A novel hybrid FDM, AHP, TOPSIS approach for successful serious game design and evaluation framework

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Abstract

Meaningful Serious-Game Flow (MSGF) is considered primary for multimedia game design education. In other words, selecting characteristics with MSGF is an issue of multi-criteria decision-making. The purpose of this study tends to develop an evaluation model with Fuzzy Delphi-AHP-TOPSIS for multimedia game design educators selecting and evaluating the design with MSGF characteristics. Fuzzy Delphi Method is utilized for selecting the evaluation criteria with MSGF characteristics, Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is used for analyzing the criteria structure of MSGF and determine the evaluation weight of criteria, and Fuzzy TOPSIS is applied to sequencing the evaluations. A real case is also used for evaluating the selection of MSGF criteria design for three games, and both the practice and evaluation of the case could be explained. The results show that the Attention (C11), Skills (C22), Playfulness (C24) and Personalized (C35) are determined as the four most important criteria in the MSGF selection process by fuzzy AHP. And an evaluation results of case study point out that game 1 has the best score overall (Game 1 > Game 3> Game 2).Finally, proposed MSFG evaluation framework tends to evaluate the effectiveness and the feasibility of the evaluation model and provide design criteria for relevant multimedia game design educators.

Keywords –Game Evaluation, Game Design Education, Fuzzy Multiple Criteria Decision Making (MCDM), Serious Game.

Introduction

This study aims to provide a system evaluation model for multimedia game design educators selecting the most suitable MSGF design from a series of evaluation criteria. The selection of MSGF design criteria is regarded as a multi-criteria problem, including the subjectivity, uncertainty, and fuzziness in the evaluation process.

Based on the above factors, six reasons are proposed for the evaluation. (a) The confirmation of criteria is determined by group experts that they present subjective and objective considerations. (b) TOPSIS logic is rational and understandable. (c) The judgment rules close to human thinking could be acquired through fuzzy linguistic evaluation. (d) The alternatives could be compared with the objectives and criteria decision-making process. (e) The weights of importance between criteria are taken into account and included in the comparison. (f) The calculation process is simple and easy to understand (Wang & Chang, 2007).

Furthermore, Fuzzy Delphi Method is utilized for screening the criteria indicators form the literatures. The entire Fuzzy AHP is used for pair-wise comparison of weights, as there are plenty evaluation criteria in the literatures. It is expected to reduce the large amount of comparisons with AHP and achieve the final sequence. Fuzzy

TOPSIS therefore simplifies the process of AHP, and rapidly calculate the ideal solution and positive ideal solution. The alternatives are compared with ideal solution and positive ideal solution for the sequence. A project is regarded as the best one when it is close to ideal solution and far away from positive ideal solution. The optimal projects are further sequenced. The remainder of this study is structured as follows: Section 2 briefly describes the proposed methods. In Section 3, proposed model for Meaningful Serious-GameFlow selection is presented and the stages of the proposed approach are explained in detail. How the proposed model is used on a real world example is explained in Section 4. In Section 5, conclusions and suggestions are discussed.

Literature review

Fuzzy Multiple Criteria Decision Making

1. Fussy Set

Fuzzy set theory is a mathematical theory pioneered by Zadeh (1965), which is designed to model the vagueness or imprecision of human cognitive processes. The key idea of fuzzy set theory is that an element has a degree of membership in a fuzzy set (Negoita, 1985; Zimmermann, 1985). A fuzzy set is defined by a membership function that maps elements to degrees of membership within a certain interval, which is usually [0, 1]. If the value assigned is zero, the element does not belong to the set (it has no membership). If the value assigned is one, the element belongs completely to the set (it has total membership). Finally, if the value lies within the interval, the element has a certain degree of membership (it belongs partially to the fuzzy set) (Ayagˇ, 2005). Table 1 show the structure of triangular fuzzy numbers that are used in this paper.

Table 1. Membership function of fuzzy scale

Intensity of importance	**Definition**	**Membership function**
9	**Extremely more importance(EMI)**	**(8,9,10)**
7	**Very strong importance(VSI)**	**(6,7,8)**
5	**Strong importance(SI)**	**(4,5,6)**
3	**Moderate importance(MI)**	**(2,3,4)**
1	**Equal importance(EI)**	**(1,1,2)**

2. Fuzzy Delphi Method

Fuzzy Delphi Method was proposed by Ishikawa et al. (1993), and it was derived from the traditional Delphi technique and fuzzy set theory. Noorderhaben (1995) indicated that applying the Fuzzy Delphi Method to group decision can solve the fuzziness of common understanding of expert opinions. Laarhoven and Pedrycz (1983) proposed the FAHP, which is to show that many concepts in the real world have fuzziness. Therefore, the opinions of decision makers are converted from previous definite values to fuzzy numbers and membership numbers in FAHP.

3. Fuzzy AHP

Satty(1980) proposed the analytic hierarchy process (AHP) methodology which was a systematic method developed. It is to solving complex, and multi-criteria decision problems powerfully. Cheng, Chen and Lee (2006) improve the AHP by Fuzzy theory. Hsieh et al. (2004) employed fuzzy analytic hierarchy process (FAHP) method to solve the problem of planning and design tenders selection in public office building. And FAHP method was also applied in the research of Chen et al. (2005) to evaluate expatriate assignments. Thus, in this study, due to the fuzziness existed in the part of evaluation criteria, we decide to adopt the FDM to form the primary evaluation criteria of MSGF selection, and employ the FAHP to calculate the weight of individual criteria so as to establish the Fuzzy Multi-criteria Model of MSGF selection criteria.

4. Fuzzy TOPSIS

Chen and Hwang (1992) proposed TOPSIS multiple criteria method to identify solutions from a finite set of alternatives and initially proposed. Hwang and Yoon (1981) define the ideal solution and negative ideal solution. The optimal solution should have the shortest distance from the positive ideal solution and the farthest from the negative ideal solution. In recent years, Several researcher adopt fuzzy TOPSIS methods and applications to solve the problem and conflict (Chen & Tsao, 2007; Gligoric, Beljic,& Simeunovic, 2010; Yong, 2005). Fuzzy TOPSIS methodology requires preliminarily information about the relative importance of the criteria. This importance is expressed by attributing a weight to each considered criterion wj. Chen (2000) adapted the methodology to calculate the weight of each criterion and evaluate by fuzzy AHP.

Serious Game

Serious games have been some attempts to bring in learning effectiveness evaluation models. Garris et al. (2002) presented a far-reaching input-process-output model of instructional games and learning that has implications for the design and implementation of effective instructional games. Prensky(2001) proposed Digital game-based learning (DGBL) which includes activities that involve learning through solving problems or overcoming challenges posed in games. Specifically, learning arises as a result of the game's tasks, knowledge is enhanced through the game's content, and skills are developed while playing the game (McFarlane & Sparrowhawk & Heald, 2002). The design of digital games is critical in learning. A successful digital game must involve challenge, curiosity and fantasy to increasing interest and intrinsic motivation for learning (Dickey, 200), Added practice and exercise in the game, which can helping students retaining information more easily (Dondi & Moretti, 2007), provide immediate feedback and activate prior knowledge by requiring players to use previously learned skill in order to advance to higher levels of the game (Oblinger, 2004).

ARCS Model

The ARCS model is a problem solving approach to designing the motivational aspects of learning environments to stimulate and sustain students' motivation to learn (Keller, 1983). There are two major parts to the model. The first is a set of categories representing the components of motivation. The second part of the model is a systematic design process that assists in creating motivational enhancements that are appropriate for a given set of learners. To accurately measure the change in learner motivation, Karoulis and Demetriadis (2005) indicated that the ARCS model (Keller, 1987) can be the standard of how much the learning motivation is increased by the game. The four dimensions of ARCS are the following: Attention- attention which increases the learner's curiosity, Relevance- establishment of the relevance of the learning content to learners, Confidence- feedback to the learner, through the effort and the learning process of self-control, Satisfaction- the satisfaction or reward the learner can gain.

Flow Theory

Csikszentmihalyi(1975) proposed the original definition of flow and he defined it as ''the holistic experience that people feel when they act with total involvement.'' Flow describes a state of complete absorption or engagement in an activity and refers to the optimal experience (Csikszentmihalyi, 1991). During the state, people are extreme involved with activity that nothing seems to matter. Csikszentmihalyi (1975, 1991,) summarized the most commonly exhibited factors of flow into nine characteristic dimensions, including clear goals, immediate feedback, potential control, the merger of action and awareness, personal skills well suited to given challenges, concentration, loss of self-consciousness, time distortion, and autotelic experience. The concept has been broad applied in studies such as sports, work, shopping, rock climbing, dancing, games, and others (Csikszentmihalyi, 1991).

It is important that the challenge that player to face in the game match the player's skill. If challenge is significantly higher than player's skill, the player will fell anxiety. In contrast, if the challenge is significantly lower than player's skill the player will feel bored. The three channel model of flow explains above situation in Figure 1. Therefore, for keep a player in a flow state game designers should ensure that while a player's skill increases the challenges also should become more difficult.

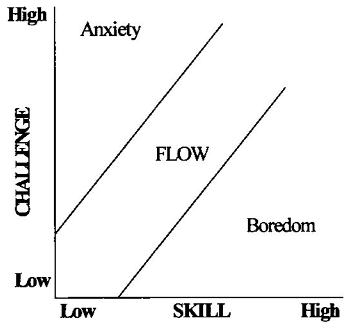

Figure 1. Flow

Meaningful learning

Ausubel(1963) proposed meaningful learning strategy with research of cognition and learning. Meaningful learning is able to importance students' acquisition of new knowledge and it's relevant to previous experiences in the personal's information and unique understandings (Rendas, Fonseca, & Pinto, 2006). In recent years, several researches have employed mobile technologies to support the achievement of meaningful learning (e.g., Karppinen, 2005; Rick&Weber, 2010). Huang, Chiu, Liu & Chen (2011) design and implement a meaningful learning-based evaluation model for ubiquitous which based on previous study are active, authentic, constructive, cooperative and personal. Several characteristics of u-learning are also linked to attributes of meaningful learning. Therefore, this study adopted these five characteristics of meaningful learning as the evaluation criteria of MSGF selection.

The proposed model

A MSGF design evaluation model (Figure 2) is proposed in this study. By integrating group experts' wisdom with AHP and multi-criteria decision-making (MCDM) in Fuzzy TOPSIS, three stages are included. (1) Identification of necessary criteria for MSGF design by Fuzzy Delphi Method. (2) Fuzzy AHP to calculate the weights of criteria. (3) Evaluating and determining the final rank of alternatives by Fuzzy TOPSIS.

Stage 1: Establishing expert criteria. MSGF design evaluation criteria are first collected through literatures, and the hierarchy model identified by experts is screened with Fuzzy Delphi Method.

Stage 2: Evaluating criteria weight. Criteria confirmed by FDM (Fuzzy Delphi Method) are evaluated the hierarchic weight with AHP. The evaluation criteria weights of MSGF design are then formed the matrix through pair-wise comparisons.

Stage 3: Determining the priority of alternatives. The decision team would distribute the evaluation criteria weights and determine the optimal alternatives for sequence.

Our overall survey instrument was based on both past literature published surveys (ARCS, Flow theory, Meaningful learning) and serious game-based learning. To consider the Meaningful Serious Game Flow selection practices in Game design evaluation, we built on the MSGF (Meaningful Serious Game Flow) selection criteria. We gathered and developed the instruments of serious game design selection criteria from these different sources. All of instruments were distributed in 17 critical constructs; all of the instruments were represented in Table 2.

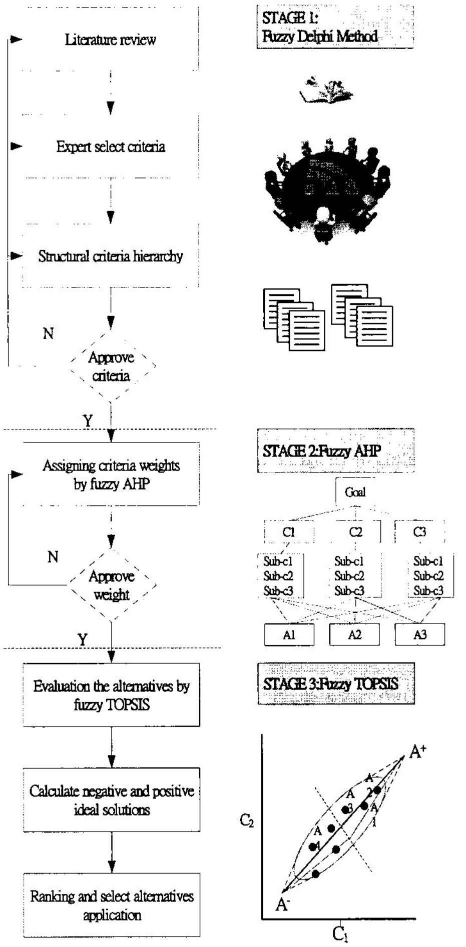

Figure 2. Evaluation framework of MSGF evaluation

Case study

Evaluated Game description

Game 1:3D-CCGBLS game which functions as follows: The learners can understand the operation procedure through game-based simulation of Clinical Path and be evaluated according to the risk management, knowledge procedure and acquaintance for the qualification to continue the next level. With the game-based simulation of Clinical Path, this system is expected to achieve the three objectives, (1) the simulation of various operations allows the player being familiar with the operation process. (2)The operation simulation allows the player understanding the complication in the operation process. (3)The healthcare information offered in the game could assist the player in acquiring knowledge.

The game provides four different game situation levels to be chosen. Figure 3(a) is shown a doctor visits patient and talk. In the game of Cardiac Catheterization, this study uses the first person view control of the game, which will show the situation of view Cardiac Catheterization training. The player must solve the all the problem in the game which order to keep going forward. In this task, the multiple choice questions are designed by the meeting record from the game. Besides solving all problems in the game, The Figure 3(b) is shown that the player must find a way out in order to increase his interest and keep the player's attention on game-based learning. In this task, the player must distinguish the emergencies will be happen by occasionally in the 3D-CCGBLS. If the answer is wrong the health points will decrease by one and the question will reappear and the countdown will be reset, in order to give the player the chance to correct the mistake. The player must answer in limited time, to increase the challenge of the game. At the end of the learning phase, the player have to take an learning evaluation then the learner's learning data will be collection into learner's portfolio by Mobile intelligent agent and then he will get the score which will provided to the teacher for reference.

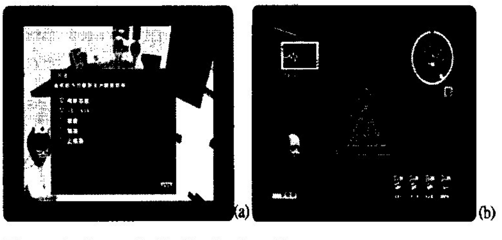

Figure 3. Game 1: Medical education game (a)Asking clinic situation (b) Cardiac catheterization simulation.

Game 2: Software Engineering Project management game which functions as follows:
The game situation- The construction of the game, besides the design of the game screen, also includes the drama and character design. The

story is set in a computer and internet service company whose clients and complicated equipment are getting more and more. This company therefore wants to develop systems that can answer questions of clients and increase the efficiency. The player must help the company evaluate and develop software, act as different roles in the developing process and complete different tasks as different roles to complete the software development. (2) The interface design- The game this study develops takes the story background, environment and age of players into consideration. The game provides five different roles to be chosen. Figure 4(b) shows that every role corresponds to different situations and tasks, and the player can go through the different roles to learn all different tasks of various positions. In the requirements analysis, this study uses the maze game, which will show the problem sign and player position. When passing a problem sign, the character must stop, and the player must solve the current problem in order to keep going forward. In this task, the multiple choice questions are designed by the meeting record from the game. Besides solving all problems in the maze, The Figure 4(a) show that the player must find a way out in order to increase his interest and keep the player's attention on game-based learning. In this task, the player must distinguish the requirements into functional and non-functional. The player has to take an evaluation then he will get the score which will provide to the teacher for reference.

Figure 4. Game 2:Project management game
Discuss a project cost (a) Evaluation a project(b)

Game 3: Energy Education game which functions as follows:

Green City is a serious game which was designed for achieving energy education for Elementary School. It takes the form of mobile game played within Android pad. Each of the game level and eleven different building locations around Taiwan is instantiated as a team in the game. Each game element has been equipped with real-world energy sensors to measure energy use and this monitoring is the main source for scoring of each team. Additionally, players play simple, fast eco-action based mini-games, take quizzes and learn about energy efficiency from sources on cloud. The actions of a team of players combine to win awards that improve and upgrade the virtual representation of their team building. Figure 5(b) shows teams cooperate on virtual environment and to build the energy city.

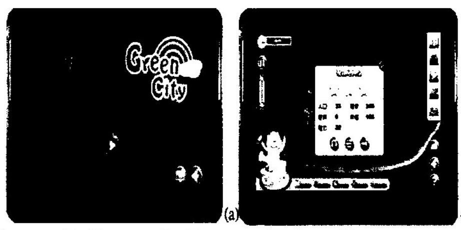

Figure 5. Game 3: Energy Education game
(a)Green City game menu (b) Understanding your environment

Identification of necessary Criteria

In this stage, we focused on the analysis of evaluation criteria of MSGF selection. Thus, the experts chosen were the professionals in the arena related to our study with the experience of serious game design experts. Besides, they should be rich working experience with the serious game design and their positions were at least the rank of department managers over 10 years working experience. In general, the numbers of expert were from three to fifteen (Manoliadis,Tsolas, and Nakou, 2006). This study was sent out to eleven serious game design experts as the questionnaire subjects.

After that we designed the questionnaire in a 9-point fuzzy semantic differential scale, see Table 1. And, we asked the selected experts to answer instrument survey. The selected experts assigned a relative importance to every collected variable with respect to three dimensions of ARCS, Flow and Meaningful learning in order to confirm critical constructs as the evaluation criteria of MSGF selection. The expert questionnaires collected, triangular fuzzy function with respect to every potential variable was established as represented in Table 2.

When selecting the evaluation criteria, it was generally considered important if relative importance is greater than 65%. According to the above filtering treatment, we obtained from the collected experts' questionnaires, there are 17 important criteria commonly agreed by 11experts. And, totally 17 instrument items were eliminated. They were listed as follows Table 2.

According to the experts' decision, Evaluation hierarchy of MSGF model was built. There are four levels in the decision hierarchy structured for MSGF design evaluated criteria (Figure 6). The overall goal of the MSGF decision process determined is in the first level of the hierarchy. The criteria are on the second level, sub criteria are on the third level and evaluated MSGF are on the fourth level of the hierarchy.

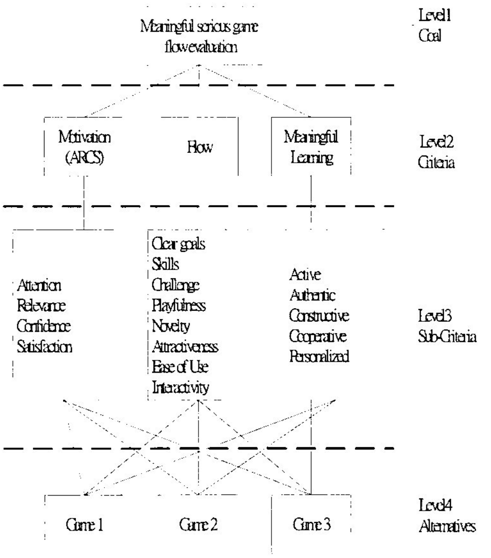

Figure 6. Evaluation hierarchy of MSGF model

Table 2. Criteria select by expert

Criteria	Sub-criteria	source	Score(De-fuzzy>0.65)				
			Min	Max	M	De-fuzzy	R
Motivation(C1) (ARCS)	Attention(C11)	(Keller, 1987)	2	9	7.68	7.14	V
	Relevance(C12)		3	10	7.33	6.82	V
	Confidence(C13)		2	9	7.42	6.90	V
	Satisfaction(C14)		2	9	7.29	6.78	V
Flow(C2)	Clear goals(C21)	Csikszentmihalyi (1975)	4	10	8.37	7.78	V
	Skills (C22)	Csikszentmihalyi (1975);Hoffman & Novak(2000)	5	10	8.66	8.05	V
	challenge(C23)	Csikszentmihalyi (1975);Hoffman & Novak(2000)	5	10	8.21	7.64	V
	Playfulness(C24)	Agarwal & Karahanna, (2000)	6	10	8.78	8.17	V
	Novelty(C25)	Huang (2003)	3	10	8.22	7.64	V
	Attractiveness(C26)	Skadberg & Kimmel(2004)	4	10	8.13	7.56	V
	Ease of Use(C27)	Hsu & Lu(2003)	5	10	8.39	7.80	V
	Interactivity(C28)	Choi & Kim & Kim(2007)	4	10	8.13	7.56	V
Meaningful Learning(C3)	Active(C31)	Ausubel (1963) Huang Y.M., Chiu P.S., Liu T.C., & Chen T.S.(2011)	3	10	7.63	7.10	V
	Authentic(C32)		4	10	7.39	6.87	V
	Constructive(C33)		3	9	7.66	7.12	V
	Cooperative(C34)		3	9	7.28	6.77	V
	Personalized(C35)		4	10	8.61	8.01	V

Calculate the weights of criteria

In this stage, was employed to calculate the fuzzy weights. The next three steps were shown below.

Step1. Collection: This method was based on the experts' precise value and synthesized the experts' opinions with the geometric mean instead of the fuzzy numbers input directly by experts.

Step2. Defuzzification: Since the weights of all evaluation criteria were fuzzy values, it was necessary to compute a non-fuzzy value by the process of defuzzification. Through the following formulas, the defuzzified weight Wi can be obtained.

Step3. Normalization: In order to effectively compare the relative importance among evaluation criteria, we normalized the obtained weights using the following formula. They were listed as follows Table 2.

In the finalization of AHP steps, results are shown in Table 3.From these obtained results, it may be conducted that the specialization, interactivity and the accuracy of MSGF selection. The results obtained from the computations based on the pairwise comparison matrix provided in Table 3.

Result shows the C11, C22, C24 and C35 are determined as the four most important criteria in the MSGF selection process by fuzzy AHP. Consistency ratio of the pairwise comparison matrix is calculated as $0.068 < 0.1$. So the weights are shown to be consistent and they are used in the selection process.

Table 3. summary of the evaluation criteria weight

Criteria	Weight	Sub-criteria	Weight	Total weight
Motivation(C1) (ARCS)	0.21	Attention(C11)	0.38	0.0798
		Relevance(C12)	0.25	0.0525
		Confidence(C13)	0.14	0.0294
		Satisfaction(C14)	0.23	0.0483
Flow(C2)	0.51	Clear goals(C21)	0.07	0.0357
		Skills (C22)	0.08	0.0408
		challenge(C23)	0.11	0.0561
		Playfulness(C24)	0.24	0.1224
		Novelty(C25)	0.08	0.0408
		Attractiveness(C26)	0.22	0.1122
		Ease of Use(C27)	0.09	0.0459
		Interactivity(C28)	0.11	0.0561
Meaningful Learning(C3)	0.28	Active(C31)	0.25	0.07
		Authentic(C32)	0.15	0.042
		Constructive(C33)	0.17	0.0476
		Cooperative(C34)	0.18	0.0504
		Personalized(C35)	0.25	0.07

Evaluation and determine the final rank of alternative

As the following step, decision makers assessed the quality of the alternative hospital web sites. The same fuzzy scale is used for evaluation as in fuzzy AHP and the decision matrix with alternatives and criteria can be seen with linguistic terms in Table 1. In the case study there are three game alternatives. After constructing the fuzzy decision matrix, the normalized matrix using TOPSIS method expression (Chen,2000) to calculate. The last step of the methodology consists of ranking the selected game project to the ideal solution. The performance indices are computed to rank the alternatives and the obtained results are given in Table 4. The evaluation results point out that Game has the best score overall (Game 1 > Game 3> Game 2).

Table 4. The final evaluation and ranking of alternative

Criteria	C11	C12	C13	C14	C21	C22	C23
Game 1	0.160	0.112	0.051	0.033	0.048	0.032	0.033
Game 2	0.131	0.092	0.042	0.027	0.039	0.026	0.027
Game 3	0.152	0.106	0.048	0.031	0.046	0.030	0.031
Criteria	C24	C25	C26	C27	C28	C31	C32
Game 1	0.046	0.021	0.032	0.040	0.138	0.070	0.018
Game 2	0.038	0.017	0.026	0.033	0.113	0.057	0.015
Game 3	0.044	0.020	0.030	0.038	0.131	0.067	0.017
Criteria	C33	C34	C35	Dt+	Dt-	Ci	Ranking
Game 1	0.162	0.027	0.022	0.152	0.106	0.320	I
Game 2	0.133	0.022	0.018	0.147	0.068	0.189	III
Game 3	0.154	0.026	0.021	0.146	0.096	0.298	II

Conclusion and suggestions

Multimedia game design education criteria evaluation refers to the selection of instructional strategies, which could affect the learning effectiveness of game design education. A lot of alternatives should be taken into account and evaluated the factors in different game design criteria. In this case, an efficient decision evaluation method is necessary for reinforcing the decision evaluation quality for MSGF design.

A system evaluation process for MSGF design is proposed in this study, which applies triangular fuzzy numbers to expressing the evaluation linguistics and considering the subjective judgment and objective analyses. A mixed fuzzy multi-criteria decision-making is further applied to completing the group decision evaluation model. The evaluation mode is completed the MSGF design evaluation based on literatures and experts' definitions. The criteria comparisons of the case are preceded for the optimal design sequence.

The criteria weights are acquired by Fuzzy AHP, which provides the calculations of ideal solution and positive ideal solution of Fuzzy TOPSIS in the criteria decision process. Meanwhile, weighted decision evaluation is further calculated according to such weights to generate alternatives and determine the sequence.

The proposed MSGF design evaluation decision model has largely enhanced the working efficiency of MSGF design education. Fuzzy TOPSIS simplifies the solution of AHP calculating the evaluation process and rapidly generates the results and sequence of decision evaluations. Moreover, the calculation of indicator weights through Fuzzy TOPSIS is important for the evaluation comparison in the case. Different weights could generate the priority sequence of the evaluation results. It shows that the weights are determined through experts' group decision to avoid prejudice, reduce bias in the decision process, and benefit the correctness of criteria evaluation (Bilsel, Büyüközkan, & Ruan, 2006).

Most decisions are complex and conflict that decision-makers should consider solving problems with scientific methods. The development of MSGF design evaluation decision model could assist game design educators in proposing teaching strategies.

A mixed multi-criteria decision-making evaluation model is combined in this study. Although the research model is compared with MSGF design, the future research could revise the criteria and be utilized for the selection from distinct design course evaluation. Besides, distinct multi-criteria decision-making evaluations are used for comparing the priority sequence of decision projects. For instance, the comparison between TPOSIS, VIKOR, and ANP could have evaluation decisions be more valuable.

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