design Experience the world of the visual / hearing impaired vision impaired “eye mask experience” hearing impaired “lip-syncing game”
5th ~ 6th Period	Find the barriers for people with vision / hearing impairments in our school
7th ~ 12th Period (programming)	We are AT developers Pupils design problem-solving methods for inviting people with vision / hearing impairments to school and solve the problems for the invitees by the program Micro:bit.
13th ~ 14th Period	Learn from the people with vision / hearing impairment

3.3 Survey items

There were two evaluation items related to the period for integrated study: “I was able to achieve what I wanted to do” and “I could program based on what I planned” (scored on a scale of 1-4; “4: I really think so”; “3: I think so”; “2: I don’t think so”; “1: I don’t think so at all”). In addition, there were five evaluation items related to programming: “I enjoy programming classes,” “I worked on the programming without giving up until the end,” “Thinking about the order of the instructions, I worked on the programming,” “What I learn in programming is useful in my daily life,” and “I became interested in programming” (scored on a scale of 1-4; “4: I really think so”; “3: I think so”; “2: I don’t think so”; “1: I don’t think so at all”).

3.4 Teaching materials using single-board microcontroller

The main teaching material is a single board computer called Micro:bit. It was adopted to develop a tool that would allow people with disabilities to visit the school safely. Micro:bit has a 5x5 LED screen, and you can control how it shines. In addition, sound can be controlled by connecting sensors and speakers as peripheral devices. The visual programming environment “MakeCode” can be used for Micro:bit. Since the interface is user-friendly, even elementary school pupils can easily program (Figure 2).

We made it possible for pupils to solve problems without aid using the “Tutorial” function of the visual programming environment MakeCode and preparing the manuals of MakeCode. In addition, we grouped pupils with similar input/output programming tasks to facilitate collaborative learning. We prepared a worksheet to understand what kind of AT device the pupils will develop. The worksheet was filled with details of the type of impairment (vision/hearing), the problems to be tackled and their function to solve, and the behavior of Micro:bit.

DOI: 10.6232/JTEE.202012_50(1/2).0002

4. Results and Discussion

First, we analyzed the worksheets filled out by the pupils. As a result of classification by the developed functions, five functions were obtained: “Communication,” “Understanding the location and direction,” “Detection of obstacles and stairs,” “Reassuring the user’s feeling,” and “Other.” Communication includes displaying greetings on Micro:bit’s LED screen . Understanding the location and direction includes reading the direction with a Micro:bit magnetic sensor and displaying it with light or expressing it with sound. Detection of obstacles and stairs included counting the number of stairs and installing a Micro:bit in front of a dangerous place, then sounding an alarm when the Micro:bit vibrates. Reassuring the user’s feelings includes LED screens that display words of encouragement. Another included those that attempt to measure the user’s condition.

Table 2 shows the types of impairment that were tackled and the functions that were developed based on the pupils’ design. Regarding the response by type of impairment, seven pupils (25.93%) designed ATs for people with vision impairments, 14 pupils (51.85%) designed ATs for people with hearing impairments, and 6 pupils (22.22%) designed ATs for both. Although no statistically significant difference was observed, about half of the pupils worked on dealing with people with hearing impairments ($\chi2(2)=4.22$, ns, $w=0.40$). On the other hand, there was a significant difference in the developed functions ($\chi2(4)=15.41$, $p<.01$, $w=0.76$). As a result of multiple comparisons by the accurate binomial test, more functions to promote “understanding the location and direction” were tackled than “reassure the user’s feelings” and “Other.”

Table 3 shows the mean and standard deviation of each item in gender. Regarding the two items of evaluation on the period for integrated study, the average value of the answers to “I was able to achieve what I wanted to do” and “I could program based on what I planned” was high at 3.0 or more. Thus, it can be seen that the pupils were able to work on problem-solving using information technology, and the period for integrated study was substantial for them. This trial practice with the task of “developing assistive technology using Micro:bit” for pupils to discover and overcome problems in the school through the experiences of being blind and deaf was effective.

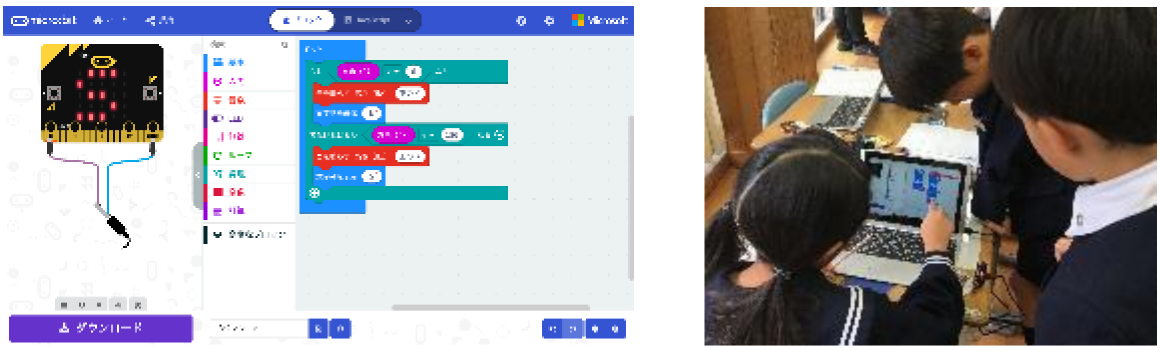


Figure 2. Program examples created by pupils using MakeCode and learning activities.

DOI: 10.6232/JTEE.202012_50(1/2).0002

Table 2
Types of impairment and functions that pupils worked to solve

Type of impairment	n	%
Visual	7	25.93
Hearing	14	51.85
Both	6	22.22

Type of function	n	%
communication	4	14.81
Understanding the location and direction	13	48.15
Detection of obstacles and stairs	6	22.22
Reassuring the user’s feelings	2	7.41
Other	2	7.41

Table 3
Mean and SD of evaluations for “the period for integrated study” and programming

Item	Female		Male		All	
	Mean	SD	Mean	SD	Mean	SD
I was able to achieve what I wanted to do.	3.46	0.52	3.07	0.92	3.26	0.76
I could program based on what I planned	3.38	0.51	3.29	0.83	3.33	0.68
I enjoy programming classes	3.62	0.51	3.71	0.61	3.67	0.55
I worked on the programming without giving up until the end	3.54	0.52	3.57	0.85	3.56	0.70
Thinking about the order of the instructions, I worked on the programming	3.54	0.66	3.57	0.51	3.56	0.58
What I learn in programming is useful in my daily life	3.77	0.44	3.36	0.84	3.56	0.70
I became interested in programming	3.69	0.48	3.64	0.63	3.67	0.55

In addition, regarding the evaluations during programming activities, “I worked on the programming without giving up until the end” and “Thinking about the order of the instructions, I worked on the programming” both received extremely high scores of 3.4 or higher. The evaluation of items related to programming, “I enjoy programming classes” and “I became interested in programming” were extremely high, with an average response of 3.5 or higher. It can be said that the programming tackled in this trial practice was attractive to children and increased their interest in programming. The average value of responses to “What I learn in programming is useful in my daily life” were also extremely high at 3.4 or higher, probably because programming was used to solve the problems found in the school. It was shown that this trial practice raised the interest for programming in the pupils and made them feel the usefulness of it.

Next, text mining was performed on the descriptions obtained using KH-Coder (Higuchi, 2017). The following reflective responses were obtained. “What I have learned in today's class is that programming is an important device that connects people to people. The next time I do programming,

DOI: 10.6232/JTEE.202012_50(1/2).0002

I want to make harder blocks and help people with disabilities one after another. Next time, I want to show the flashing lights and help people in wheelchairs.", "When I was programming, I noticed something. In the future, I would like to use programming more to create things that are useful to the blind and deaf. In the future, I would like to use programming more to make things that are useful for people with disabilities." and so on. As a result of morphological analysis, a total of 1,814 words were extracted from the learners' reflections on this study. When the extracted words with more than 10 occurrences were sorted out, in order of the most frequent occurrences, "programming" was used 35 times, "think" 22 times, "make" 17 times, "person" 16 times, "inconvenience" 13 times, and "self" and "class" 11 times.

Then, co-occurrence network analysis was conducted to explore the relationships among the extracted words, and nine co-occurrence relationships were obtained. Figure 3 shows the obtained co-occurrence network. From the nine co-occurrence relationships obtained, we focused on 1, 2, 7, 8, and 9, which are a series of four or more words. The following were the co-occurrence relationships we considered relevant. (1) This included content related to cooperating with friends and being able to utilize it in daily life. It can be said that the goodness of the program was felt through learning to develop AT through programming. (2) This included an interest in devising a mechanism to help people with disabilities. From this, it can be said that the pupils' motivation to help others had increased. (7) There was a description of pressing the button on the Micro:bit and its function. It was presumed that the pupil's understanding of the programming teaching material, Micro:bit, had deepened. (8) There was a description that the user noticed that he or she was informed of his / her situation by making a sound. It turns out that the pupil became aware of the functionality of sound. (9) This included a description of the outline of this class. It can be said that the children worked on learning to incorporate programming after understanding the concept of developing AT for people with vision/hearing impairment through this practice. The following groups of co-occurrence relationships were obtained: (1), corresponding to the review of the learning activities of this trial practice; (2), (7), (8), corresponding to the understanding of AT / programming; and (9), corresponding to the understanding of disabilities. Based on these findings, it was shown that this trial practice was a learning experience that led to better understanding of disabilities and the removal of barriers, with the aim of being able to interact with anyone.

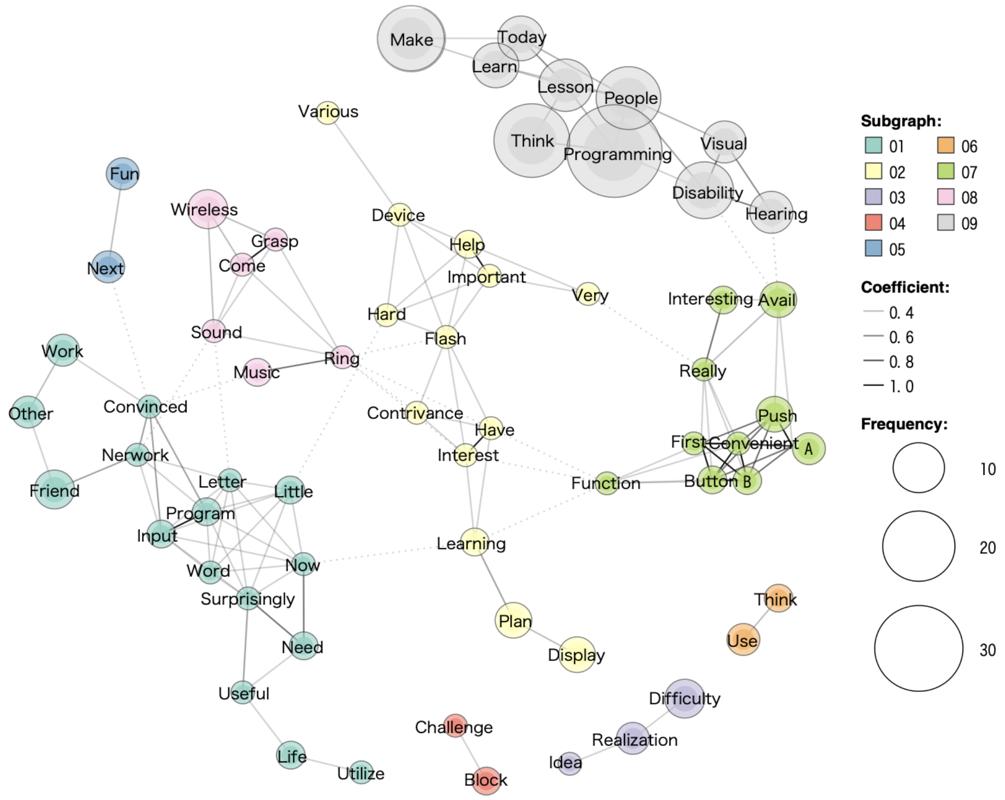


Figure 3. Co-occurrence network diagram for the retrospective description of this learning.

5. Conclusion

As mentioned, we tried to develop learning content incorporating programming from the viewpoint of understanding disabilities, in the period for integrated study for fourth graders. Under the conditions of this study, the following conclusions were drawn:

1) Learning programming with MakeCode and Micro:bit raises interest in programming for fourth graders

2) Incorporating the experience of understanding disabilities in advance helped clarify the problems to be solved using programming.

3)Working on programming to remove barriers creates positive feelings toward programming

In the future, it is thought that understanding disabilities will be further deepened by setting up opportunities to discuss ways to overcome barriers together through learning programming with people with disabilities. We would like to continue our research so that we can develop the technical literacy of pupils who can appropriately apply programming and information technology toward the realization of a society where everyone can live with peace of mind, regardless of age or gender, with or without disabilities.

DOI: 10.6232/JTEE.202012_50(1/2).0002

6. References

Bando, T., Fujihara, N., Sone, N., Chono, H., Yamada, T., & Ito, Y. (2019). Proposal of a primary programming education curriculum and management based on fostering information literacy. *Journal of Information Education in Naruto University of Education*, *16*, 27-36. [in Japanese]

Central Board of Education, Primary and Secondary Education Section. (2012). Promotion of Special Needs Education for Building an Inclusive Education System Toward the Creation of a Symbiotic Society (Report). Retrieved from https://www.mext.go.jp/b_menu/shingi/chukyo/chukyo3/044/attach/1321669.htm [in Japanese]

Higuchi, K. (2017). A Two-Step Approach to Quantitative Content Analysis: KH Coder Tutorial Using Anne of Green Gables (Part II), *Ritsumeikan Social Science Review*, *53*(1), 137-147. [in Japanese]

Ito, F & Hasegawa, H. (2019). A Study of Integrated Study Incorporating Programming: Practical Experience and Evaluation of the Elementary School 6th Grade Unit “Computers in Our Lives”, *Journal of Japan Society of Educational Information*, *36*(1), 25-38. [in Japanese]

Japanese Cabinet Office (2016). The 5th science and technology basic plan. Retrieved from https://www8.cao.go.jp/cstp/english/basic/5thbasicplan.pdf [in Japanese]

Joint Research Centre (2016). Developing computational thinking in compulsory education. Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104188/jrc104188_computhinkreport.pdf

Kuroda, M & Moriyama, J. (2019) Practical Study of Elementary School Programming Education Focusing on Problem Solving against Issues in Daily Life from the Viewpoint of Promoting Technological Literacy, *Journal of the Japan Society of Technology Education*, 61(4), 305-313 [in Japanese]

MEXT; Ministry of Education, Culture, Sports, Science and Technology (2017). Guide to National Curriculum Standards for elementary school: General. Retrieved from http://www.mext.go.jp/component/a_menu/education/micro_detail/__icsFiles/afieldfile/2019/03/18/1387017 [in Japanese]

MEXT; Ministry of Education, Culture, Sports, Science and Technology (2020). Guide to primary programing education. Retrieved from https://www.mext.go.jp/content/20200218-mxt_jogai02-100003171_002.pdf [in Japanese]

OECD Education Today (2019). Computer Science and PISA 2021. Retrieved from https://oecdedutoday.com/computer-science-and-pisa-2021/

DOI: 10.6232/JTEE.202012_50(1/2).0002

Ozaki, H. & Ito, Y. (2017). Practical problems of primary programming education. *Journal of Information Education in Naruto University of Education*, *15*, 31–35. [in Japanese]

Takano, H & Kataoka, M. (2014). Practical study on a way of exchange activities and collaborative learning: Seeking for valued pre and post-learning, *Bulletin of the educational research and practice, Faculty of Education, Kagoshima University*, *23*, 111-120. [in Japanese]

Yamamoto, T., Suzuki, K., Takeno, K. & Kano, T (2017) Programming Learning in Elementary Education Using Tablet PC, *Educational Information Research*, 33(1), 41-48, 2017 [in Japanese]

科技與工程教育學刊 2020，50(1/2)，27-48
DOI: 10.6232/JTEE.202012_50(1/2).0003

學校創新：以三創跨域學程結構嵌入技術型學校課程系統之偏鄉案例

摘要

臺灣東部地區由於地理經濟等因素影響，孕育出許多與都會地區不同之文化特色，而學生的學習態度、技能學習、以及學校重點資源挹注都與都會地區有所差異。當中「創新」是當代經濟的關鍵詞，管理學之父彼得杜拉克 Peter Drucker 甚至以「不創新，即滅亡」來說明其之於未來經濟時代的重要。要如何在文化背景與資源均與都會區有別之情形下，培養學生具備創新力與思考力，進而具備職場競爭力以面對未來時代，學生創意、創新、創業(以下簡稱三創)能力的培養成了東部地區學校的重點挑戰。

為培養學生創新與思考力，進而具備職場競爭力，筆者參考 2015 年經濟合作暨發展組織(簡稱 OECD)所提之系統創新，於臺灣東部地區專科學校有限的師資、課程與資源之組織系統中，提出嵌入融合式設計的三創跨領域學分學程於課程系統內，將原本個別學科導向的課程系統，以結構性的課程變更方式，根本性的改變學校氛圍，形塑創新，預期能達到(1)培養學生提升基礎三創能力，擴展各科學生所學專業；(2)新創作品跨域開發，使學生具備較高之職場競爭力；(3)促進建立產學機制，使學校專業學習與社區有效接軌之目的。除採跨領域、多元教學、知識性、應用性與趣味性的教學方式，並規劃相關活動競賽，鼓勵並積極輔導學生爭取校內外榮譽，從中提升學生就業競爭力。此外，該學程的學生基於創新創業產生之目的，跨科修課自由度相對大，因而有助跨域學習。

而同 F. Geels 與 R. Raven(2006)的系統創新擴散的過程觀點，本文章透過辦理三創學程前後在學生新創作品獲獎情形，促進教師學術交流與產學合作之發展，與教師教學創新與環境活絡情形三個面向改變情形的討論，看出運用此組織創新方法設立三創學程後，除達成學程設立目的外，更超乎所求的使學生有更多參與國際競賽或專業研究機會，學校與社區的產學不僅能有效銜接，亦逐步產生創育模式，校際交流開始頻繁並締結策略聯盟。此外，校園學習氛圍亦越發活絡，不僅形成學校特色且可影響至社區。可說明本創新策略，除可促使學校組織內部有效形成創新，亦能影響地方產業經濟。

關鍵詞：組織創新、三創、融合式課程、跨領域、產學合作

科技與工程教育學刊 2020，50(1/2)，27-48
DOI: 10.6232/JTEE.202012_50(1/2).0003

School Innovation: A Case of Embedding a Cross-Disciplinary CIE Program Structure into the Curriculum System of a Rural Technical School

Ching-Hsing Lin, Shao-Ying Li, Yu-Jr Tsai*
Center of General Education,
National Taitung Junior College

Abstract

Due to the influence of geographical and economic factors in eastern Taiwan, many cultural characteristics differ from those in metropolitan areas. As a result, students' learning attitudes, their ability to acquire skills and key resources at schools there are different from those in metropolitan areas. Innovation is the key word of the contemporary economy. Peter Drucker, the father of management, even used the phrase "innovate or die" to explain its importance in the future economic era. The authors are seeking how to train students to have the ability to innovate and think creatively despite their cultural backgrounds and resources differing from those in metropolitan areas, in turn obtaining the competitiveness needed for the workplace. The cultivation of students' capacities for creativity (C), innovation (I) and entrepreneurship (E) (collectively referred to as “CIE”) has become a key challenge for schools in this region.

In order to cultivate students' creativity, thinking skills and workplace competitiveness, the authors have referred to the system of innovation proposed by the Organization for Economic Co-operation and Development (OECD) in 2015. There are limited faculty, courses and resources at technical schools in eastern Taiwan. In this organizational system, is the authors proposed embedding innovative, cross-disciplinary CIE credits into the curriculum. The originally single-discipline-oriented curriculum system was changed structurally, foundationally changing the atmosphere of the school to promote innovation with the expected outcomes of 1) boosting the students’ foundational CIE skills and expanding the disciplinary scope of each student, 2) promoting the cross-disciplinary development of innovative products to allow students to boost their workplace competitiveness, and 3) promoting the establishment of an industry-academia cooperation system to effectively link learning to the community. In addition to adopting an instructional method that is cross-disciplinary, diversified, knowledge-based, application-based and fun, the curriculum also includes related activities/competitions and encourages and actively guides students to strive for honors inside and outside of school so as to enhance their workplace competitiveness.

DOI: 10.6232/JTEE.202012_50(1/2).0003

Furthermore, the purpose of promoting innovation and entrepreneurship in this curriculum includes considerable freedom in cross-disciplinary study and helps with cross-disciplinary learning. Moreover, through related activities, such as awards won by students' projects and the promotion of the development of teachers' academic exchanges and industry-academia cooperation, in the context of teaching innovation and the environment, we can indirectly see related organizational innovation methods that have driven the shaping of the school's unique characteristics. In addition, it is helping the development of local industries and forming a model of social responsibility for schools of higher education through inter-school exchanges and care for the local culture.

As with the concept of systematic innovation diffusion described by F. Geels and R. Raven (2006), this study discusses the changes in the state of awards won by students for projects, the promotion of academic exchanges among teachers and industry-academia cooperation, and the states of innovative instruction and environmental activation after implementing the CIE curriculum. The results show that using an organizationally innovative method in establishing the curriculum has not only allowed the program to become well-established but also has had the effect of inspiring more students than expected to enter projects in international competitions or obtain opportunities to participate in discipline-specific studies. The cooperation between the school and the community not only effectively created a more innovative education method but also led to more frequent exchanges and strategic alliances among schools. Furthermore, the learning atmosphere at the school was activated, in turn producing an effect on the community. Thus, the strategy boosted innovation within the school culture and even had an influence on the local industry and economy.

Keywords: Organizational innovation, CIE; fusion curriculum, cross-disciplinary, industry-academia cooperation

DOI: 10.6232/JTEE.202012_50(1/2).0003

1. Introduction

In Taiwan’s education system, technical and vocational education were established due to the needs of technical professionals, especially in areas where the economy is to be developed. Agriculture, forestry, fishery, animal husbandry, industry and other industries are in the development process. Local residents pay more attention to the training of technical professionals. In eastern Taiwan, due to the rich diversity of ethnic groups and the natural landscape, the barriers of mountains and the distance have allowed economic development in major cities to nurture many distinctive customs. The differences in capacity to acquire skills and school resources are also due to factors such as geographical environment and economic development. The courses and school development focus of eastern schools are also different from those in metropolitan areas due to the above-mentioned factors. In addition, based on the basic economic needs of people’s livelihood in rural areas, whether the local technical and vocational schools can cultivate appropriate talent, are good at using local natural and cultural resources, respect multiculturalism, create a community that is beautiful and good, and create a more stable economy for the local people’s livelihood are all major issues. For technical and vocational schools in eastern Taiwan, these are intangible but relatively important subjects outside of school education.

In the contemporary economy, under the influence of various technologies and transnational cultures, all kinds of products are constantly being created and innovated, especially with the changes of the times. No matter how outstanding an enterprise is, it must continue to innovate to survive. The key to this is, as explained by Peter Drucker, the father of management, the concept to "innovate or die." However, for technical and vocational schools, various subjects usually have long-established syllabuses and courses that have used specific teaching materials and training models for many years but rarely lead students to think on their own or understand innovation, which is of course the case when they begin to work for an enterprise. This is especially true for areas in eastern Taiwan whose economic development is mainly characterized by agriculture. Besides the need for financial assistance in these areas, the authors also considered the possibility that “agricultural technology innovation is conducive to agricultural economic development and can better promote sustainable rural development” (Liu, Y. et al., 2021). For rural vocational and technical schools, whether it be cultural background, the acquisition of educational resources, or the various resources of the community, all are clearly different from those in metropolitan areas, and many cultural influences may even be added to the general syllabus. Under these circumstances, the authors have investigated how a school locates its value and proposes specific and effective practices in school affairs taking into account social expectations, such as the revival of the local culture, the prosperity of industry,

DOI: 10.6232/JTEE.202012_50(1/2).0003

and the cultivation of students’ ability to think on their own and innovate in various workplace competitions. Faced with the old organizational system, schools obviously need to conduct systematic organizational innovation in order to effectively achieve the above goals regardless of environmental culture or talent cultivation expectations.

As the school’s talent cultivation method used curriculum teaching as the main method and operates in a systematic manner, in order to cultivate students' thinking and innovation ability, and thus obtain workplace competitiveness, the authors decided to start with fundamental curriculum system innovation. Due to the career-oriented nature of technical colleges, the authors specially used the three stages of social and corporate innovation activities to put forward the idea of cultivating students' creativity, innovation and entrepreneurship (collectively referred to as “CIE”). Based on the limited number of teachers, courses and resources of a certain technical school in eastern Taiwan, which had adopted the traditional curriculum system, a cross-disciplinary CIE credit course has been added, and teachers have been encouraged to integrate the concept of CIE into their instruction. The addition of the CIE program was to help students be more adept at using creative ingenuity, innovating on the basis of their original technical capabilities, and even further their capacity for entrepreneurship. The establishment of this program used the system innovation described by OECD (2015), fusing it with the curriculum structure, which in turn promoted the formation of an innovative structure in the curriculum system and created a dynamic curriculum system change. Regardless of the organizational system changes that may have been affected, the hope for the CIE program in its early stage was to achieve the following objectives:

1.1 Boost the students’ foundational CIE skills and expand the disciplinary scope of each student.

1.2 Promote the cross-disciplinary development of innovative products to allow students to boost their workplace competitiveness

1.3 Promote the establishment of an industry-academia cooperation system to effectively link learning to the community.

The operation of related programs was based on changes in user preferences, regulations, facilities and culture each year. This study will not only share how limited resources were used to set up the CIE program in junior colleges in eastern Taiwan but also discuss the CIE program setup strategy, the design of CIE courses and the impact of implementation on school organization.

2. Literature Review

In 1998, UNESCO presented the World Declaration on Higher Education for the Twenty-first Century: Vision and Action in Paris. Article 7 of the declaration states the need to strengthen

DOI: 10.6232/JTEE.202012_50(1/2).0003

cooperation with the world of work and respond to social needs, and Subparagraph (d) discusses the use of higher education in cultivating job-hunting capacity, creating employability and raising the capacity of higher-education graduates to cultivate their workplace ability. The system emphasizes that if the reform of the curriculum system is to respond to the requirements of Article 7, the establishment of creativity, innovation and entrepreneurship programs is indeed one of the best ways (including for technical colleges).

2.1 Organizational and technological innovation

The contemporary concept of innovation is mostly based on the innovation economy described by economist Joseph Alois Schumpeter. He believed that innovation is a "process of industrial mutation, that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one" (Śledzik, K., 2013). In business and economics, innovation can be a catalyst for growth. According to Drucker (2002), innovation originates from possible emergencies, unexpected occurrences and incompatibility. Coordinating factors, such as incongruities, process needs, industry changes, market changes, demographic changes, changes in perception and the output of new knowledge, cause people to leapfrog the imagination to make the correct response. This imagination is a kind of functional inspiration and a driving force for innovation.

From the perspective of innovation capability, H. Tsai and S. Huang (2016) summarize the views of many scholars and roughly divide corporate innovation activities into (1) technology-based innovation activities and (2) non-technology-based innovation activities that emphasize organizational innovation. The key is to obtain an understanding that technological innovation ability has an intermediary effect on organizational innovation and performance. In addition to knowing that economic changes may affect organizations, they must also follow technological innovations. Technological innovations can also promote drastic changes in the world. OECD (2015) cited experts and scholars in the field of techno-economic analysis. Studies and theories on general-purpose technologies (GTP) and large technical systems (LTS) clarify the long-term relationship between technological innovation and the economy. However, a new and successful enterprise needs cooperation between its organizational innovation and technological innovation. The implementation of organizational innovation requires the support of technological innovation, and the implementation of technological innovation needs organizational innovation as a guarantee (Tsai, H. & Huang, S., 2016). Therefore, with the inspiration of innovation, besides guiding organizational innovation, the cooperation between industry and schools of higher education is often related to the research and

DOI: 10.6232/JTEE.202012_50(1/2).0003

development of technological innovation. For example, we may look at agricultural innovation in industry-academia cooperation. Agricultural industrialists need the support of research for the sake of innovation in agricultural technology, and they also have financing and marketing needs. Meanwhile, schools and governments can conduct the necessary research, and the creation of innovation platforms is viewed as “a promising vehicle to foster a paradigm shift in agricultural research for development” (Schut, M. et al., 2016), especially since the transition of agriculture “from technology-oriented to system-oriented approaches requires structural changes” (Schut, M. et al., 2016). These platforms should be managed by a public agency or non-profit organization to ensure impartiality. Besides the contribution research generally makes, the agricultural research conducted has the function of promoting innovative momentum on a number of levels (Lamers, D. et al., 2017).

2.2 System innovation

System innovation is actually a conceptual framework. It is defined as the fundamental innovation of a social technology system that fulfills social functions (OECD, 2015). System innovations are thus defined as radical insofar as they alter existing system dynamics innovations in socio-technical systems (OECD, 2015) and can be regarded as an excessive and fundamental solution for changes in management systems, which usually occur due to impacts or challenges in the broad-field environment (such as the climate, economy or population) or are generated within the system. For example, when the population within the system changes suddenly, the system must be used in another new form to deal with such impact, such as through the use of new skills, new infrastructure, new intermediary organizations or new rules/governance methods. For enterprises, internal system innovation requires architectural innovation (OECD, 2015), which does away with the existing technology-side or customer-side interaction methods, so it usually requires the generation of new business models, new regulations, new facilities and new cultures. System innovation and changes are usually a complex and long process. The transition period is roughly divided into four stages: development, take-off, breakthrough and stability. Since fundamental system innovation has a systemic impact on user preferences, regulations, facilities, culture, etc., in the open process of innovation, it is best to explore gradually expanding from the perspective of experimentation and learning. Of course, there may be risks or failures during experimentation and learning. The OECD (2015) specifically cited the system innovation diffusion process proposed in 2006 by Geels and Raven (Figure 1) to show that innovation is not only a result but also a continuous process of change.

DOI: 10.6232/JTEE.202012_50(1/2).0003

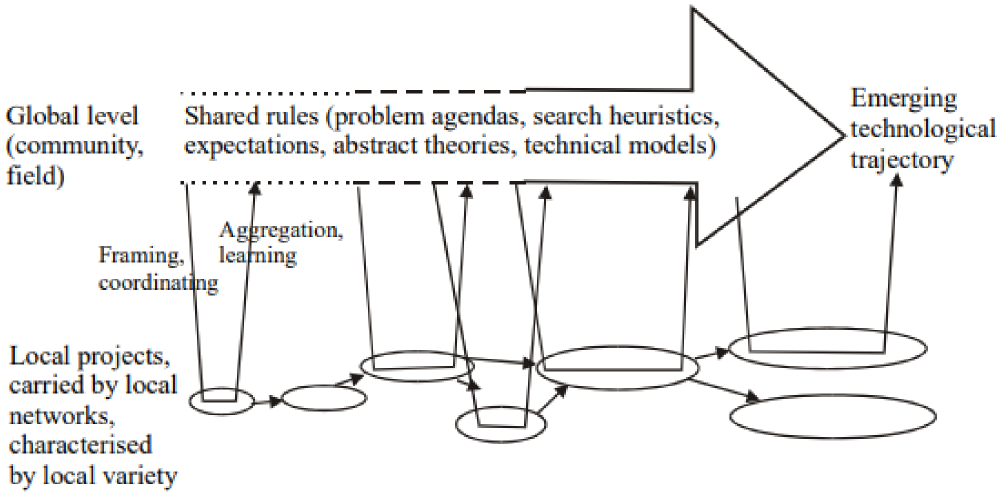


Figure 1. Diffusion as a process of niche-accumulation (Geels, F. & Raven, R., 2006, as cited in OECD, 2015)

Schools are inherently organizations with special functions. When an organization is carrying out foundational innovation, it is the same as the way J. Bessant et al. (2014) view radical innovation as a framing problem, that is, attempting to change the original routine within framing. This method happens to coincide with the OECD (2015) concept that "system innovation entails architectural innovation." To establish a successful foundation of innovation at a school, choosing appropriate functional systems inside and outside of the school to conduct architectural innovation is a good way to improve the foundation. Once it was decided that innovation would be conducted through changes to the curriculum system, embedding the CIE curriculum became a necessary aspect of the architectural innovation that spurred the success of innovation at this school.

2.3 General and entrepreneurial integration courses

R. W. Tyler (1949) divides the general curriculum into the four parts of the specific subject, broad field, core curriculum and experience curriculum to form the basis for the classification of curriculum forms. Subsequent curriculum classification has expanded on Tyler's. For example, the curriculum format of B. Lin and Z. Li (1970) includes subject-based courses, related courses, integrated courses, broad-field courses, core courses and experience courses. There are also scholars, such as Z. Huang (1991), who combine related categories. Regarding the integration of subject-based courses, related courses, integrated courses and broad-field courses as subject courses, the curriculum is divided into three parts: subject courses, core courses and experience courses (activity courses), the majority being subject courses. The curriculum system of higher education in Taiwan is also classified from this perspective. Subject courses are mainly established by various departments, core courses

DOI: 10.6232/JTEE.202012_50(1/2).0003

are based on general education centers and assistance for experience courses may come from academic affairs or internship units. This curriculum system forms a single vertical connection among the teacher, course and student.

Based on the nature of CIE, the establishment of the CIE program must be based on specific disciplines and possess talents that can engage in cross-disciplinary dialogue. However, for rural areas and some schools with small staffs, there exists the question of how to timely and effectively apply diversified and innovative teaching with knowledge, applicability and fun, as well as to encourage the integration of courses and essential concepts/practices of the CIE innovations into specific disciplines. In particular, entrepreneurship is mainly embodied in the realm of industry. Therefore, teaching in colleges and universities needs to focus on the integration of specific disciplines and innovation/entrepreneurship education (Chen, L., 2019). In addition to similar integrated teaching at American schools of higher education, the integration of entrepreneurship education and specific-discipline education in higher education, Z. Huang and Z. Wang (2013) specifically analyzed the three fusion modes of entrepreneurship education and specific-discipline education in the United States: the magnet model, radiation model and hybrid model. The magnet model refers to the concentration of entrepreneurial education in a few departments or the type of courses in the college. The radiation model disperses entrepreneurial education in individual departments or colleges and then manages it through the administrative department or center. The hybrid model combines the magnet model and the radiation model. In addition, some schools adopt staged and layered teaching in entrepreneurship education. However, the above are only distinctions among implementation modes. Other key elements that affect integration include financial support, infrastructure, professional teaching staff, teaching concepts/methods, curriculum development/implementation, entrepreneurial practice and alumni support (Huang, Z. & Wang, Z., 2013).

3. Setup and structure of the CIE program

The number of teachers at the technical school in eastern Taiwan that is the subject of this study is about 60 to 70, and there are six departments for the two-year and five-year programs. Before the establishment of the CIE course, the traditional teaching mode was adopted. Below is an analysis of that mode (Table 1).

DOI: 10.6232/JTEE.202012_50(1/2).0003

Table 1.
SWOT analysis of pre-CIE program school and region

Internal Analysis	
Strengths (S)	**Weaknesses (W)**
1. It is a technical college (which began as an agricutlural school) with many practical vocational courses, and all courses could be closely connected with local industries. 2. The faculty had deep practical experience in industries, and the promotion of industry-academia, technology transfer and training had achieved results. 3. Alumni have developed well in many places, and the industry has a high degree of connection and recognition, which is in line with the birthplace of new ventures. 4. There were various skill-verification venues, and teachers had skill-verification licenses and counseling experience, thus being able to help students obtain licenses.	1. Due to the remoteness of the school and the prominence of agriculture in the region, further education for teachers was restricted, and there was a weak connection between teachers and available resources, thus affecting teaching themes. 2. There were only six departments at the school. Most teachers taught in multiple disciplines and concurrently served as administrators. They were thus basically incapable of offering additional courses or inquiring beyond their specialties. 3. The students came from various cultures, and their technical competence and confidence needed to be enhanced.
External Analysis	
Opportunities (O）	**Threats (T）**
1. In line with the county government's policies, tourism and local industries are in urgent need of transformation and upgrading. The government interacts well with local industries, which is beneficial for arranging cooperative endeavors. 2. Many areas are natively inhabited by indigenous people, which will help the development of multicultural industries. 3. Local small and medium-sized enterprises develop talent needs, and the cultivation goals of various disciplines meet the needs of local industries and mid-level technical manpower. 4. Regarding local technical talent industry needs, vocational training is in line with filling the local manpower shortage.	1. Being remote, transportation obstacles affect industry development willingness. 2. The scale of industrial and commercial industries in the region is small and less-developed than in western Taiwan. Also, cooperating businesses tend to be relatively traditional industries. 3. Local multicultural communication and establishment methods are different and thus require effective communication. 4. The business industry is not booming, and it is not easy to get sponsorship or support funds from enterprises here compared with metropolitan areas.

The CIE program was the solution proposed by the authors based on the above relationships of strengths-threats (ST), weaknesses-opportunities (WO), weaknesses-threats (WT) and strengths-opportunities (SO). After the implementation and enhancement of the phased experience learning cycle, the weaknesses (W) and threats (T) gradually grew toward becoming strengths (S) and opportunities (O). After the CIE program was incorporated into the original curriculum system in a mixed mode, the school curriculum dynamics changed (see Figure 2). In addition, the establishment of the academic program used the perspective of learning in a more timely manner to incorporate the expansion process of the innovation system (see Figure 1), thereby completing the establishment of the learning core of the school organization in innovation and entrepreneurship. The innovative

DOI: 10.6232/JTEE.202012_50(1/2).0003

products produced by students in the program have provided students with the opportunity for entrepreneurship and off-campus technology transfer projects through the Research and Development Office and incubation center. Moreover, it can be seen from the above literature review that the establishment of the CIE program not only aims to produce technological innovation results but also uses the organizational innovation of the curriculum system innovation through the mutual supplementation of technology-based and non-technology-based innovations. This in turn has allowed for greater overall innovation at the school.

In order to use the resources at the school more flexibly, the authors adopted a mixed mode of integration. That is, each subject offers specific-discipline courses that comply with the concept of the CIE courses. Concepts can be taught in stages. The General Education Center is responsible for the development of core CIE courses, and assistance for the experience courses comes from the academic affairs office and internship tutoring units. As for the students, in addition to the necessary core courses, as long as regulations are complied with, they can take courses in other disciplines based on their personal interests.

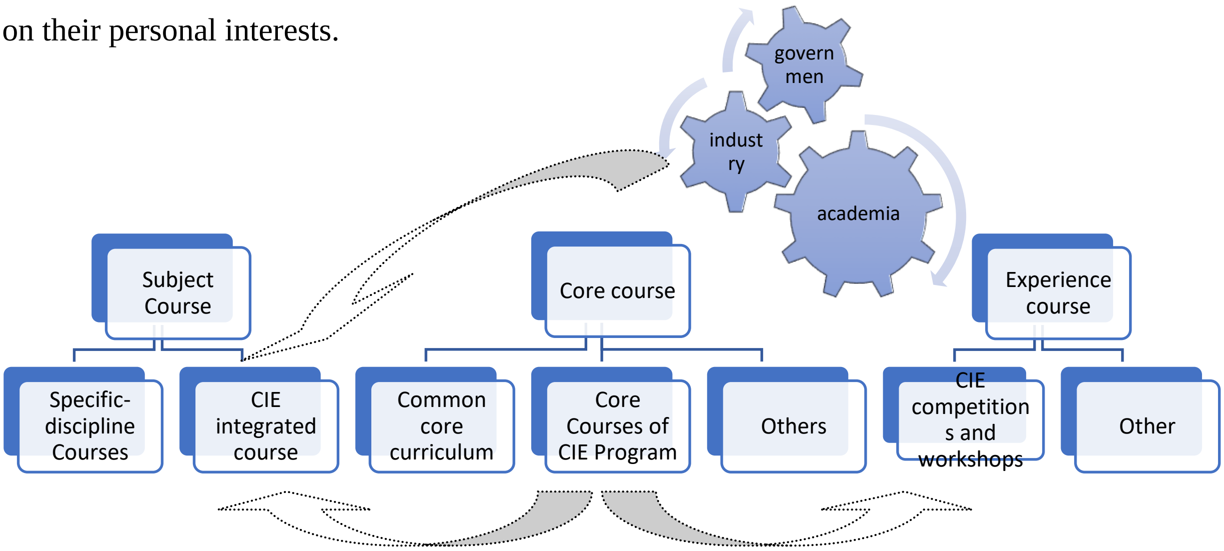


Figure 2. Structural relationship between school curriculum and CIE program

Since the curriculum system structure sees the addition of many horizontal links once the CIE program is in place (see Figure 2), it also indirectly promotes cross-disciplinary dialogue among the various subjects at the school. In order to provide CIE education more appropriately, we have also formed CIE support for the six dimensions of teachers, courses, grants, resources, localities and enterprises. We also cultivated and trained seed teachers, created CIE characteristic courses, established reward/subsidy measures, held CIE research activities, enriched CIE education resources and promoted CIE competition activities. We further enabled the school to face the impact of the (WT) with greater stability, as shown in Figure 2. The triple helix structure of university-industry-government relations (Etzkowitz, H. & Leydesdorff, L., 1995) is a collaboration between schools of

DOI: 10.6232/JTEE.202012_50(1/2).0003

higher education through cooperation with external government departments and the industry. It is not only a response to UNESCO's (1998) questions about strengthening and the world of work. The project operation, which cooperates with and responds to social needs through cooperation outside the school, also promotes the school's organizational innovation and technological innovation. When the school in this study established the CIE curriculum in 2015, the authors considered developing (SO) and allowing (W) and (T) to gradually transform into (S) and (O) (see Table 1). In the aspect of the short-term development strategy of industry-academia cooperation, the authors held to the school’s agricultural foundation, developing in the area of agricultural-related industry with a focus on the feature of native crops. We also promoted agrotourism and conducted related packaging design to help develop the local features and boost the local economy. In addition to adding related thematic design to the CIE curriculum to create more creative agriculture products, we also look to guide related industry R&D and technology innovation.

4. Examples of integrated "Creative Thinking and Practice (CTP)" courses

As seen in Table 2, in addition to offering courses that integrate the concept of CIE into undergraduate majors in each subject, the core subjects also adopt a curriculum design model that integrates various disciplines. This was launched within the "Creative Thinking and Practice (CTP)" in the General Studies Center. As a case to illustrate, this course is mainly taught to students in the CIE program. Fourth- and fifth-year students in the five-year program and two-year program students from different disciplines learn together in mixed classes. Students from different disciplines, such as from the engineering, agriculture and management departments, are encouraged to work together in groups. Student-centered learning in which students must solve problems is adopted to stimulate thinking and creativity in different fields.

The CTP course content covers the important concepts of creative thinking, creativity training, patent and intellectual property management, innovative product development and commercialization. Through multiple teaching methods, such as lectures, demonstration, hands-on instruction and group competitions, students are taught to understand and learn by discovering problems, finding solutions, generating creative ideas and designing new product development procedures while learning about intellectual property rights protection concepts and knowledge systems. In order to establish a holistic concept of innovative product development, based on the academia-industry-government cooperation concept and the students’ interests and areas of expertise, we planned out creative hands-on product-making activities. For example, during the 2019 academic year, the "Aromatic Essential Oil Mousse Creation" and "Dragon Boat Festival Wormwood Creative

DOI: 10.6232/JTEE.202012_50(1/2).0003

Product Packaging Experience" creative handiwork events were held, which the students collectively were highly satisfied with. The average score on the satisfaction surveys completed by the students (on a scale of 1 to 5 points) was 4.7 or more in the areas of planning, event administration and service. The relevant course unit modules are shown in Figure 3:

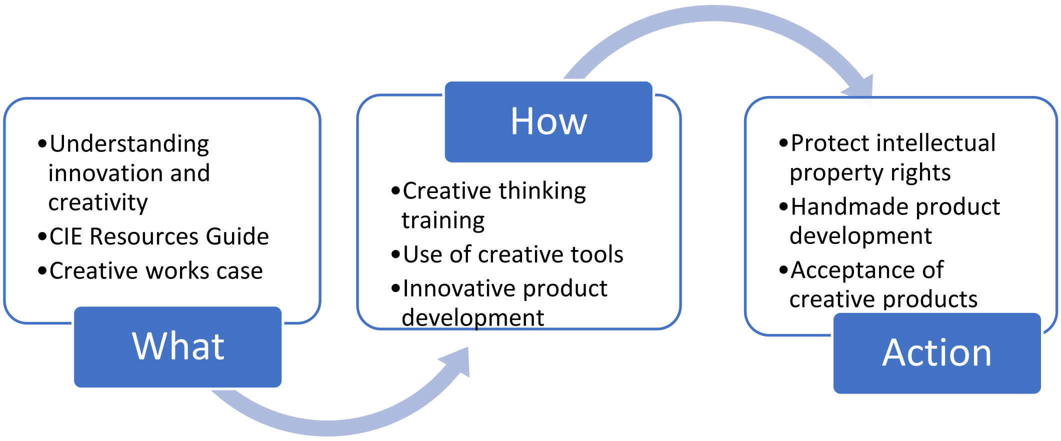


Figure 3. Creative thinking and practice course unit module

Due to the needs of the curriculum, the teachers of the CIE core curriculum focus on the introduction of practical new product cases and then guide the students to discuss the economic value of commodities and develop integrated or related products. The students adopt a fusion grouping approach, so there are plenty of opportunities for discussion. They can stimulate creativity through discussions with each other and learn to understand the ideas and thinking methods of others through effective listening, communication, dialogue and reflective feedback. This allows them to support and cooperate with each other and make new creations of their own. Such method can be said to be a literacy-oriented method established through expression and practical operation. Therefore, students who take this course can gain an understanding of not only the significance of CIE education but also the diversity in product development and the skills required for product development. There are many opportunities to create new products through the training from the course. The students boost their problem-solving and thinking-learning abilities, expand their undergraduate skills and further cross-disciplinary learning and connection.

Students are encouraged to submit the excellent works they have produced during the course to relevant competitions at home and abroad. For example, in 2015 a Solar Water-condensation Device was made. After fusion and organization, it was created through cross-disciplinary discussions that stimulated creativity. The device uses solar energy to condense moisture in the air to make water. It uses a combination of solar power cells and a heat exchanger. The moisture in the air is condensed and collected in a water storage tank for use as an emergency or auxiliary water supply source during a disaster or water shortage. The power required by the fan, refrigeration chip module and submersible

DOI: 10.6232/JTEE.202012_50(1/2).0003

motor in the heat exchanger is supplied by the solar cells. The refrigeration chip is attached to the heat exchanger. The air is brought by the fan through the filter, enters the heat exchanger and is then cooled by the refrigeration chip so that the temperature of the moisture in the air drops below the dew point and condenses into droplets. The water collects in the storage tank for later use. The system design is shown in Figure 4.

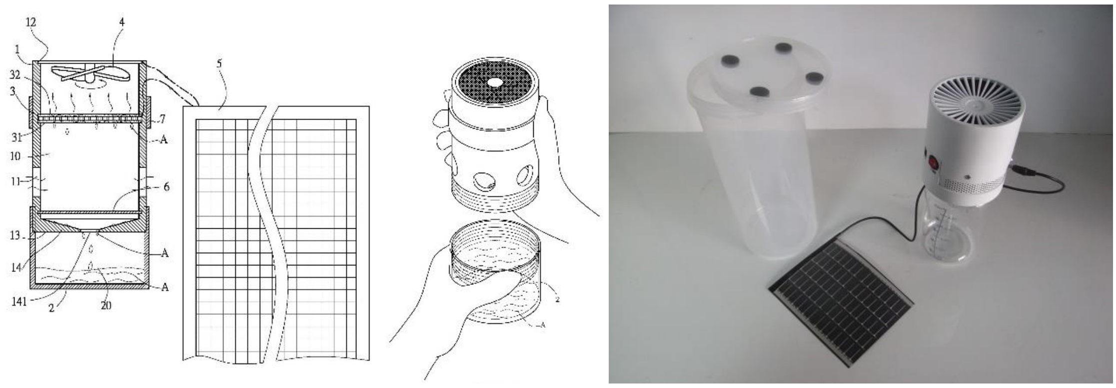


Figure 4. Solar Water-condensation Device

、This product is an effective tool for irrigation in places that lack water, which is obviously helpful in agriculture. A patent application was submitted for this product. It can be used as a foundation for students to take a further step toward starting a business via a patented product. It can also provide relevant technology transfer for commercial use in the industry and academia. This project was the first entry from the school at the ITEX International Invention Exhibition in Malaysia (in 2015). It won a gold medal, and another product made by students and teachers at the school, an Ultrasonic Cleaning Apparatus, also won a gold medal at that same competition.

The students filled out CTP course surveys (responding to questions on a scale of 1 to 5), 28 of which were valid and analyzed to produce the results in Table 2. According to the results, the students' level of cognition for each instructional unit was between 2.75 and 3.54 before the course, and it increased to 4.14 to 4.54 afterward, showing that their cognition of innovation, creativity and creativity-related curriculum units improved significantly.

DOI: 10.6232/JTEE.202012_50(1/2).0003

Table 2.
Scores on degree of cognition for each unit of instruction

Unit	Before instruction	After instruction
Cognition of innovation and creativity	2.93±0.77	4.29±0.53
Creative thinking training	2.54±1.29	4.50±0.51
Guided reading and use of books from the CIE curriculum	2.64±0.99	4.14±0.80
Concepts on innovation and product development	2.82±1.06	4.36±0.56
Creative product examples and hands-on experience	3.04±0.96	4.36±0.56
Product development and intellectual property rights protection concepts	2.75±1.00	4.39±0.57
Product design competitions and evaluation process	3.04±0.92	4.18±0.77
Use of online instruction platform and uploading results	3.54±0.88	4.54±0.64

5. Discussion and conclusion

Since the launch of the CIE program in 2015, the school has allowed students to boost their CIE skills and expand their disciplinary scope. Below, based on the awards students have won for their creations, we discuss how the CIE curriculum has achieved the cross-disciplinary development of innovative products to allow students to boost their workplace competitiveness. Then, based on the promotion of the teachers' academic exchanges and industry-academia cooperation development, we discuss how the curriculum promoted the establishment of an industry-academia cooperation system to effectively link learning to the community. Finally, we discuss how the instructional innovation and activation of the school environment after the establishment of the curriculum positively influenced the school organization culture.

5.1 Awards

Since the implementation of the CIE program, teachers and students worked together to develop new products, such as the Solar Water-condensation Device mentioned above. They participated in the Malaysia ITEX International Invention Exhibition for the first time in 2015, winning two gold medals. According to statistics from 2015 to 2017, during the early stages of the CIE program, more than 30 students from the school entered projects at the international competitions of the iENA in Nuremberg, Germany, the Taipei International Invention Show & Technomart and the ITEX in Malaysia, winning more than 10 gold, silver and bronze medals. The school's students gained unparalleled confidence and a sense of accomplishment from this. Domestic competitions they have entered outstanding works in include the 6th TBSA National College Innovation Planning

DOI: 10.6232/JTEE.202012_50(1/2).0003

Competition in 2016, the Local Potential Industry Entrepreneurship and Brand Marketing Competition, the Craft x Design IN Taitung "Bonfire and Starry Sky" Cultural and Creative Design Competition, the 2015 Kolin "Discover and Enjoy the Beauty of Taiwan with Heart" Competition, the 2015 Environmental Issue Art Creation Competition, the 2015 Taitung Art Exhibition and the 2015 National LED Creative Design Competition. As for entrepreneurial competitions, the school won five awards from the 2015-2016 "Dream Power" Student Entrepreneurship event. In addition, with the promotion of the school's CIE program and teachers' active guidance, students were awarded for the 2014 Solar Emergency Auxiliary Water Supply System and the 2017 Design of New Water-absorbing Ceramic Flower Products, which were developed under the auspices of the Ministry of Science and Technology College Student Research Project. In addition, teachers and students co-created the patented Ultrasonic Vibration Water Purifier and also received a grant from the Ministry of Science and Technology to encourage the carrying out of a practical research project in 2020. It can thus be seen that, in addition to specific new achievements after the establishment of the CIE program, more students have been able to win awards or obtain specific-discipline research opportunities through their works. The curriculum allowed students the experience of developing patented products and winning awards, which will help them in their future careers to develop and market products, and they may even use the products they have developed to start their own businesses.

5.2 Promotion of the development of teachers' academic exchanges and industry-academia cooperation

Due to geographical location and transportation, the commercial and regional development in eastern Taiwan has fallen behind that of the west. Rural technical schools hope that through social innovation action, that is, through the innovative application of technology and business models, all groups in society can be changed. Through such changes, they hope to find innovative ways to solve social problems (Executive Yuan, 2018a) and gradually reach the United Nations' 17 SDGs (such as eliminating poverty, gender equality, responsible production and consumption, elimination of inequality and high-quality education) and related visions of the sustainable development of indigenous culture (Executive Yuan, 2018b) in order to deal with the WT in Table 1. In terms of implementation, schools can promote community and regional school resource links, cultivate talent in the community or at school with innovative thinking and practice or promote social innovation cultivation and experimental fields with local entity platforms (Executive Yuan, 2018a). Looking at the establishment of the CIE program from this perspective, it can be seen that the program not only allows many innovative and creative inventions to be made but also promotes considerable

DOI: 10.6232/JTEE.202012_50(1/2).0003

advancement in the development of industry and academia. It is also in line with the community industry and academia. From the establishment of strategic alliances, a creative and educational model has been gradually produced.

In 2015, teachers and students developed the Complex Orange Fermentation Liquid and Orange-based Environmental Cleaning Liquid through an industry-academia cooperation project in 2015. These products have been made available for sale at township farmers' associations. In addition, they were awarded trophies for "Assisting the Farmer's Association in the Development of Local Agricultural Specialty Products-Orange-based Enzyme Liquid and Environmentally Friendly Natural Cleansing Essence" on Farmer's Day by a township farmers’ association. In 2016, they won the county farmers’ association’s "Sweet Orange Yeast Liquid Technology Transfer Authorization Contract Transfer Agreement" to continue to assist farmers in developing more economically valuable products, increase farmers’ income, solve the problem of slow sales of special local agricultural products and boost the local economy. Also through the research and development of product sales, farmers' income was boosted. There are also cases in which the development of other special agricultural products in the region has promoted economic benefits. In 2017, teachers from the school were commissioned to develop innovative red quinoa products, and they came up with the Red Quinoa Healthy Drink. In 2018, they obtained a manufacturer’s technology transfer contract for this product. The study cooperation program provides students with many opportunities to participate in off-campus internships. Students participate in design, production and post-processing, witness the development of various processes and become more familiar with local enterprises. From 2017 to 2019, teachers and students co-created three patented inventions and six utility-patent inventions. The effects and success of the CIE program since its establishment are thus apparent.

As a result, in 2017, the school was awarded a place in the University Social Responsibility Practice (USR) Program of the Ministry of Education-Industry Value Added and Local Practice Educational Experimental Program, using industry-practice two-dimensional learning combined with campus environmental innovation, teaching innovation, social participation of tribal villages and communities and regional integration of local teaching resources to build a learning circle with a ripple effect in the field from the inside out and from the small to the large. With the support of the plan, through the connection and reconstruction of technical and vocational education at technical schools and regional industries, the school worked with the community in innovating and recreating value in indigenous villages and communities and further promoted innovative business strategies and the development of special industries in the city. In the aspect of academia-industry-government cooperation, as the number of innovative inventions grows, dialogue and exchanges between the school and other academic organizations and between the school and the industry have increased.

DOI: 10.6232/JTEE.202012_50(1/2).0003

Besides more and more cooperation with the community, the school has also formulated a new agriculture development strategy alliance development plan based on the Global Research and Industry Alliance—New Agriculture Program (Shieu, F., 2019).

5.3 Instructional innovation and activation of the environment

Due to the establishment of the CIE program, the school has made many breakthroughs in supporting the CIE approach, indirectly promoting teachers' exchanges and interactions via production, education and teaching innovation. Teachers have gained many more opportunities to be involved in more interactive activities based on common goals. In terms of teaching, CIE teachers need to strengthen social connections, and there is a high demand for professional teachers. When the school interacts frequently with the outside world, relevant teachers especially need the joint support of teachers with considerable expertise from all walks of life, government and academia. At present, besides part-time teachers in the field, most of the collaborative teaching methods involve introducing course resource support from local sources. In order to improve teaching quality, the school also organizes training seed teachers to encourage teachers to look beyond traditional concepts and try to innovate, such as through flipped teaching methods, different forms of integration of the curriculum structure, the design of multiple core competence courses, etc. It has also established a cross-discipline innovation reward mechanism and developed cross-discipline courses. At present, various fields have proposals for teaching innovation. For example, life science courses plan to include such classes as "The Taste of Life," "Life Character," and "Ecological (Environmental) Quality." English instruction is based on a focus on the local culture and taking action, and informal curriculum activities, such as "Daily English, Talks from the Masters & Green Creativity" are organized. In addition, the technology of the multi-functional classroom is used to its full extent to develop digital teaching materials and innovative teaching methods.

Furthermore, since teachers are eager to hone their abilities with the gradual increase in the momentum of the CIE, and due to the joint preparation of lessons and the mutual observation learning model of teacher community activities, an inter-school teacher community has gradually developed over the years, allowing them to discuss industry-academia cooperation, academic research exchanges and innovative teaching. This has provided more opportunities for the school to communicate with the academic and teacher communities at other schools, thereby enhancing R&D capacity and expanding educational influence by such means as participating in regional teaching resource centers, sharing research/teaching resources and exchanges with/visits to other schools. This has gradually turned into part of the normal operation of the teacher community. The school also

DOI: 10.6232/JTEE.202012_50(1/2).0003

encourages teachers to study, participate in academic seminars and publish research papers to promote research and development so that more achievements can be made and promoted.

In addition, the school’s learning atmosphere can be seen in detail due to the appropriate improvement of learning goals and environmental equipment. By developing the CIE program, related books and digital learning resources have increased, and there is now a CIE learning and display area. Faced with the needs of innovative technology, teachers of various subjects are more actively seeking funding to update teaching and research equipment, and research momentum is gradually making breakthroughs. In addition, the learning atmosphere also is now different due to the school's promotion of CIE competitions. The power of students' creativity and ability to think on their own is now integrated holistically with life goals and vitality through the cohesion provided by activities. For example, each unit of the school is based on creative thinking. With many dynamic and static display activities of artistic and cultural creativity, the school's learning atmosphere has been activated, in turn promoting the school's innovative characteristics, which has even extended to the community.

6. Discussion and conclusion

This study discusses how a school in rural eastern Taiwan has used education to aid in the process of changing the local industry. By means of embedding a cross-disciplinary, credited CIE program into the school curriculum, the school has successfully guided students in learning about innovation, creativity, and entrepreneurship, achieving the three goals of 1) boosting the students’ foundational CIE skills and expanding the disciplinary scope of each student, 2) promoting the cross-disciplinary development of innovative products to allow students to boost their workplace competitiveness, and 3) promoting the establishment of an industry-academia cooperation system to effectively link learning to the community. In addition, due to the use of a method that has an innovative foundational organizational structure, the strategy effectively activated the atmosphere at the school to make it more innovation-oriented, bringing about development in the area of the school’s unique characteristics and creating a positive influence on the community’s industry and culture. This innovative method allowed the school to achieve organizational innovation, serving as a good example of a school that exhibits care for the community and aids in local industrial development. It is also a great example of organizational reform in guidance-based education.

As described by the process of system innovation diffusion of Geels and Raven (2006), system innovation can be regarded as a process of niche accumulation. Through the strategy of situation analysis and the method of organizational innovation, a junior college in rural Taiwan embedded a

DOI: 10.6232/JTEE.202012_50(1/2).0003

CIE program into its courses, not only establishing a CIE curriculum but also allowing for more possibilities in the curriculum dynamic. As stated above, students have not only enhanced their knowledge of innovation, creativity and entrepreneurship but also had their confidence and employment competitiveness boosted through competitions inside and outside the school. Also, the curriculum has allowed them more opportunities to join international competitions, themed projects and research programs for college students. The system innovation has driven organizational innovation. It provides positive feedback for students' learning and promotes the development of teachers' academic exchanges and industry-academia cooperation. For example, industry-academia cooperation with companies in the community has specifically yielded the development of such products as the Complex Orange Fermentation Liquid, the Orange-based Environmental Cleaning Liquid, and the Red Quinoa Healthy Drink, pushing innovation vitality between industry and academia and helping the local economy through technological innovation and creative products. Because of this industry-academia development, exchanges between the school and other academic organizations and companies have become more frequent. Also, the school has formulated a strategy alliance development plan. Furthermore, the creative thinking of the CIE program has pushed teaching innovation and the activation of the campus environment. Aside from using more innovation in their instruction, teachers are making more outstanding achievements in the area of R&D in related industrial technology.

For education, not only does industry need innovation, but school organization does too, especially because growing and learning is a process of continual innovation, and the global learning model is gradually trending towards sustained learning. Innovation in organization, systems and teaching has also become constant, allowing for adaptation to changes and the pursuit of breakthroughs. Growing and learning are not only needed at technical schools; they are required for advancement by people around the world. Any school organization may use innovation in its system, organization or technology to produce more innovative energy in the face of this global variable of learning. The school which is the subject of this study using an embedded CIE program in its curriculum to carry out organizational innovation is a stage in the process of innovation for the system. In the future, programs for the intermediate and advanced stages will be developed. We may not know how the environment will change or how to deal with changes in the economy and life of the future, but this method of learning has allowed us to more firmly believe that anything is possible with the power of innovation and creativity that drives human growth. In this way, we will have the power to face difficulties and forge ahead.

DOI: 10.6232/JTEE.202012_50(1/2).0003

Acknowledgements

This study was supported with subsidies from the Creative Practice Plan of Flip Education in Partial Township of the Ministry of Education's Teaching Practice Research Program (project no. PGE1080275) and from the Development of Automatic Backwashing Ultrasonic Water Purifier Research Program of the Ministry of Science and Technology (grant no. MOST 109-2637-E602-001).

References

Bessant, J., Öberg, C. & Trifilova, A. (2014). Framing problems in radical innovation. Industrial. *Marketing Management*, 43(8).1284-1292.

Chen, L. (2019). An analysis of the countermeasures of law education and innovation and entrepreneurship education in colleges and universities. *Education Research*, 2(1), 5-6.

Drucker, P. F. (2002). *The discipline of innovation. Harvard Business Review*. Retrieved from https://hbr.org/2002/08/the-discipline-of-innovation

Etzkowitz, H. & Leydesdorff, L. (1995). The triple helix -- University-Industry-Government relations: a laboratory for knowledge based economic development. *EASST Review*, 14(1), 14-19.

Executive Yuan (2018a). *Promote social innovation action plan*. Retrieved from https://www.ey.gov.tw/Page/5A8A0CB5B41DA11E/ad3272ab-6b66-4c35-b02d-92c146f9fb23

Executive Yuan (2018b). *Social innovation action plan (2018-2022) (approved version)*. Retrieved from https://si.taiwan.gov.tw/Files/News/47/Social%20Innovation%20Action%20Plan.pdf

Geels, F. & Raven, R. (2006). Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003). *Technology Analysis and Strategic Management*, 18(3-4). 375-392.

Huang, Z. & Wang, Z. (2013). On the integration of entrepreneurial education and professional education in universities. *Educational Research*, 407, 59-67.

Huang, Z. (1991). *Curriculum design*. Taipei: Tung-Hua Books.

Lamers, D., Schut, M., Klerkx, L.& van Asten, P. (2017). Compositional dynamics of multilevel innovation platforms in agricultural research for development. S*cience and Public Policy*, 44(6), 739–752.

Lin, B. & Li, Z. (1970). Curriculum types. In Wang, Yun-Wu (Eds.). *Yun-Wu Social Science Dictionary*. Taipei: The Commercial Press.

DOI: 10.6232/JTEE.202012_50(1/2).0003

Liu, Y., Ji, D., Zhang, L., An, J. & Sun, W. (2021). Rural Financial Development Impacts on Agricultural Technology Innovation: Evidence from China. *International Journal of Environmental Research and Public Health*, 18(3): 1110.

OECD (2015). *System innovation: synthesis report*. Retrieved from http://www.pte.pl/pliki/2/1/OECD%20System.pdf

Schut, M., Klerkx, L., Sartas, M., Lamers, D., Mc Campbell, M., Ogbonna, I., Kaushik, P., Atta-Krah, K. & Leeuwis, C. (2016). Innovation platforms: Experiences with their institutional embedding in agricultural research for development. *Experimental Agriculture*, 52 (4), 537–561.

Shieu, F. (2019). Ministry of Science and Technology report of “Global research and industry alliance projects: Neo-agricultural global research and industry alliance project”. Department of Materials Science and Engineering, National Chung Hsing University. Retrieved from https://www.grb.gov.tw/search/planDetail?id=12483563

Śledzik, K. (2013), Schumpeter’s view on innovation and entrepreneurship. In Štefan Hittmár (Eds.) *Management trends in theory and practice*. Slovak Republic: University of Žilina.

Tsai, H. & Huang, S. (2016). Examining the mediating of technological innovation capability relationship between organizational innovation and firm performance: the moderating effects of innovation policy. *Journal of Technology Management*, 21(1), 1-28.

Tyler, R. W. (1949). *Basic principles of curriculum and instruction*. Chicago: University of Chicago Press.

UNESCO (1998). *World declaration on higher education for the twenty-first century: vision and action*. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000141952

科技與工程教育學刊 2020，50(1/2)，49-62
DOI: 10.6232/JTEE.202012_50(1/2).0004

以混沌系統為基礎之物聯網安全資料流

Secure Data Stream of IoT Based on Chaotic System

吳錫聰 副教授
國立宜蘭大學 電子工程學系

Shyi- Tsong Wu
Associate Professor of National Ilan University

摘要

物聯網目前正蓬勃發展，物聯網資料流的安全性是資安的一個新課題。物聯網資料流的安全運算必須具有快速特性與有具良好的效率，而串流加密器具快速運算的優點，常應用於即時通訊的安全，其亦切合物聯網安全資料流的保密需求。混沌理論的輸出序列與初始值相關，其於密碼學之應用具有保密性、效率高、隨機性佳等優點，近來亦常見應用混沌理論於串流加密器的實現。本研究基於物聯網安全資料流的需求，結合不同低維度混沌理論建構金鑰流產生器的基本元件，以強化系統輸出序列的安全性。透過軟體實現產生輸出金鑰流，接著我們以 FIPS PUB 140-1 與美國國家科技標準局 NIST 的 SP 800 對輸出金鑰流作亂度分析，結果顯示，在 FIPS PUB 140-1 的測試方面，過率為 100%；在 NIST SP800 的測試，金鑰流的通過率至少為 92%。此外，我們進一步將此基於混沌系統的金鑰流產生器實現於物聯網系統，我們以物聯網平台 Raspberry Pi 為基礎，以實現一個以混沌系統為基礎的物聯網安全資料流，實作結果顯示在接收端可以解密得到正確的原始明文。

關鍵詞: 物聯網、安全資料流、混沌映射

DOI: 10.6232/JTEE.202012_50(1/2).0004

Abstract

With the rapid development of IoT, the security of IoT is a new topic of information. The secure data stream of IoT requires the characteristics of operation fast, well efficiency, and that is just the advantage of stream cipher. The stream cipher is used for the security in real time communications, and it matches the requirement of the security of secure data stream of IoT. The outputs of chaotic system are highly related with the initial value, high randomness, and high efficiency. It is able to apply to cryptography. Recently the applications of chaotic theorem have been highlighted to enhance the security of stream cipher. In this paper, we combine 1-dementional chaotic systems with other basic elements of stream cipher and construct a hybrid chaotic stream cipher, to promote the period length, randomness, and the linear complexity of the output. After the implementation of stream cipher by Matlab, the output of the cipher will be examined via FIPS PUB 140-1 as well as NIST SP 800 for the randomness. For the test of FIPS PUB 140-1, all the pass rates of the proposed keystream generator are 100%. For the pass rates of NIST SP800-22, the proposed keystream generators is at least 92%. Besides, the proposed the hybrid chaotic based algorithm will be realized in the IoT platform Raspberry Pi for the security in IoT communication and wireless communication practically. From our implementation, the decrypted data is identical to the transmitted data correctly.

Keywords: IoT, secure data stream, chaos system

科技與工程教育學刊　2020，50(1/2)，49-62
DOI: 10.6232/JTEE.202012_50(1/2).0004

壹、簡介

隨著科技發展與資訊通訊系統的普及，物聯網(Internet of Things，簡稱 IoT)已成為新的網路科技潮流及趨勢。物聯網創造了一個可以讓很多生活物品藉由網路彼此相連結並整合的世界，而這樣的世界將帶給使用者更為「智慧化」的服務。藉由這些快速而即時的資訊傳遞，提供人們通訊上及資訊需求的即時性與便利性。

串流加密器(Stream Cipher)為目前運用於通訊系統中最常見的加密器，其具有高速加密的特性，並且易於實現。在物聯網資料流的安全保護上，串流加密器自然比對稱式區塊加密器(Block Cipher)優越 0。圖 1 簡單描述串流加密器的加解密步驟，一開始加密程序是由虛擬亂數位元產生器(Pseudorandom bit generator)來產生一個較長的二進制序列之金鑰流(Keystream)，接著將明文與金鑰流做互斥或閘(XOR)運算以產生密文(Ciphertext)，反之則為解密步驟 000。

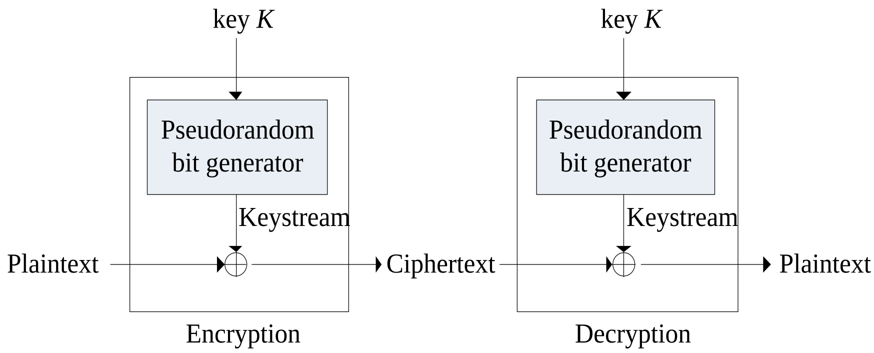


圖 1　串流加密器

近期來講混沌理論(chaotic system)這名詞在這幾年引起眾多學者的注意和研究。著名的學者 E.N. Lorenz 在 1963 年指出混沌系統通常是非線性系統並符合下列幾項特徵，主要有以下特性：非線性、敏感於初始條件、奇異吸引子、系統簡單、回饋和疊代，即為混沌現象 0。英國數學家 Matthews 提出用混沌演算法來對資料加密，在非線性系統科學理論中，混沌理論是一種現代科學結合電腦高速運算的產物，從有限狀態的系統中得到不規律的特性。

混沌理論應用到串流加密的文獻很多，高維度的混沌系統雖較安全，但其具更多的參數，會造成系統過於龐大的運算量 000，低維度的混沌系統其結構簡單，控制參數較少，執行速度快，但安全性較弱易受攻擊。混沌運算的輸出轉為二進制的輸出序列之金鑰流，若每混沌疊代輸出一個位元 0，效率上似乎有待提升。

基於物聯網安全資料流的需求，我們結合低維度混沌理論建構金鑰流產生器的基本元件，採組合方式提高系統輸出序列的週期、線性複雜度與亂度，以強化物聯網資料流的安全。此外，在輸出效率上，我們將每次混沌疊代運算結果產出提高至 64 位元之二進制金鑰流，使

DOI: 10.6232/JTEE.202012_50(1/2).0004

我們所提出的金鑰流產生器更具效率。

本論文第貳段介紹混沌理論的相關知識與原理，接著在第參段，我們提出以一維混沌系統建構的金鑰流產生器，第肆段針對所提之金鑰流產生器作安全分析與亂度測試，我們並說明測試結果，第伍段將所出之提金鑰流產生器在物聯網平台上實現，實際完成串流加密器的加密與解密運作，最後，第陸段是本論文的結論。

貳、相關知識與原理

在國內外研究中，串流加密器和混沌理論的研究不少，以下將針對混沌理論及其在串流加密器的應用，簡略提出說明與探討。

一、 Logistic 映射之混沌演算法

Logistic 映射目前被廣泛應用於混沌加密，其對初始條件有高的靈敏度。定義如下：

$$X_{n+1} = \mu X_n (1 - X_n) \tag{1}$$

式中的 μ 是一個控制參數，X_n 是一個實數且範圍在[1,0]之間，而當 μ 大於 3.56995567 小於 4 時，系統就會進入混沌狀態，Logistic 映射優點是簡單，而且實現容易 0。

二、 Tent 映射之混沌演算法

Tent 映射又稱為帳篷映射 0，是片段線性的一維混沌映射，具有均勻的機率分佈特性。其定義如下所示：

$$X_{n+1} = \begin{cases} uX_n & ,X_n < 0.5 \\ u(1-X_n) & ,X_n \geq 0.5 \end{cases} \tag{2}$$

這裡的 u 範圍介於[0,2]之間，而且因為函數簡單，且對系統造成負擔低，因此用於加密時容易實現，因含有混沌系統的特性，因此具備有相當的安全性。

三、 Sine 映射之混沌演算法

Sine 映射函數亦稱正弦映射函數，由於該函數的值域比較特殊，所以可以將自變數以及值域都控制在[−1,1]的區間之內 0。其定義如下式(3)：

$$X_{n+1} = a\sin(\pi X_n) \tag{3}$$

其中的的 a 介於[0,1]之間，該函數的優點在於它的值域可以輕易控制，且疊代次數與平均計算時間也較短，平均誤差也偏低。

四、 高維度混沌演算法

高維度的混沌系統比一維度混沌具複雜的形式和更多的系統參數，相對的它所需要運算量會較大。Hui-yan Jiang 提出一種以三維 Lorenz 混沌系統為基礎的數位影像加密方法 0，使

DOI: 10.6232/JTEE.202012_50(1/2).0004

用系統生成的序列分析和預先處理方法，這使得金鑰流具有良好的統計特性與安全性，高維度的混沌系統雖較安全，但其具更多的參數，恐會造成系統過大的運算量 0。

五、 複合式混沌系統

單一混沌系統其結構較簡單，系統參數也較少，容易被攻擊。而高維度的混沌系統所需要運算量較大，所以為了解決其各自的缺點，並擷取串流密碼和低維度混沌系統之優點，我們使用使用多個低維度混沌系統和不同的參數來構建一個新的系統，一方面可以增加控制參數數量，但卻不會有高維度的混沌系統所造成的系統負擔 00000。

在另一方面，混沌運算的輸出轉為二進制的輸出序列之金鑰流，在輸出效率上，若每混沌疊代輸出一個位元 0，效率上似乎有待提升。在即時通訊系統上，若無法完成快速的加解密運算，則不能達到即時通訊保密的目的，在物聯網的應用上亦是如此。

我們約略介紹混沌理論中比較主流的幾個系統，也從國內外的文獻中，得知大部分都已經成功實現於數位資訊加密，所以如果要研究一種新的串流加密演算法，不能單單光靠單獨種類的系統，而是朝複合系統發展 00，經由組合方式以複合式混沌系統來提升物聯網資料流之安全性。而在輸出效率上，我們設計每次混沌疊代運算產出更多位元之二進制金鑰流，將使其具更佳的效率，在應用上也會有更多的優勢。

參、混沌系統金鑰流產生器

本段將提出一維複合式混沌系統為基礎的金鑰流產生器，首先我們先介紹其架構，接著是由輸入金鑰產生一維混沌系統之所需之初始值與系統參數，最後介紹輸出金鑰流的產生方法。

一、 一維複合式混沌系統

我們實驗之複合式混沌系統，其基本組成元件為一維的混沌映射，我們的電路使用 XOR 元件來結合不同的混沌映射，以下為我們實現的混沌系統基本架構:

- XOR 結合 Logistic 映射及 Tent 映射
- XOR 結合 Logistic 映射及 Sine 映射
- XOR 結合 Tent 映射及 Sine 映射。

(一) XOR 結合 Logistic 映射及 Tent 映射

在本小節，我們介紹 XOR 結合 Logistic 映射及 Tent 映射，如圖 2 所示，圖中 key1、key2 分別是 128 位元的輸入金鑰，l_n 是 Logistic 映射的輸出序列，t_n 是 Tent 映射的輸出序列。二進制序列之 Q_n 是 l_n 及 t_n 經 XOR 運算產生。

DOI: 10.6232/JTEE.202012_50(1/2).0004

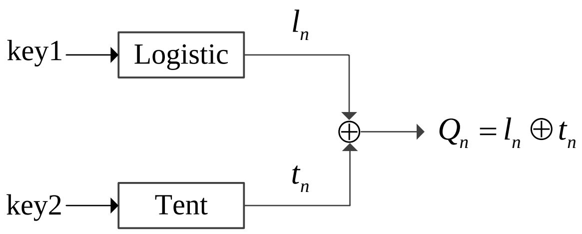


圖 2　XOR 結合 Logistic 映射及 Tent 映射

(二) XOR 結合 Logistic 映射及 Sine 映射

如圖 3 所示 XOR 結合 Logistic 映射及 Sine 映射，在本圖中，l_n 是 Logistic 映射的輸出序列，s_n 是 Sine 映射的輸出序列。二進制序列之 Q_n 是 l_n 及 s_n 經 XOR 運算產生。

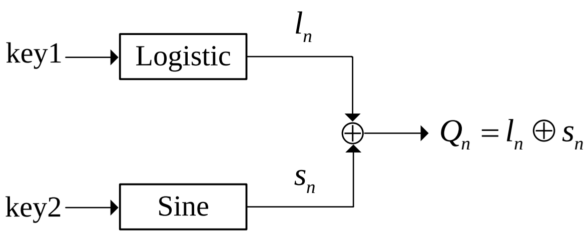


圖 3　XOR 結合 Logistic 映射及 Sine 映射

(三) XOR 結合 Tent 映射及 Sine 映射

Tent 映射及 Sine 映射的結合如圖 4 所示。在圖中，t_n 是 Tent 映射的輸出序列，s_n 是 Sine 映射的輸出序列。二進制序列之 Q_n 是 t_n 及 s_n 經 XOR 運算產生。

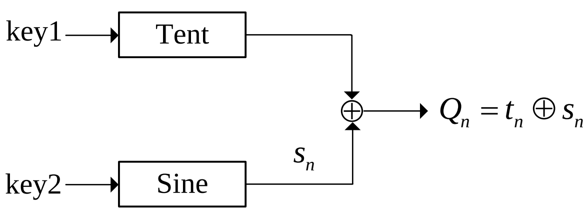


圖 4　XOR 結合 Tent 映射及 Sine 映射

二、 混沌系統之初始值

混沌系統之初始值與系統參數設定由輸入金鑰所決定，首先，混沌系統的輸入為 128-bit 之金鑰，然後將 128-bit 金鑰分成左右兩個 64-bit 之 r_i，作為混沌映射的初始值及系統參數。

由於 Logistic 映射的初始值 X_0 必須在（0,1）之間，所以我們將 r_i 的 64-bit 對應到實數（0, 1）。從 64-bit 資料到實數的轉換方法如下：

$$F_1(r_i) = r_i \,/\, 1.8447 * 10^{19} \tag{4}$$

使用相同的方法，設定 Logistic 映射中 μ 參數，使其對應到 3.569 與 4 之間，其方法如

DOI: 10.6232/JTEE.202012_50(1/2).0004

下：

$$F_2(r_i) = 3.569 + (r_i \ / 1.8447*10^{19})*(4-3.569) \quad (5)$$

同樣的，Sine 映射的初始值 X_0 與參數 a 同方程式(4)與式(5)，Tent 映射的參數μ在 0 和 2 之內，我們透過方程式(6)的 F_3( )，將 r_i 轉換為其初始值：

$$F_3(r_i) = (r_i \ / 1.8447*10^{19})*2 \quad (6)$$

三、 金鑰流輸出

混沌系統的輸出的一個實數，而金鑰流為二進制序列，之間需要實數與二進制的轉換，轉換方法如下:

$$T(X_n) = y_n = X_n * 2^{64} \quad (7)$$

其中，X_n 是混沌系統的實數輸出，y_n 是二進制輸出金鑰流，在此轉換中，將每次的混沌疊代輸出轉為 64 位元的二進制序列。

肆、安全性分析

在本段中，我們將呈現對我們設計之金鑰流產生器所產生的二進制序列所作的亂度統計測試結果。首先，我們忽略輸出序列的前 200 個輸出，原因是避免攻擊者對初始值與系統參數的攻擊，以之提高系統的安全性性。我們採用的測試標準是 FIPS PUB 140-1 與 SP800-22 兩種，以下將對此二測試與結果作進一步的說明。

一、 FIPS PUB 140

FIPS PUB 140-1 基本上有 4 種亂度測試: Monobit test、Poker test、Runs test 與 Long run test 0。針對這些試，我們先任意選 100 個金鑰與 100 個系統參數初值 initial values 來產生 100 個不同的輸出金鑰流，每一個金鑰流有 20,000 個位元，表 1 (a)至(c)分別是是我們所提出的混沌系統的密鑰流產生器輸出的亂度測試結果，從這些表中，顯示針對 FIPS PUB 140-1 的通過率皆為 100%。

表 1 FIPS PUB 140-1 測試結果

(a) 結合 Logistic 映射及 Tent 映射

FIPS PUB 140-1 tests	Pass rate under 20,000 bits/sample
Monobit Test	100%
Poker Test	100%
Runs Test	100%
Long Run Test	100%

(b) 結合 Logistic 映射及 Sine 映射

FIPS PUB 140-1 tests	Pass rate under 20,000 bits/sample
Monobit Test	100%

DOI: 10.6232/JTEE.202012_50(1/2).0004

Poker Test	100%
Runs Test	100%
Long Run Test	100%

(c) 結合 Tent 映射及 Sine 映射

FIPS PUB 140-1 tests	Pass rate under 20,000 bits/sample
Monobit Test	100%
Poker Test	100%
Runs Test	100%
Long Run Test	100%

二、 NIST SP800-22

NIST SP800-22 基本上有 15 種統計測試 0。針對這些測試，我們也是任意選 100 個金鑰與 100 個系統參數初值 initial values 來產生 100 個不同的輸出金鑰流，每一個金鑰流有 20,000 個位元(Bit)。表 2 (a)至(c)則是 NIST SP800-22 對我們所提出的複合式混沌系統之密鑰流產生器輸出的亂度測試結果，從表 2 (a)到(c)中，我們可以發現我們所提出三個不同混沌系統組合之金鑰流產生器的每個亂度測試的通過率至少約為 92%。

表 2 NIST SP800-22 測試結果

(a) 結合 Logistic 映射及 Tent 映射

Statistical tests	*p* value	Pass rate under 10^7 bits/sample
Frequency	0.554774	95 %
Block Frequency	0.562421	96 %
Runs	0.241574	98 %
Longest Runs of Ones	0.632541	99 %
Rank	0.547188	99 %
Discrete Fourier Transform	0.634885	95 %
Non-overlapping Templates Matching	0.514274	97 %
Overlapping Templates Matching	0.542223	97 %
Universal Statistical	0.664214	100 %
Linear Complexity	0.674141	98 %
Seria	0.842154	100 %
Approximate Entropy	0.659858	99 %
Cumulative sums	0.554120	93 %
Random Excursions	0.547114	92 %
Random Excursions variant	0.965841	93 %

(b) 結合 Logistic 映射及 Sine 映射

Statistical tests	*p* value	Pass rate under 10^7 bits/sample
Frequency	0.475125	97 %
Block Frequency	0.354715	97 %
Runs	0.848252	99 %
Longest Runs of Ones	0.752124	97 %
Rank	0.542181	99 %
Discrete Fourier Transform	0.485884	97 %
Non-overlapping Templates Matching	0.745885	98 %
Overlapping Templates Matching	0.475145	97 %
Universal Statistical	0.554854	98 %
Linear Complexity	0.605447	98 %
Seria	0.732014	99 %

DOI: 10.6232/JTEE.202012_50(1/2).0004

Approximate Entropy	0.586220	98 %
Cumulative sums	0.614451	95 %
Random Excursions	0.725150	94 %
Random Excursions variant	0.695478	93 %

(c) 結合 Tent 映射及 Sine 映射

Statistical tests	*p* value	Pass rate under 10^7 bits/sample
Frequency	0.547445	97 %
Block Frequency	0.588545	97 %
Runs	0.614751	98 %
Longest Runs of Ones	0.701421	98 %
Rank	0.410021	98 %
Discrete Fourier Transform	0.554103	96 %
Non-overlapping Templates Matching	0.944745	98 %
Overlapping Templates Matching	0.841221	97 %
Universal Statistical	0.654451	98 %
Linear Complexity	0.741155	98 %
Seria	0.681422	99 %
Approximate Entropy	0.554511	98 %
Cumulative sums	0.515508	96 %
Random Excursions	0.684545	94 %
Random Excursions variant	0.745510	94 %

伍、混沌系統於物聯網之實現

本段中我們將實現物聯網之渾沌密碼的應用。首先我們使用之嵌入式系統是廣為人知的樹莓派，樹莓派同時是一種物聯網平台，它在物聯網中的應用場合是非常多，比如智慧家庭與工業物聯網系統中都有其應用，我們使用其內部提供的 TCP 通訊函式 Socket，完成基於混沌系統之安全物聯網的通訊保密應用。

一、 物聯網發展平台 Raspberry Pi

物聯網的快速崛起帶動相關硬體技術的迅速發展，本實驗我們實做所使用的核心為 Raspberry Pi 3B，它為物聯網之基礎平台之一 0。樹莓派最大的優勢之一在它的軟體方面，其支援的操作系統已經達到幾十種，其函式庫較多，主要開發語言為 Python，並支援各種程式語言，包括 Python、Java、C 等，這為物聯網的軟體開發提供了很大的便利性 0。

如圖 5 所示，為以混沌系統為安全資料流之物聯網系統方塊圖，一開始加密程式是由複合式混沌金鑰流產生器來產生一個長的二進制之序列金鑰流，接著將明文與金鑰流做互斥或閘運算以產生密文，並通過無線網絡進行傳輸數據，反之則為解密步驟。

DOI: 10.6232/JTEE.202012_50(1/2).0004

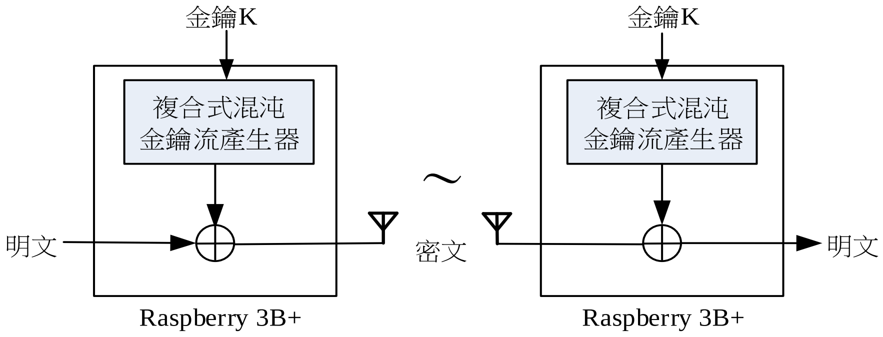


圖 5　以混沌系統為安全資料流之物聯網系統方塊圖

二、 TCP/IP 函式

TCP/IP 為網路傳輸控制協定，socket( )是建立 TCP 通訊的一種函式，它與其他通訊程式的不同是它能實現不同主機間的程式通訊，我們網路上各種各樣的服務大多都是基於 socket 來完成通訊，例如我們每天瀏覽網頁，收發電子郵件等。要解決網路上兩台主機之間的通訊程序問題，首先要標識該程序，在 TCP/IP 網路協議中，主要是依：(1)IP 地址 (2)協議 (3)埠號，來標識通訊程序，用程序標識以建立 TCP/IP 之通訊 0。

TCP 是一種單向連線的傳輸層協議，TCP socket 是基於一種 Client-Server 的程式設計模型。socket 進行通信時，是在伺服器與客戶端之間進行通信，伺服器端監聽客戶端的連線請求，一旦建立連線即可以進行傳輸資料。如圖 6 所示，雙方建立 socket 時都有自己的 IP 位址及埠號，並通過 IP 位址及埠號對應，以保證了送收雙方間的資料傳輸 0。

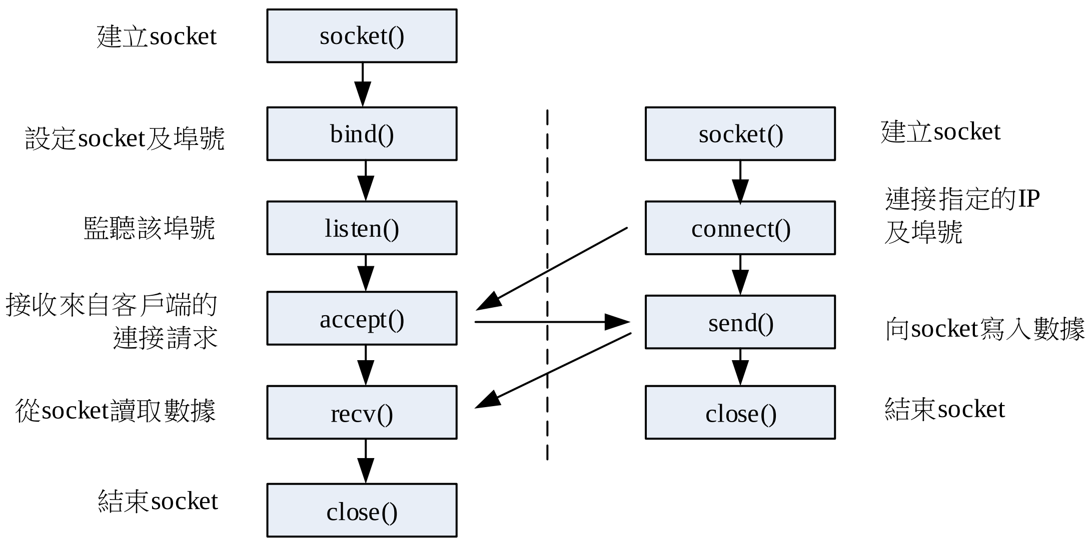


圖 6　送收雙方之 TCP 通訊協定方塊圖

三、 Raspberry Pi 實驗結果

本小節將介紹 Raspberry Pi 的實驗結果。如圖 7 所示為混沌系統初始值及系統參數，左

邊為伺服器端，右邊則是客戶端，本實驗架構以使用 Logistic 映射與 Sine 映射之組合為例。首先介紹 Logistic 映射的部分，key 為我們以隨機產生 128-bit 之金鑰，將 128-bit 金鑰分成左右兩個 64-bit，即 KeyLeft 與 KeyRight，KeyLeft：8d6a8a02547b473f、KeyRight：94b9fe25cd129cf6。KeyLeft 代入方程式(4)得到 Logistic 映射的初始值，KeyRight 代入方程式(5)得到 Logistic 映射的系統參數。在 Sine 映射的部分，金鑰 key 亦為隨機產生之 128-bit，將 128-bit 金鑰分成左右兩個 64-bit ，即 KeyLeft 與 KeyRight，KeyLeft：e065fe2e2b7643b6、KeyRight：82aa1793f4385729。透過方程式(4)即可得到 Sine 映射的初始值及系統參數。伺服器端顯示其 IP 地址:192.168.50.191，接著刪去複合式混沌金鑰流產生器輸出序列的前 200 個，等待客戶端的連接。

伺服器端:

```
Logistic部分
key: 8d6a8a02547b473f94b9fe25cd129cf6
KeyLeft: 8d6a8a02547b473f
KeyRight: 94b9fe25cd129cf6
Logistic映射初始值 : 0.5524069076241008
Logistic映射系統參數 : 3.819395063498118
**********
Sine部分
Key: e065fe2e2b7643b682aa1793f4385729
KeyLeft: e065fe2e2b7643b6
KeyRight: 82aa1793f4385729
Sine映射初始值 : 0.8765562880248234
Sine映射系統參數 : 0.9580963024357582
**********
HOST is 192.168.50.191
1
0x1cb1b631e5f2b000
2
0x43091927d75ea50
 …
199
0x43277db7dd42445f
200
0xbbddd11ef7f58089
Wait for connect
```

客戶端:

```
Logistic部分
key: 8d6a8a02547b473f94b9fe25cd129cf6
KeyLeft: 8d6a8a02547b473f
KeyRight: 94b9fe25cd129cf6
Logistic映射初始值 : 0.5524069076241008
Logistic映射系統參數 : 3.819395063498118
**********
Sine部分
Key: e065fe2e2b7643b682aa1793f4385729
KeyLeft: e065fe2e2b7643b6
KeyRight: 82aa1793f4385729
Sine映射初始值 : 0.8765562880248234
Sine映射系統參數 : 0.9580963024357582
**********
1
0x1cb1b631e5f2b000
2
0x43091927d75ea50
…
199
0x43277db7dd42445f
200
0xbbddd11ef7f58089
```

圖 7　混沌系統之初始值及系統參數設定

雙方經 TCP/IP 連接成功後即可傳輸加密數據，如圖 8 所示。首先雙方儲存 8 個輸出金鑰流，每個金鑰流為 64-bit，且每進行一組傳送、接收後都重新儲存，滿足 8 個未用的金鑰流。由客戶端先進行數據傳送，64-bit 作為一個封包，以“/0”作為結尾符號，之後的填充字元為“0”。每一個封包皆由一組金鑰流進行加密，最後將所有封包一併發送；伺服器端進行接收時，收到的原始數據為密文，會呈現亂碼，計算封包數量後分別進行解碼，解碼完成後將結尾符號“/0”及填充字元“0”捨去，最後顯示出客戶端所傳送之正確數據。

科技與工程教育學刊　　2020，50(1/2)，49-62
DOI: 10.6232/JTEE.202012_50(1/2).0004

圖 8　實驗結果之數據傳輸過程

在物聯網平台樹莓派實現安全資料流的運算效能評估部份，首先我們忽略混沌系的初始化部份，因為此部份可於開機時即完成該運算程序。表 3 分別就我們所提出的混沌架構評估其計算量，而此計算亦正是實現物聯網安全資料流的額外負擔。輸出 64 位元的二進制序需要一次方程式(7)的轉換運算 $T(\,)$，計算量表為 $1T$，兩個混沌序列經一個 XOR 運算得到最後輸出金鑰流，計算量表為 $1XOR$。Logistic 映射一次疊代的計算量為 $2Mul + 1Sub$；Tent 映射一次疊代的計算量，依疊代輸入而定，可分為 $1Mul + 1Sub$ 或 $1Mul$，我們以最差狀況計算為 $1Mul + 1Sub$；Sine 映射一次疊代的運算量為 $2Mul + 1Sin$。由表 3 可發現以平均輸出 64 位元的金鑰流而言，XOR 結合 Logistic 映射及 Tent 映射的混沌架構有較小的計算量，而 XOR 結合 Logistic 映射及 Sine 映射的混沌架構相對有較大之計算量。

表 3
計算量比較

混沌系統	計算量
XOR 結合 Logistic 映射及 Tent 映射	$2T + 1XOR + 3Mul + 2Sub$
XOR 結合 Logistic 映射及 Sine 映射	$2T + 1XOR + 4Mul + 1Sub + 1Sin$
XOR 結合 Tent 映射及 Sine 映射	$2T + 1XOR + 3Mul + 1Sub + 1Sin$

- T：實數對二制 64 位元的轉換運算
- XOR：XOR 運算
- Mul：乘法運算
- Sub：減法運算
- Sin：sine( )函數運算

陸、結論

本文中，我們提出基於混沌系統之通訊加密技術來改良物聯網通訊之安全性，我們的設

DOI: 10.6232/JTEE.202012_50(1/2).0004

計以低維度混沌系統為基礎，並加以整合為複合式混沌系統，我們提出三個組合的之金鑰流產生器，在 FIPS PUB 140-1 的測試方面，實驗結果顯示三個組合的通過率皆為 100%；在 NIST SP800-22 的測試，金鑰流的通過率至少為 92%。

在實作部分，我們也完成了混沌金鑰流產生器在物聯網平台 Raspberry Pi 上的實現，經由所產生之複合式混沌金鑰流與明文作 XOR 運算進行加密，在接收端我們亦使用相同方法解密，實驗結果我們在接收端解密後，可獲得到正確的明文。未來我們的研究方向將朝非線性組合混沌系統方面以創造安全性更佳的金鑰流產生器。

柒、參考資料

賴溪松、韓亮、張真誠（1998）。**近代密碼學及其應用**。松崗電腦圖書資料股份有限公司。

程式前沿。取自 https://codertw.com/程式語言/369901/

玩轉樹莓派。取自 https://kknews.cc/zh-tw/tech/e8ra86q.html

N. W. Abderrahim, F. Z. Benmansour, O. Seddiki (2014, April). A Chaotic Stream Cipher Based on Symbolic Dynamic Description and Synchronization. *Science Business Media Dordrecht*.

M. S. Azzaz, C. Tanougast, S. Sadoudi, A. Dandache (2011). Robust Chaotic Key Stream Generator for Real-Time Images Encryption. *J. Real-Time Image Proc*, DOI 10.1007/ s11554-011-0219-4.

Chen, Li Zhang, Yifang Weng (2010, Dec.). A Data Encryption Algorithm based on Dual Chaotic System. *International Conference on Computer Application and System Modeling*, 431-435.

M. François, T. Grosges, D. Barchiesi, R. Erra (2014, April). A New Image Encryption Scheme Based on a Chaotic Function", *Communications in Nonlinear Science and Numerical Simulation*, *19*(4), 887-895.

HanPing Hu, LingFeng Liu, NaiDa Ding (2013, March). Pseudorandom Sequence Generator Based on the Chen Chaotic System. *Computer Physics Communications, 184*(3), 765–768.

Jaejin Jang, Im Y. Jung, Jong Hyuk Park (2017). An Effective Handing of Secure Data Stream in IoT. *Applied Soft Computing*, *Elsevie*.

Hui-Yan Jiang, Chong Fu (2008). An Image Encryption Scheme Based on Lorenz Chaos System. *Natural Computation of IEEE*, 600-604.

Feng J. Li and X. Yang (2009, Aug.). Discrete Chaotic Based 3D Image Encryption Scheme. *Sympos on Photonics and Optoelectronics*, 1-4.

Jian-Dong, Liu, et al. (2012). Research on Performance of Coupled Tent Map Lattices System. *Fourth International Conference on Multimedia Information Networking and Security*

DOI: 10.6232/JTEE.202012_50(1/2).0004

(*MINES*), 345-348.

E. N. Lorenz (1963). Deterministic Nonperiodic Flow. *J. of Atmos*. Sci., 20, 130-141.

Yongyi Mao, Xiang Chen (2011). An Encryption Algorithm of Chaos Based on Sine Square Mapping. *2011 Fourth International Symposium on Computational Intelligence and Design (ISCID)*, 1,131-134.

Martin Mittelbach, Adolf Finger (2004). Investigation of FCSR-based Pseudorandom Sequence Generators for Stream Ciphers. *Proceedings of the 3rd International Conference on Networking*.

National Institute of Standards and Technology (1994, Jan.). Security Requirements for Cryptographic Modules. *Federal Information Processing Standards Publication* 140-1.

A. Rukhin, J. Soto, J. Nechvatal, M. Smid, E. Barker, S. Leigh, M. Levenson, M. Vangel, D. Banks, A. Heckert, J. Dray and S. Vo (2008, Aug.). Special Publication 800-22 Revision 1: A Statistical Test Suite for Random and Pseudorandom Number Generators for Cryptographic Applications. *National Institute of Standards and Technology*.

Dixiong Yang, Zhenjun Liu, Jilei Zhou (2014, April). Chaos Optimization Algorithms Based on Chaotic Maps with Different Probability Distribution and Search Speed for Global Optimization. *Communications in Nonlinear Science and Numerical Simulation*, 1229-1246.

J.C. Yen, J.I. Guo (2000). A New Chaotic Key Based Design for Image Encryption and Decryption. *Proceedings of the IEEE International Symposium Circuits and Systems*, 4, 49-52.