Constructing Competence Indicators for Makers in Elementary School

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Abstract

Most of the current empirical studies of Maker Education emphasize the enhancement of learners' abilities after undertaking the curriculum, but few studies have been conducted on the overall core concepts of makers. Therefore, this study aims to define the key competences of makers to construct the competence indicators of Maker Education in elementary school. On this basis, a curriculum can be developed, and an evaluation system for learning effectiveness can be built to equip students with the abilities to adapt to life and tackle challenges. In this study, the Fuzzy Delphi Method (FDM) was applied to collect and analyze data in the form of a questionnaire survey. The subjects were 12 experts from enterprises, governmental institutions, schools and research institutes. The achievements include three aspects of competence indicators of makers in elementary school ("Making," "Collaboration" and "Knowledge sharing"), seven factors ("Theoretical knowledge," "Practical application," "Maker's mindset," "Personal participation," "Team interaction," "Way of sharing" and "Motivation of sharing"), and 20 indicators. The competence indicators of Maker in elementary school offer an important basis for developing curriculum which involves key competences of Maker.

Keywords: Maker movement, Maker, DIY

1 Introduction

In past few decades, there were lots of researcher working on computer-based curriculums and approved the feasibility of e-learning at elementary school. Chen et. al. [1] developed the integration of the MOODLE e-learning into elementary school's curriculum. Their statistical analysis approves potentials of students on self-studying and better understanding of the e-course contents. Not only for students but for teachers, Chen et. al. [2] presented that an integration of novel teaching methodology is an innovative opportunity for teachers. The applications and development of e-learning methodology is obviously contributive to the establishment of maker environment, especially for students and teachers at elementary school.

The advent of the digital era and advancements in technology have strengthened the relevance between humans and making, and the maker movement has become a new trend. The popularization of network communities has obscured the barriers in time and space, making "sharing" a part of our daily lives. Meanwhile, the making unit has expanded from individuals to groups. On online platforms and in actual communities, a "co-creation" mechanism has promoted the exchange of expertise and experience, reduced the number of wrong attempts of participants in making, increased the efficiency of production, and attracted a greater number of enthusiasts who do not specialize in the field. In most studies, "making" was applied to programming and STEM (Science, Technology, Engineering and Math); several studies incorporated game design into biology and medicine courses [3-4]. The summary shows that most of these academic papers were positive regarding student learning [5]. The observed progress in learning included the concepts of computer science [6], self-efficacy, interest and motivation [7]. Unfortunately, existing empirical academic papers seldom explore the core concepts of the maker education. This study attempts to construct maker indicators according to the collected academic papers and the suggestions from experts in different areas and to describe the maker role in elementary school education to provide evidence for future curriculum development.

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2 Literature Review and Indicator Construction

2.1 Key Competences of Maker

Dougherty divided a maker's development into three stages: (1) Zero to Maker, in which a person becomes acquainted with the application of tools and enjoys the process of making purely from interest; (2) Maker to Maker, in which a person can share, make connections and cooperate with others in communities; and (3) Maker to Market, in which a person develops services and products and starts a business through public fund-raising or other business models [8]. Mark Hatch [9] proposed the manifesto of the maker movement, which included nine important concepts: "Make," "Share," "Give," "Learn," "Tool up," "Play," "Participate," "Support" and "Change." Moreover, he identified the importance of object construction in the maker movement.

Regarding empirical educational studies of makers, Papavlasopoulou et al. [5] selected 43 representative empirical academic papers using three standards: "rigorousness," "reliability" and "relevance." These researchers observed that the instruction curricula of these studies were implemented in "making" activities, such as the making of computer games [10], the making of wearable devices [11], and the making of sport strength-sensing products [12]. Aside from the above research topics, 37 studies (accounting for 86%) mentioned the importance of collaboration. According to these studies, collaboration was an essential factor that motivated and facilitated learning.

A summary of the above views and activities of the initiators of the maker movement shows that "making" is the most critical activity in the maker movement. The participants must develop the "making" ability and apply it, and the process highlights the correlation with the participants' surroundings. The maker education also focuses on equipping learners with curiosity about creation and the confidence that they can find a solution to a problem through DIY. "Collaboration" is another basic ability in the maker movement, and the human interaction influences learning efficacy. Fields, Vasudevan, and Kafai [13] pointed out that learners would become more deeply involved in collaboration by exchanging ideas and guiding each other. Sharing information with peers will deepen learners' understanding of concepts, but an inappropriate interaction can cause negative consequences. "Knowledge sharing" was seldom mentioned in the empirical studies on makers, but Dougherty and Hatch regarded it as an essential factor in the maker movement. In the definition of maker, Halverson and Sheridan [14] also identified "sharing" as a distinctive feature of makers, saying, "Makers refer to those who create and produce objects in daily life; moreover, they [share] the products and the creation with others in actual or digital forums."

Therefore, this study defined "Making," "Collaboration" and "Knowledge sharing" as the first-layer aspects of maker indicators and made the following operation-based definitions: (1) Making: possess the theoretical knowledge and apply it in reality; have an appropriate maker's mindset to overcome difficulties in the face of challenges. (2) Collaboration: enthusiastically participate in group activities and have positive interactions with peers to fulfill group objectives. (3) Knowledge sharing: be motivated to share knowledge and information and do so in an appropriate way.

2.2 Making

Based on Papert's theory, the maker education in the maker movement focuses on the design, construction, modification and reuse of objects and materials to make a product that can be used, shared and displayed out of interest and usefulness [15]. According to the survey by Papavlasopoulou et al. [5], most technique-oriented studies emphasized "practical application." In particular, 32 of the studies, or 74%, aimed to improve programming design and computational thinking; 6, or 14%, were cognition-oriented and focused on expanding "theoretical knowledge," concentrated on strengthening STEM abilities through art, design and technological making. In addition, several studies paid attention to affection objectives and underlined the development of a "maker's mindset," such as the growth of self-efficacy, interest and motivation [7].

Many countries have added "making" to their curricula. For instance, importance is attached to four learning aspects ("Design," "Make," "Evaluate" and "Technological Knowledge") in all stages of the course of Design and Technology in the UK. In recent years, the US has been advocating an integrated education in STEM. The nation aims to increase accomplishments in science, technology, engineering and mathematics through the making model. Moreover, the US believes that these four competences are a necessary foundation for making. Taiwan adjusted and modified the parts that lacked a making element. According to "The Draft Technology Curriculum in Twelve-Year National Fundamental Education", the basic ideas of the Technology curriculum included students' abilities to "make," "use" technological products, and "think" about designing and evaluating technologies. Learning performance was divided into four types: "Knowledge of technology," "Attitude towards technology," "Operation techniques" and "Ability to integrate."

Regarding the classification of educational objectives, the three scopes defined by Bloom et al. in 1956 are still adopted, namely, "cognitive domain," "psychomotor domain" and "affective Domain." Therefore, this study subdivided "Making" into three factors according to Bloom's classification and defined them according to the empirical studies and curricular policies:

1-1 Theoretical knowledge: the understanding of the knowledge of science, technology, engineering, mathematics and art

1-2 Practical application: the application and practice of theoretical knowledge

1-3 Maker's mindset: the interest in the acquisition of knowledge, the active thinking in the face of problems, and the understanding of technological influence

The above three factors were subdivided into the following 11 indicators:

1-1-1 Knowledge of science: be able to comprehend scientific principles in daily life

1-1-2 Knowledge of technology: be able to comprehend the conceptual and procedural knowledge of technology

1-1-3 Knowledge of engineering: be able to comprehend engineering principles applied in the making of products

1-1-4 Knowledge of art: be able to understand that the principle of beauty must be followed in the product design

1-1-5 Knowledge of mathematics: the mathematical abilities to analyze, count, compute and measure

1-2-1 Design and planning: design targeted, functional and attractive products using design rules

1-2-2 Conversion and application: be skillful in using theoretical knowledge to design and make products

1-2-3 Hands-on movements: be able to operate, use and maintain tools

1-3-1 Learning interest: be passionate about making and become engaged in it

1-3-2 Active thinking: be able to solve problems with a positive attitude

1-3-3 Influence of technology: be active to understand the interaction among technology, individuals and family life

2.3 Collaboration

Collaboration aims to optimize resources and connect organizations to solve the problems that cannot be easily approached by individuals [16]. In education, this concept is described as "cooperative learning." Many empirical studies have found that collaboration has positive effects on the learning of participants. For example, Nejad and Keshavarzi [17] found that if team members trusted and supported each other, students' reading anxiety would be reduced, and their reading comprehension would be improved. With the advancement of communication technologies, the number of online communities has increased yearly. Apart from common discussion, a number of online communities have been equipped with online publication and instruction [18], which has not only surpassed temporal and spatial limitations but has also increased problem-solving efficiency. Nevertheless, most of the online collaboration models for makers are loosely structured. If the communication is not positive, the exchange can become insulting and accusatory, which could have negative impacts on learning [19]. Hence, school education should guide students in how to cooperate with each other to ensure that they can achieve collaboration [20]. Learners should possess the following two abilities in collaboration, which are defined by this study as follows:

2-1 Personal participation: Individuals have faith in the team's interdependence and are active to finish the team's tasks.

2-2 Team interaction: Individuals can give appropriate replies to others to promote collaboration; they review and evaluate the team's operation.

According to the elements of cooperative learning [21], this study subdivided the two factors of collaboration into 5 indicators:

2-1-1 Positive interdependence: show a sense of responsibility for the team performance

2-1-2 Individual accountability: strive to have excellent performance in the team

2-2-1 Interpersonal and small group skills: acquire appropriate interpersonal interaction skills in collaboration

2-2-2 Face-to-face promotive interaction: help peers and give them appropriate feedback at an appropriate time

2-2-3 Group processing: participate in group discussions and evaluate the collaboration development that helps to fulfill the team's objectives

2.4 Knowledge Sharing

"Knowledge sharing" refers to providing others with information concerning tasks and cooperating with others to solve problems, develop new ideas and implement strategies or procedures [22]. Hendriks [23] believed knowledge sharing included two bodies: the knowledge provider and the knowledge re-constructor. The former must convey and externalize implicit knowledge using different methods such as encoding, display and description, while the latter absorb and internalize the received knowledge through decoding, learning-through-practicing and reading. In the process, knowledge sharing is hampered by problems caused by cultural differences, social distances and language barriers. Therefore, those with knowledge must share knowledge using a language that can be understood by knowledge re-constructors. In this respect, knowledge can be divided into two types [24]: (1) explicit knowledge: the knowledge that can be expressed in a written, non-verbal or numerical form; and (2) implicit knowledge: the knowledge that must be expressed through analogy or metaphor. Aside from practice and experience, makers can quickly acquire implicit knowledge through peer discussions and teachers' instruction. Knowledge sharing enables makers to achieve the "making," which is different from traditional "DIY." Knowledge sharing can facilitate "collaboration" and, more importantly, enables a greater number of participants who do not specialize in the field to play a role in it.

In the fields of business management and education, a large number of academic papers have been published regarding knowledge sharing, including the way of sharing and motivations. Daft and Lengel [25] argued that face-to-face knowledge sharing was more abundant than document-based knowledge sharing. According to a survey by Hsu and Chang [24], employees often shared knowledge by "Turning to experts and colleagues for help" or through "Team interaction and meetings" to solve problems because the interpersonal interaction model in reality could effectively convey implicit knowledge. In the maker movement, learners often start with explicit knowledge, such as the search for instructional documents on the Internet. However, in practice, learners still encounter problems with implicit knowledge. In this stage, learners need demonstrations by experts, either through short-distance observation or by receiving guidance from experts. This is the "Maker to Maker" stage, the second stage in the maker behavior model as defined by Dale Dougherty. Experienced makers can help new makers such that the latter can quickly analyze and overcome problems. The main reason why the maker movement is so popular globally is the rise of the online community. Eid and Al-Jabri [26] divided the social network behaviors that might influence knowledge sharing into four types: (1) chatting and discussion, (2) content creation, (3) file sharing, and (4) enjoyment and entertainment. These researchers also found that "chatting and discussion" and "file sharing" had significant effects on knowledge sharing.

Second, the motivation for knowledge sharing will be discussed. The maker movement is often conducted in communities that are not officially organized, which most participants join voluntarily. Therefore, this study ruled out such factors as "reward," "incentive" and "organization norm," which apply more to official organizations, and merely explored personal motivation. Using the arguments of Moghavvemi, Sharabati, Paramanathan, and Rahin [27], this study concluded that the personal motivation of knowledge sharing was based on the following factors: (1) perceived reciprocal benefit: the participants share knowledge and expect to be benefitted from the knowledge shared by other participants; (2) perceived enjoyment: the experience of making includes the fun of participating in social networks, enjoying interpersonal interaction, helping others solve problems, and pursuing knowledge; and (3) perceived reputation: the experience of making involves gaining appreciation from others.

The purpose of knowledge sharing is to convey knowledge in an effective way and help others acquire useful information. "Way of sharing" and "motivation of sharing" are two important factors of successful knowledge sharing defined in this study. Their operational definitions are as follows:

3-1 Way of sharing: knowledge is effectively shared with others in an appropriate way

3-2 Motivation of sharing: the passion for and the commitment to sharing is great

According to the above literature review, the two factors were subdivided into seven indicators:

3-1-1 Discussion and presentation: knowledge is shared verbally

3-1-2 Demonstration and practice: knowledge is shared through demonstration and practice

3-1-3 File sharing: knowledge is shared through files and archives

3-1-4 Social network sharing: knowledge is shared through online communities

3-2-1 Perceived reciprocal benefit: the benefits of sharing can be felt in the sharing and interaction

3-2-2 Perceived enjoyment: fun can be felt in the process of helping others acquire knowledge

3-2-3 Perceived reputation: the intention of sharing becomes stronger because of being appreciated by others in the process of sharing

3 Research Method

In the first stage, a questionnaire survey was conducted in which scholars who led a research plan about "making" education or published papers about "making" education in the past 5 years were selected for the construction of content validity. The questionnaire was scored using the responses "Retain," "Remove" and "Modify." If the experts chose "Retain" or "Modify" for an indicator, the indicator was retained or it was modified according to the experts' suggestions and later retained; if one of the five experts chose "Remove" for an indicator, the indicator would be removed.

In the second stage, the Fuzzy Delphi Method (FDM) was adopted to define the indicators. The subjects of this study were experts from enterprises, governmental institutions, schools and research institutes. The enterprise experts were key figures operating in the maker space, including directors in the maker space and providers of funds and equipment. The experts from governmental institutions were those with permission to make decisions regarding the maker movement. The school experts were frontline teachers or administrators who promoted the maker movement for more than two years in elementary school. The experts from research institutes were researchers who had published papers examining maker education in the past five years. Currently, the FDM can be implemented in different ways. This study adopted the model proposed by Hsu and Yang [28]. First, the questionnaire survey was conducted, in which the language scale and the corresponding fuzzy numbers were used to represent the experts' views. Details about the language scale and the corresponding triangular fuzzy numbers are as follows: "Very important" (0.8, 0.9, 1.0), "Important" (0.6, 0.7, 0.8), "Average" (0.4, 0.5, 0.6), "Unimportant" (0.2, 0.3, 0.4) and "Very unimportant" (0.0, 0.1, 0.2). The specific implementation process and analysis are as follows:

Step 1. Collect all possible competence indicators.

Step 2. Construct the triangular fuzzy numbers of each indicator [29].

$$T_i = (L_i, M_i, U_i)$$
$$L_i = \min(X_{ij})$$
$$M_i = \sqrt[n]{\prod_{j=1}^{n} x_{ij}} \ ,$$

where j refers to the "j" (ordinal number) expert, j=1, 2, 3……., n

$$U_i = \max (X_{ij})$$

If (T) is the fuzzy number of the competence indicator, X_i is the evaluation of the "j" expert, and L_i is the minimum evaluation of the expert, and if M_i equates the geometric mean of the experts' evaluation, then U_i is the maximum of the expert's evaluation.

Step 3. Reduce fuzziness and the simple center of gravity [30]. D_i represents a definite value or the expert consensus value, and the equation is as follows:

$$D_i = (L_i + M_i + U_i) / 3$$

Step 4. Establish the importance threshold "S" of all indicators according to the study's needs and compare the expert consensus value "Di" and the threshold "S." If D_i is higher than "S," the indicator is retained; otherwise, it is removed.

4 Research Results

Three aspects were constructed in the questionnaire survey in the first stage, including "Making," "Collaboration" and "Knowledge sharing," which were subdivided into seven factors and 23 indicators. In the second stage, the experts from enterprises, governmental institutions, schools and research institutes were invited to evaluate the competence indicators. In this study, the threshold of competence indicators was set as "0.6" because "0.6" was the maximum of "Average" and the minimum of "Important" on the language scale [30]. Finally, this study defined 20 competence indicators and removed three indicators. The results of the analysis are shown in Table 1.

Table 1. Competence indicators and results of analysis

Indicators	Min	Geo	Max	Fuzzy number	Di	Results
1-1-1 Knowledge of science	.40	.77	1.00	(.40, 0.77, 1.00)	0.72	select
1-1-2 Knowledge of technology	.40	.74	1.00	(.40, 0.74, 1.00)	0.71	select
1-1-3 Knowledge of engineering	.20	.67	1.00	(.20, 0.67, 1.00)	0.62	select
1-1-4 Knowledge of mathematics	.40	.67	1.00	(.40, 0.67, 1.00)	0.69	select
1-1-5 Knowledge of art	.20	.60	0.80	(.20, 0.60, 0.80)	0.53	reject
1-2-1 Design and planning	.40	.68	1.00	(.40, 0.68, 1.00)	0.69	select
1-2-2 Conversion and application	.40	.67	1.00	(.40, 0.67, 1.00)	0.69	select
1-2-3 Hands-on movements	.40	.79	1.00	(.40, 0.79, 1.00)	0.73	select
1-3-1 Learning interest	.60	.85	1.00	(.60, 0.85, 1.00)	0.82	select
1-3-2 Active thinking	.60	.85	1.00	(.60, 0.85, 1.00)	0.82	select
1-3-3 Technological influence	.40	.70	1.00	(.40, 0.70, 1.00)	0.70	select
2-1-1 Positive interdependence	.60	.81	1.00	(.60, 0.81, 1.00)	0.80	select
2-1-2 Individual accountability	.40	.63	0.80	(.40, 0.63, 0.80)	0.61	select
2-2-1 Interpersonal and small group skills	.60	.85	1.00	(.60, 0.85, 1.00)	0.82	select
2-2-2 Face-to-face promotive interaction	.40	.77	1.00	(.40, 0.77, 1.00)	0.72	select
2-2-3 Group processing	.60	.78	1.00	(.60, 0.78, 1.00)	0.79	select
3-1-1 Discussion and presentation	.40	.76	1.00	(.40, 0.76, 1.00)	0.72	select
3-1-2 Demonstration and practice	.60	.79	1.00	(.60, 0.79, 1.00)	0.80	select
3-1-3 File sharing	.00	.57	1.00	(.00, 0.57, 1.00)	0.52	reject
3-1-4 Social network sharing	.00	.61	1.00	(.00, 0.61, 1.00)	0.54	reject
3-2-1 Perceived reciprocal benefit	.40	.77	1.00	(.40, 0.77, 1.00)	0.72	select
3-2-2 Perceived enjoyment	.60	.78	1.00	(.60, 0.78, 1.00)	0.79	select
3-2-3 Perceived reputation	.40	.70	1.00	(.40, 0.70, 1.00)	0.70	select

The removed indicators were "1-1-5 Knowledge of art," "3-1-3 File sharing," and "3-1-4 Social network sharing." The possible reason why "1-1-5 Knowledge of art" was rejected was that making in the maker movement is objective-oriented and focused on the functionality and purpose of products [12], paying little attention to the knowledge of art. This finding is consistent with the finding of Papavlasopoulou et. al.'s study [5]. Out of the 43 empirical studies, only one included the knowledge of art.

Additionally, on-site making and sharing in the maker movement are key activities, and verbal and practice-based sharing in the on-site domain is more effective in conveying implicit knowledge [24]. Although document- and community-based sharing contribute greatly to the popularization of the maker movement, they are seldom mentioned in practice. The curriculum in elementary school still prioritizes on-site practice; therefore, the experts arrived at the consensus that “3-1-3 Flie sharing” and “3-1-4 Social network sharing” should be removed.

5 Conclusions

The indicators in this study were constructed based on the views of experts from enterprises, governmental institutions, schools and research institutes. In other words, the competence indicators defined in this study referred to the key competences that the experts believed the makers in elementary school must possess. The meaning of these competences includes three aspects—namely, “Making,” “Collaboration” and “Knowledge sharing,”—which were subdivided into seven factors (“Theoretical knowledge,” “Practical application,” “Maker’s mindset,” “Personal participation,” “Team interaction,” “Way of sharing” and “Motivation of sharing”) and 20 competence indicators. Aside from designing and planning the rules for a maker curriculum in elementary school, competence indicators are also the basis for evaluating teaching efficacy. If students have these key competences, they will surely be able to adapt to present and future life. Even if they leave the school, they will be able to use the community’s maker space or participate in society and industry’s maker movements and stay competitive in a challenging environment.

The contribution of this study is the construction of the overall core concepts of competence for makers in elementary school. However, at present, most existing courses merely cover certain indicators. Elementary schools should consider the completeness and integrity of their curricular planning. In integrated courses, the schools should conduct empirical studies on the performance of a semester or an academic year and subsequently move on to the spiral courses that cover different stages.

The indicators shows the characters of on-site practice in elementary school, however, the characters may come from other factors. Learning should be considered an active and dynamic process. As pointed out in Thorndike and Woodworth’s notion, transfer of learning is the dependency of human conduct, learning, or performance on prior experience. The purpose of indicators is to define the key competences of makers. Those indicators can be taken as a reference for students’ initial capacities, which aim to ensure learners be capable of transferring indicators to abilities to adapt to life and tackle challenges.

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