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Application of multi-criteria decision-making in STEAM teaching in design innovation at the university

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Abstract
STEAM education cultivated implementation, invention, and innovation, and advocated the educational principles of "cross-domain, implementation, application, problem-solving, and five-sense learning." In this study, teachers' acceptance and satisfaction with STEAM teaching were explored using the fuzzy analytical hierarchy process by determining the weight of criteria that teachers valued. 80 teachers participated in the questionnaire survey. The collected responses were analyzed using the multi-criteria decision-making and problem-solving method to make reasonable solutions to complex problems of STEAM teaching. The result showed that teachers' acceptance and satisfaction were most important in implementing STEAM education. At the same time, teachers need to improve their professionalism and capabilities in STEAM courses to improve students' design and innovation literacy. In addition, learning needs to be integrated into the curriculum and sufficient time needs to be provided for smooth promotion. When teachers were satisfied with the integrated STEAM education, the students' improvement in design innovation literacy and learning results were observed in this study. Experience and background knowledge affect effectiveness in teaching and learning. Also, "ease of learning and acceptance" and "ease of integration into teaching" were found to be important criteria for teachers to improve professionalism, increase the investment of their resources in teaching, and overcome the difficulties of learning. To enhance the professionalism of teachers, appropriate knowledge and curriculum reform is demanded through the interdisciplinary education of STEAM courses.

Keywords: STEAM, design, innovative literacy, university design

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education has affected the education policies of many countries as a new topic in education reform. STEM education is regarded as essential to respond to the competitive global market. Zizka et al. (2021) stated that STEM education helps to find the most feasible rather than conventional solutions for global problems through interdisciplinary learning. Students with STEM education can learn their social responsibility for sustainable development. The environment, society, and economy are interrelated in STEM education (Ntona & Morgera, 2018). Students need to be trained to be future global leaders as human resources impact the global economy. Therefore, it is important to teach students about the sustainable development of society, which can be achieved through STEM education (Zizka et al., 2021).

In STEM education, students learn the latest knowledge and thinking and problem-solving abilities to meet the needs of society for its development and progress (Badmus & Omosewo, 2020). However, as the US congressional research service stated, STEM education has problems such as the learning divide between different groups of people. In addition, the STEM education system has raised concerns about how to meet the needs of the labor market (Granovskiy, 2018). Such problems demand richer, more diverse, and newer thinking in STEM education. Thus, scholars have proposed various STEM-based education models (White

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Contribution to the literature

- The focus is on the integration and implementation of Science, Technology, Engineering, Art and Mathematics (STEAM), and the calculation process of AHP is applied.
- The contribution of this paper is mainly focused on the art design and application of teaching aids in STEAM education.
- The STEAMH and FAHP questionnaires are combined for the development of art design.

& Delaney, 2021). Sometimes, art (A) and reading (R) are added to form STEAM or STREAM education as a developed form of STEM education. To develop a new teaching model, the connotations, limitations, and challenges of STEM, STEAM, or STREAM education must be understood.

In STEAM education, design innovation is taught as a subject closely related to aesthetics and technological literacy. The related courses of design innovation include 3D printing, digital manufacturing, robot controllers, and intelligent building block production. These courses emphasize innovation with hands-on practice and cooperation with peers. In a STEAM educational model, it is encouraged to generate ideas, solve problems, and think critically to make innovations and decisions for multi-criteria problems.

Teachers must accept various teaching and learning models related to STEAM education for its effective implementation. Therefore, it is essential to determine the ease of learning and integration and the available equipment and administrative support to persuade teachers to accept and use the models. For the related research, we invited professors who practiced STEAM education and have developed a curriculum to create a questionnaire to determine the important factors of STEAM education for relevant decision-making. Teachers participated in the questionnaire survey. We used the analytical hierarchy process (AHP) in which various criteria are considered to construct a decision-making structure and the fuzzy theory that is used to mitigate ambiguity in cognitive problems.

By constructing a fuzzy analytical hierarchy process (FAHP) by combining AHP and fuzzy theory, we proposed the design innovation of teaching in STEAM education and related decisions. The results provide the basis of the curriculum design and educational pedagogy of the subject design innovation.

LITERATURE REVIEW

Subject-based STEM education requires students to memorize course content while ignoring high-level thinking, which cannot be used for knowledge integration and problem-solving. Therefore, it is necessary to learn and practice knowledge in a comprehensive, interdisciplined, and integrated manner (White & Delaney, 2021). Such interdisciplinary STEM education is provided with three models:

(1) integrated stem education framework in a coherent and contextualized manner (Ortiz-Revilla et al., 2021),

(2) area, linear, and discrete models (Gao et al., 2020), and

(3) problem-based learning (Smith et al, 2022).

In multidisciplinary STEM education, clear boundaries between different disciplines exist but common themes are integrated for students to learn concepts and skills of each subject. Therefore, multidisciplinary STEM education is regarded as supplementary and additive learning. In interdisciplinary STEM education, cooperation and interaction between disciplines are important. Through discussion about themes, problems, or awareness, students develop concepts within the scope of the topic, and according to the connotation and nature of the concept, the knowledge of different subjects is organized for exploration by students to understand related concepts. This is an integrative subject of learning. In transdisciplinary STEM education, the understanding and acquisition of knowledge are not affected by subject attributes. The boundaries between disciplines are blurred, and students' connection with actual life is emphasized, which cultivates students' learning interests in exploring phenomena.

In each discipline, learning resources are provided for topic inquiry. Therefore, it is inclusive learning (White & Delaney, 2021). Although the degree of integration varies, the learning models of STEAM education are accepted for teaching knowledge integration. Yakman (2008) proposed the educational concept and model of the STEAM pyramid to explain the integration and interaction between STEM and Art in education. Yakman (2008) classified art into four types: fine arts related to painting, sculpture, color theory, and tangible creative expression; physical arts related to sports, dance, and performance; manual arts related to the specific physical skills or techniques required to manipulate objects; liberal arts involving social sciences such as sociology, philosophy, psychology, theology, history, civics, and political science. The goal of STEAM education is holistic and lifelong education. In STEAM education, teaching students the knowledge of a subject is not the purpose of STEAM education; teaching strategies are rather important to help students understand and embrace changes they may face in life.

By integrating cross-domain knowledge, students can master and apply knowledge in daily life.

For effective STEAM education, teachers' roles are essential as teachers must help students learn through their curiosity by connecting interdisciplinary learning. There are various studies on how the teacher's role and attitude affect the effectiveness of STEM education. Kang (2019) reviewed the literature to understand the relationship between the satisfaction of teachers with STEM teaching. Kang (2019) assessed the teacher's job satisfaction using several satisfaction theories (Herzberg's motivator-hygiene theory, Maslow's needs hierarchy theory, the job characteristics model, and the dispositional approach).

The loyalty of teachers to STEM education was researched to explore factors influencing their decisions to use STEM education, and the importance of support from professional networks was emphasized to maintain STEM teachers in STEM education (Balgopal, 2022). STEM teachers' identities as learners, risk-takers, curriculum designers, and collaborators were determined (Jiang et al., 2021). Teachers' professionalism and self-efficacy were found to be important in STEM education to enhance the STEM literacy of students (Lin et al, 2023; Zhou et al., 2023).

In STEAM education, external beauty, design thinking, grand artistic perspective, visual process, aesthetic literacy, and artistic interpretation are taught with "humanities" subjects such as history, literature, and philosophy. The goal of STEAM education is to cultivate students' ability to strengthen integrated thinking based on interests in life. Therefore, teachers' intervention may be more important in STEAM education than in STEM education. However, there are not enough research results on STEAM teachers' recognition, acceptance, and professionalism development, which demands additional research from the perspective of STEAM education.

RESEARCH METHODS

This study was carried out to explore the impact of individual attitudes, experiences, and professionalism as well as their understanding of student's perspectives in STEAM education. A questionnaire was created in this study and modified through a group discussion by twelve professors who have been teaching education and developed a STEAM curriculum. The questionnaire contained items related to student background, ease of learning and acceptance, ease of integration into teaching, equipment, and administrative support. The questionnaire was distributed to 80 teachers at universities and high schools in Taiwan online and their responses were collected with a return rate of 100%. The responses were analyzed using AHP and fuzzy theory.

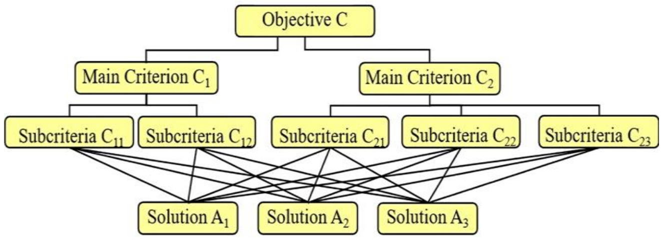

Figure 1. Hierarchical architecture diagram (Zhou et al., 2023)

Questionnaire Survey

AHP

AHP was developed by Saaty (1980) to solve decision-making problems with uncertainty using multiple evaluation criteria. A problem is decomposed into multiple levels based on their correlations. A hierarchical relationship between sub-criteria to obtain solutions (alternatives) for the multi-criteria decision-making problem. The advantages of AHP include easiness of operation, easy capturing of people's opinions, and a quantitative theoretical basis. In AHP, criteria and sub-criteria influence the selection of solutions, and the sub-criteria are influenced by the main criteria in a hierarchical structure, as shown in **Figure 1**.

In AHP, a pairwise comparison matrix is established on an evaluation scale. In this study, five levels of 'not important, slightly important, important, quite important, and extremely important' were employed with a score of 1, 3, 5, 7, and 9, respectively. For the items in the questionnaire asking the unimportance, the reverse scoring method was used: a score of 1, 3, 5, 7, and 9 for "extremely unimportant, quite unimportant, unimportant, slightly unimportant, and not unimportant". After the pairwise comparison matrix was established, the weight of criteria at each level was calculated. We tested the consistency of the questionnaire responses using the consistency index (CI), random consistency index (RI), and consistency ratio (CR). CI was calculated using Eq. (1).

$$CI = (\lambda_{max} - n) / (n - 1), \quad (1)$$

where λ_{max} is the maximum eigenvalue of the matrix.

The smaller the CI, the higher the consistency. RI was defined, as shown in **Table 1**, while CR was defined as CI/RI. If CI was less than 0.1, the pairwise comparison matrix was accepted. After the consistency was confirmed, the opinions of experts (professors) were gathered to hierarchically concatenate alternatives, and the importance of each criterion was calculated.

Fuzzy theory and FAHP

The fuzzy theory was invented to explain ambiguity and uncertain concepts by quantifying them. Semantic variables in language express the degree of perception

Table 1. RI of AHP

Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

rather than convey its numerical values (Pedrycz & Gomide, 1998).

For example, phrases (extremely poor, very poor, very poor, slightly worse, average, slightly better, very good, very good, and excellent) or (average, important, slightly important, very important, and extremely important) express the degree of good or bad. The concept of semantic variables is used to express the subjective judgment of vague information. In FAHP, trapezoidal fuzzy numbers are integrated into expert opinions into a fuzzy positive reciprocal value matrix.

In this study, the fuzzy geometric mean was used to obtain the weight of the criteria. The fuzzy total score of each criterion was calculated through hierarchical concatenation. Finally, the total fuzzy score of each plan was sorted by its priorities. Fuzzy numbers were obtained using the center of gravity method and the fuzzy max-min method. The center of gravity method was used for the defuzzification of a definite value to represent the characteristics using Eq. (2).

$$CA = \frac{\int_{-\infty}^{\infty} x\mu_A(x)dx}{\int_{-\infty}^{\infty} \mu_A(x)dx}, \quad (2)$$

where A is a fuzzy number and $\mu_A(x)$ is its membership function.

The fuzzy max-min method was used to determine the priority of the criteria (Chen & Hwang, 1992). First, the utility value of the fuzzy number was calculated, and then the total utility value of each plan was calculated based on the utility value. Then, the order of the fuzzy numbers of each criterion was determined in fuzzy number sorting using Eq. (3).

$$\mu_{max}(x) = \begin{cases} \frac{x}{T}, 0 \le x \le T \\ 0, otherwise \end{cases}, \quad \mu_{min}(x) = \begin{cases} 1-\frac{x}{T}, 0 \le x \le T \\ 0, otherwise \end{cases}. \quad (3)$$

The utility scores of fuzzy numbers were calculated, as follows:

$$L_i = sup_x min\{\mu_{min}(x), \mu_i(x)\}, \quad R_i = sup_x min\{\mu_{max}(x), \mu_i(x)\}, \quad T_i = \frac{1-L_i+R_i}{2}. \quad (4)$$

To obtain alternatives, fuzzy evaluation was conducted by determining the influencing factor set, the factor weight set, the parameter evaluation set, a single factor evaluation matrix, and fuzzy evaluation. The weight of each factor was calculated using Eq. (5), and the weight set was defined as a fuzzy subset using Eq. (6).

Table 2. Criteria and their weights

No	Criteria	Weight	CR
1	Student background	0.127	0.05
2	Ease of learning and acceptance	0.321	
3	Ease of integration into teaching	0.236	
4	Equipment environment	0.248	
5	Administrative support	0.068	

$$\sum_{i=1}^{n} a_i = 1, a_i \ge 0 \ (i = 1, 2, \dots, a_n). \quad (5)$$

$$A = \frac{a_1}{u_1} + \frac{a_2}{u_2} + \cdots + \frac{a_n}{u_n} = \{a_1, a_2, \cdots, a_n\}. \quad (6)$$

The weight of the criteria was determined using AHP using Eq. (7) and Eq. (8).

$$a_i = \frac{k_i}{\sum_{i=1}^{n} k_i}. \quad (7)$$

$$\sum_{i=1}^{n} k_i = \frac{n^2-n}{2} \times 4 = 2(n^2 - n), \quad (8)$$

where k_i is the total score of each evaluation objective and n is the number of evaluation objectives.

All criteria were assessed using fuzzy evaluation. In this study, single-factor fuzzy evaluation was used to determine the importance of the criteria in the evaluation set. The criteria were evaluated using factors in the factor set and the fuzzy set. For the evaluation, a fuzzy matrix was composed of the membership degree of each single-factor evaluation. Then, a multi-factor evaluation matrix was constructed to evaluate criteria and sub-criteria in each layer, and then conduct a fuzzy synthesis operation.

RESULTS AND DISCUSSIONS

Based on the questionnaire survey results, ease of integration into teaching, equipment environment, and administrative support were determined as criteria in FAHP. Sub-criteria of each criterion were also defined. The weight of the criteria and sub-criteria are shown in **Table 2** and **Table 3**. A pairwise comparison matrix was constructed to calculate the eigenvalue and eigenvector of the weight of the criteria and sub-criteria.

Table 4 presents the weights of the degree of acceptance of STEAM education.

When professors implemented STEAM education, the most important factors were acceptance and satisfaction with STEAM education. It is necessary to integrate cross-field courses to promote STEAM education. The curriculum must be easy to learn and use and easily integrated into teaching. Professors need to promote STEAM courses to improve students' design and innovation literacy by improving their professionality and capabilities. In addition, learning needs to be integrated into the curriculum and sufficient time needs to be provided for smooth promotion.

Table 3. Weights of criteria and sub-criteria of AHP of STEAM education

Criteria	Sub-criteria	Weight	CR
Student background	Student number	0.542	0.01
	Student structure	0.458	
Ease of learning and acceptance	Old student experience	0.34	0.01
	Learning difficulty	0.312	
	Study time	0.113	
	Easy to learn and accept	0.235	
Ease of integration into teaching	Difficulty integrating	0.418	0.02
	Study time	0.12	
	Easy to integrate into teaching changes	0.191	
	Teaching creativity	0.271	
Equipment environment	Number of devices	0.298	0.03
	Well-equipped	0.223	
	Equipment old and new	0.156	
	Teaching atmosphere	0.323	
Administrative support	Willingness to continue	0.229	0.02
	Coursework methods	0.079	
	Curriculum support package	0.298	
	Academic research	0.238	
	Academic cost estimation	0.156	

Student background and equipment problems were not decisive when implementing STEAM education. The number of students and their experience and the quality of equipment were not major issues in STEAM education. Professors were satisfied with the integration of STEAM education into teaching. Teachers were highly satisfied with students' improvement in design innovation literacy and learning results. Students showed excellent learning outcomes in STEAM education courses and improved their design innovation literacy. The effectiveness of STEAM education for senior students was significantly better than that of other students. Experience and background knowledge affected teaching effectiveness and learning. Thus, all the hypotheses were supported by the results of the questionnaire survey.

In teachers' learning and application of STEAM education, "ease of learning and acceptance" (learning time and learning difficulties) and "ease of integration into teaching" (integration difficulties and learning time) were more important criteria. Professors' improvement and professionalism, investment in teaching, and overcoming the difficulties of learning were critical for students. To enhance the professional development of professors, appropriate knowledge and curriculum reform for STEAM education are demanded. Professors and students need to learn how to analyze problems, ask questions, and think critically. STEAM interdisciplinary education courses provide opportunities for such traits. Therefore, education reform is necessary to cultivate students' innovative literacy.

CONCLUSION

Don Norman, founder of the Nielsen Norman Group, believes that design schools are derived from art schools. The cognitive and executive abilities were weak points of students majoring in science and technology and engineering. They knew how to solve problems but did not have enough creativity and innovation capabilities. However, students were weak in suggestions and problem-solving. Thus, STEM needed the intervention of art. Maeda (2013) focused on design innovation and integrated technologies, education, and art. Maeda (2013) proposed to add art (visual, performing, language arts, and design) to STEM to create STEAM. To increase students' interest in learning, knowledge from such disciplines is integrated and connected to real-world problems and solving strategies. Art design has been integrated into cross-field curriculum thinking education, STEAM (Quigley et al., 2017). In traditional STEM education, convergent thinking is important, while in STEAM education, divergent thinking is accentuated. With the integration of the two ways of thinking, students can solve cross-field problems and develop creativity and innovation capabilities. Still, subject-specific teaching methods are mostly used, and the independent subject theory is not yet effectively combined with problem-solving. In designing teaching activities, disciplines in design, creation, innovation, and problem-solving must be interconnected across subjects to help students correspond to real situations. In implementing STEAM education, it is crucial to promote related knowledge and curriculums. University students can learn how to analyze problems, ask questions, and think critically in STEAM education. STEAM courses provide opportunities for changing, inspiring, and cultivating students' innovative literacy and capabilities. In STEAM education, curriculum and improvement of self-design and innovation literacy are important. The methodology and results of this study provide a reference for further studies to explore students' and professors' engagement in STEAM education to improve innovation literacy.

Table 4. Degree of acceptance

Criteria	Extremely important	Quite important	Important	Slightly important	Not important	Defuzzification
Student background	0.286	0.008	0.328	0.101	0.277	0.500
Ease of learning and acceptance	0.274	0.021	0.274	0.158	0.274	0.466
Ease of integration into teaching	0.214	0.145	0.214	0.214	0.214	0.483
Equipment environment	0.228	0.086	0.228	0.228	0.228	0.464
Administrative support	0.239	0.043	0.239	0.239	0.239	0.451

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