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Exploring the critical influential factors of creativity for college students: A multiple criteria decision-making approach

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ABSTRACT

This study aims to explore the key factors affecting the creativity development of college students. The multiple criteria decision-making (MCDM) approach was adopted to construct an objective and effective analytical model of critical factors influencing college students' creativity. The fuzzy Delphi method (FDM) was first employed to screen the critical influential factors (criteria/sub-criteria) categorized by four dimensions: "Individual qualities," "Family background," "School element," and "Community", which are synthesized from the literature review and in consultation with experts from relevant fields in Taiwan. Then, the fuzzy analytic hierarchy process (FAHP) method was applied to calculate the relative weights of the selected critical criteria/sub-criteria that impact creativity for college students. Through expert consensus, the analysis results indicate the "Community" dimension, including two criteria, "Social education environment" and "Social cultural environment," has the most impact on creativity development for college students. And the top three critical influential sub-criteria are "Oppressive of environmental behavior," "Respect for intellectual property," and "Integration of creative education." Therefore, based on the findings, it implies that an enhanced social environment, which can create an adequate stimulus from the external environment, construct a protective domain of knowledge and creativity suitable for knowledge-based economic era, and instill diverse creativity education into daily life, is considered as the most important factor affecting college students' creativity development by the experts. The prioritized weights analyzed by the proposed model can not only serve as a useful self-assessment tool for college students to better understand key influential factors on their own creative abilities for developing their potential creativity, but also can provide an important reference for educational units and/or interested parties in policy making and strategies to help effectively promote college students' creativity development.

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1. Introduction

In today's knowledge-based economy, creativity plays an important role in obtaining global competitive advantage because it is the manifestation of wisdom and knowledge of the human brain, which can transform creativity into economic value and offer people and organizations a sustained competitive advantage. Thus, creativity is also deemed an invaluable asset of the human brain, a necessary human resource in the 21st century, and a powerful means to improve the quality of life (Williamson, 2001). Given the phenomenon that high-tech development is growing speedily and civil society is improving significantly, it has been a critical mission for schools to foster creative talent that addresses the needs of each nation, especially in higher education (Chen & Chen, 2010a).

However, with pressures like dropping birth rates, economic depression, World Trade Organization (WTO) accession, interaction with China, and the number of universities/colleges increasing year after year (Ministry of Education, 2003), unlike 20 years ago, students in Taiwan confront pressures from both their parents and school and compete with global students, resulting in a decrease in the basic creative nature of Taiwanese students (Chen & Chen, 2010c). Therefore, rather than knowledge-learning, for university/college students today, the development of creative knowledge is highly underscored by practitioners and researchers (Gardner, 1993; Williamson, 2001).

Based on the White Paper on Creative Education—Establishing a Republic of Creativity (ROC) for Taiwan published by Ministry of Education (2003), creative talent is the basis of a nation's competitive advantage, and the university is a major core for fostering such talent (Wu, Chen, & Chen, 2010). The Taiwanese government, therefore, expects to make itself an island of creativity by thoroughly nurturing creative talent within each university (Ministry of Education, 2003). Although the development and fostering of creativity has been one of a crucial educational trend and constructive educational goal, whether the higher education environment can successfully inspire creativity in students is still a debatable issue (Cheung, Rudowicz, Yue, & Kwan, 2003). In this regard, the aim of this study is to construct critical criteria of creativity for college students in order to provide a precise reference for creativity-related policy improvements for the higher education system and to assist college students themselves toward self-evaluation for understanding and further enhancing a self-centered creative orientation.

Relevant research on creativity is numerous and various, as are the research methods and assessment models (Almeida, Prieto, Ferrando, Oliveira, & Ferrándiz, 2008; Burke & Williams, 2008; Tierney & Farmer, 2002; Torrance, 1966). Most of the previous studies have utilized basic statistical analysis and placed great emphasis on the relationships between creativity and other factors, sampling either firm employees or students. That is, a large number of influential, reliable and valid creativity dimensions and variables have been developed; the main emphases, however, have been on the examination of the relationships of inter-dimensions. More recently, some of related research has focused on creativity performance (e.g., thinking skills). For instance, Wang (2012) investigated the relationship of creative thinking ability to reading and writing taking 196 university students as a sample group. Burke and Williams (2012) presented the development and potential uses of two thinking skills assessment tools (Burke & Williams, 2008) with a focus group of children (11/12 years) to make these measures (for creativity performance) available for other researchers. Studies that highlight the relative importance of critical and influential creativity dimensions and their related variables (criteria) are scarce (Wolfradt & Pretz, 2001). Consequently, different from the previous research, the study makes an attempt to construct an analytical model to help identify the relative importance of critical influential criteria of college students' creativity. The result is believed to make certain contributions to today's research and practice.

Additionally, taking into account numerous influential factors of creativity, this study can thus be conducted by employing the multiple criteria decision-making (MCDM) model. Moreover, to precisely reflect the reality of problems and fit the thinking logic of human, Zadeh (1965) proposed a fuzzy set theory as an alternative to crisp set logic. In this study, a combined MCDM approach based on fuzzy theory was utilized to explore the aim. Therefore, in addition to fuzzy Delphi method (FDM) that was used to acquire experts' consensus to select the critical factors (Ishikawa et al., 1993), the fuzzy analytic hierarchy process (FAHP) method was adopted to prioritize the relative importance of selected factors. This is because that FAHP has widely been used for MCDM (Mikhailov, 2003; Saaty, 1980; Zadeh, 1965), and the practical applications reported in the literature have shown advantages in handling unquantifiable/qualitative criteria and have obtained quite reliable results (Hsieh, Lu, & Tzeng, 2004).

2. Creativity and its relationship with higher education

This section briefly reviews the underlying concepts adopted by this research, such as the definitions of creativity, the relationships between creativity and higher education, and critical influential factors for college students.

2.1. Creativity: definition and theory

Creativity is a very important and complicated concept. Experts and scholars have mixed opinions as to what creativity is. As a result, experts and scholars have failed to reach a consensus on the definition and importance of creativity (Furnham, Batey, Anand, & Manfield, 2008). Over 60 types of creativity are defined in the field of psychology alone (Mayer, 1999; Taylor, 1988). As indicated by Mumford and Gustafson (1988), the definitions of creativity can be traced to Ghiselin (1963), who argued that creativity is not only an innovative and valuable idea but also the generation of a problem-solving strategy

Table 1
Summary of selected definitions of creativity.

Researcher	Definition
Guilford (1967)	Creativity is defined as the embodiment of a thought in the form of an external behavior, which consists of three characteristics such as fluency, flexibility, and originality.
Mohr (1982)	Creativity is a multi-staged cognition flow of behavioral changes.
Torrance (1988)	Creativity is a series of flows that include problem identification, speculation, construction of hypothetical assumptions and creation, and the sharing of ideas with others.
Mozart (1993)	Creativity is the quality of work and life of a person in society.
Amabile (1996)	Creativity can be regarded as the interaction between the individual and its external environment, which includes three components: domain-relevant skills, creativity-relevant skills creative-thinking skills, and task motivation.
Sternberg and Lubart (1996)	Everyone has creativity though with varying levels which are affected by the combination of six types of different yet interrelated elements: intellectual abilities, knowledge, thinking styles, personality, motivation, and environmental elements.
Feldman (1999)	Creativity is a multi-dimensional construct that involves a cognition process, social or emotional process, family and clan, formal and informal education, characteristics of domain and discipline, social–cultural context, and history.
Mayer (1999)	Originality and usefulness are two important characteristics of creativity.
Florida (2004)	Creativity is the product of intelligence, motivation, and a suitable environment.
Hoff and Carlsson (2002)	Individual creativity can be affected by personality including confidence, believing own thoughts, critical perspective, invention, passion, acceptance of challenge, and occasional depression.
Baer and Kaufman (2005)	Creativity can be compared to the Amusement Park Theory that states intelligence, motivation, and a suitable environment, like transportation and entrance tickets which are necessary resources to enter an amusement park, are all pre-requisites of creativity.

(Amabile, 1988, 1997; Shalley, 1991; Cropley, 1999; Oldham & Cummings, 1996; Zhou & George, 2001). Creativity is further defined as a new concept that falls within a certain system of knowledge and is recognized by experts as being innovative and valuable (Csikszentmihalyi, 1996, 1999; Csikszentmihalyi & Wolfe, 2000). In the research of Batey and Furnham (2006), they define the creativity by different aspects such as new and useful, product oriented, part of a process, and componential conceptions of creativity.

Apart from the above concepts introduced, Table 1 summarizes briefly some selected definitions of creativity. Guilford (1967) defined creativity as the embodiment of a thought in the form of an external behavior. Later on, creativity was also believed to be a multi-staged cognition flow of behavioral changes (Mohr, 1982). Torrance explained that creativity is a series of flows that include problem identification, speculation, construction of hypothetical assumptions and creation, and the sharing of ideas with others (Torrance, 1988). Mozart (1993) thought that creativity is the quality of work and life of a person in society. Sternberg (1999) defined creativity as a structurally and procedurally complicated phenomenon that generates new ideas and that cannot be fully explained while Sternberg and Lubart (1996) claimed that everyone is a creator, though with varying levels of creativity. According to them, the display of creativity requires the combination of six types of different yet interrelated elements: intellectual abilities, knowledge, thinking styles, personality, motivation, and environmental elements. Creativity may also be viewed as the interaction between the individual and its external environment or the consideration of other people about the creativeness of an idea (Amabile, 1986, 1996, 2003). Mayer (1999) emphasized that originality and usefulness are two important characteristics of creativity. Feldman (1999) suggested that creativity is a multi-dimensional construct that involves a cognition process, social or emotional process, family and clan, formal and informal education, characteristics of domain and discipline, social–cultural context, and history. The personality affecting individual creativity contains confidence, believing own thoughts, critical perspective, invention, passion, acceptance of challenge, and occasional depression (Hoff & Carlsson, 2002). In recent studies, Florida (2004) argued a similar view, that creativity is the product of intelligence, motivation, and a suitable environment. Baer and Kaufman (2005) proposed that the Amusement Park Theory of Creativity is a metaphor for creativity. It states that intelligence, motivation, and a suitable environment are all pre-requisites of creativity, like transportation and entrance tickets are necessary resources to enter an amusement park. Some domains (e.g., science, arts, and sports) require distinct forms of creativity. Once an individual commits himself/herself to such domains, the professional abilities that he develops are his or her distinctive creativity.

Currently, the idea that creativity is a way of thinking that leads to products that are at the same time new and valuable seems to be widespread and commonly adopted (Barron, 1995; Csikszentmihalyi, 1996; Feist, 1998; Mumford, 2003; Ochse, 1990; Sternberg & Lubart, 1999). After studying the various definitions scholars have for creativity, it was found that the different definitions were derived from varied perspectives. Therefore, this study adopted a multi-dimensional method to study creativity. Studies of diverse theories were compiled, and the relationships between creativity and the act of creating were illustrated. Through document analysis on an extensive literature review and consultations with experts who have years of background in the relevant field, important concepts (theories) and definitions (explanatory statements) were synthesized and used as the basis for key factors affecting creativity in this study. These concepts/definitions of creativity developed by Amabile (1996), Feldman (1999), Florida (2004), Hoff and Carlsson (2002), Mozart (1993), Sternberg (1999), Sternberg and Lubart (1996), Torrance (1988) and so on, are mainly involved into some common issues such as personality, family, school, and community/society. A more detailed classification is provided in later section.

2.2. Creativity and higher education

In today's world, where the environment is volatile, unpredictable, and highly competitive, undoubtedly, all organizations and sectors must face competitive pressure from within and outside the country. To achieve sustainability or even re-gain a competitive edge, both the academic and practical disciplines are strongly dedicated to advocating for creativity and its importance (McCloskey, 1995). As mentioned earlier, the tertiary education system in Taiwan is losing its competitive advantage. The main reasons are due to the fact that Taiwan joined the WTO, has a low birth rate, and the number of universities in Taiwan has increased exponentially, while the quality of each varies enormously (Chen & Chen, 2010a; Wu et al., 2010). Although the Department of Education has implemented an evaluation system on tertiary institutions that will be carried out in the coming few decades, the quality of these institutions is yet to be improved. According to Chen and Chen (2010a, 2010b), the improvement of quality management and development of creativity are two main directions most major universities in Taiwan are heading toward improving overall operational performance. The evaluation model for quality management includes ISO 9000 international standards for quality management and national quality awards. However, the development of standards for evaluating creativity enhancement, especially those of undergraduates, requires further research.

The success of innovation depends on the level of creativity (Dewett & Gruys, 2007). As creativity is developed from the knowledge creation of team members, fostering and improving the creativity of team members plays a major role in enhancing the overall innovation performance of the entire organization. The former and the latter are interdependent. Undergraduates are the source of innovation of a university. This idea is especially true for nowadays, where the knowledge economy and technology are growing rapidly. However, in Taiwan, the enormous pressure resulting from credentialism and the traditional cramming education has caused students to give undue emphasis to knowledge memorization. Gradually, students lose the ability to think independently, therefore causing their creativity to remain latent. Many researchers believe that creativity is the generation of innovative products, i.e., being successful in life or the display of talents or creative experiences in everyday life. A creative experience might be an innovative thought, act, or activity (Golann, 1963). Because the objective of the university is to produce talents in the academic and practical fields, it should provide better opportunities to its students to foster and display creativity (e.g., academic research), compared with the opportunities the students can obtain when they join the workforce later (e.g., technology innovation). The challenge, however, is to find the best way to identify and control the key factors affecting undergraduates' creativity to develop or even to enhance their creativity and, in turn, enhance the innovation performance of the university. Such challenge has certainly become an unavoidable issue.

2.3. Critical influential factors for college students

Due to the rise of the knowledge-economy era, an increasing number of enterprises have placed an emphasis on the production of innovative products and services. The ultimate aim is to gain a competitive advantage. Much research in the past has studied creativity.

Yamamoto (1964) studied the creativity of tribes and its influence on their future. Montgomery, Bull, and Baloche (1993) studied, from the point of view of a university professor, the characteristics of an innovative person. They collected literature related to creativity and the lesson content of 67 professors from 61 universities, who discuss creativity. The data were compiled, summarized, and analyzed. Ninety-five major characteristics of creativity were identified. A questionnaire survey was then conducted with a 5-point Likert scale on professors that had the experience of teaching creativity-related subjects. Thirteen major characteristics of creativity with a median exceeding 4.5 points were identified. They were, in sequence of importance, as follows: imagination, openness to experience, inquisitiveness/curiosity, intuition, idea-finding, tolerance for ambiguity, independence, innovation, insight, internal/external openness, illumination/insight, problem-finding, and imagery. Baker, Rudd, and Pomeroy (2001) studied, from the theoretical point of view, the five major factors of interpersonal variables, personal/educational variables, attributes of creativity, cultural variables, and biological variables. They tried to construct a model for a creative thinking process that would stimulate the creativity of tertiary students with the aim of developing a cognition map that would help inspire student creativity.

However, the construction of an analytical model of critical influential factors for creativity can be very complicated. It requires careful yet practical measures. Analyzing the widely used 4P aspects of "person," "process," "place," and "product" developed by early creativity psychology, Davis (1986) believed that the creative thinking process is a problem-solving system adopted by the individual. When new ideas or problem-solving solutions are generated, the individual changes or converts his or her perception and applies, with or without his or her own knowledge, skills and strategies such as new ideas, relations, definitions, and perceptions. These are some common scenarios found with undergraduates in the university. For example, many undergraduates would attempt to display their creativity in class during discussions, examinations, and case study debates. In the workplace or in society in general, the use of creativity is required even more. For example, the display of creativity is required to improve performance at work or to enhance the quality of life and improve the financial status of society.

Furthermore, Guilford (1950) thought that creative personality is the unique characteristics of a creative person, including the ability to tolerate the existence of an ambiguous concept, to think liberally, to be flexible, to be adventurous, and not to be content with the current situation, among other things. These personality characteristics and their opposites are commonly observed among students today. These are mainly due to (1) family background (Feldhusen & Goh, 1995; Piirto, 1992; Zhou
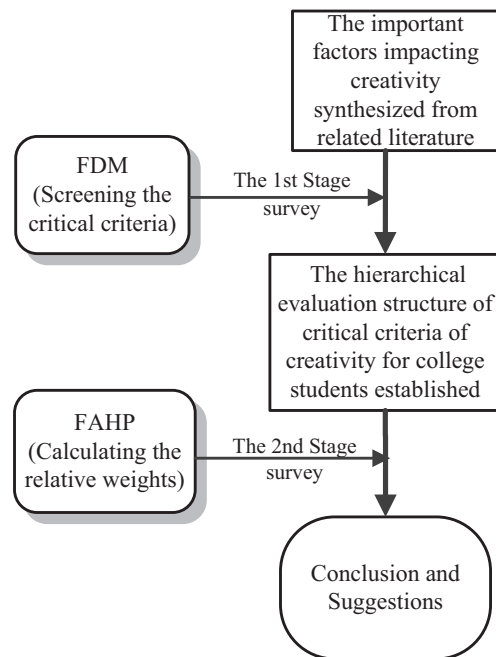
Fig. 1. The proposed research framework.

& George, 2003) and (2) schools, classes, or organizational cultures in the workplace (Csikszentmihalyi, 1999; Runco & Walberg, 1998; Siau, 1997; Woodman, Sawyer, & Griffin, 1993; Zhou & George, 2001).

The ability to create is aroused by environmental stimuli, such as interaction among peers, parents and their opinions, and the availability of time and space (Dodds, Smith, & Ward, 2002; Mellou, 1996). Csikszentmihalyi (1996) further mentioned that creativity cannot be detached from society, history, and culture. It is a product of interaction among the individual, scope, and special domains of the three sub-systems of society, organization, and domain. From the perspectives of the above scholars, we may infer that creativity of undergraduates is developed through the interactions among the student, his or her school, family, and workplace as well as with society in general. Among these interactions, the more important influencing factors are schools and family.

As mentioned above, from major literature discussions related to creativity theory, this study, based on the relative theory and model of the influence of an organizational environment, identified four major evaluation dimensions influencing the creativity of undergraduates (Csikszentmihalyi & Wolfe, 2000; Csikszentmihalyi, 1990, 1999; Feldhusen & Goh, 1995; Feldman, 1999; Mayer, 1999; Sternberg and Lubart, 1996; Taylor, 1988; Zhou & George, 2003): "I: Personal characteristics," "F: Family background," "S: School element," and "C: Community." This study has further isolated the criteria and sub-criteria of each dimension. In summary, this study identified 4 major dimensions, 11 criteria, and 46 sub-criteria influencing the creativity of university students. For better understanding, the above factors and their detailed illustrations with their main references are listed in Tables 2–6.

3. Research methods

According to the analysis of the previous literature review, the research framework of critical influential factors of creativity for college students proposed by this study is shown as Fig. 1. This research is attempted to propose an analytical model determining the critical influential factors of college students' creativity using a MCDM approach. It first adopts the fuzzy Delphi methods (FDM) to screen the critical criteria categorized by four dimensions: personality characteristics, family background, school element, and community (social environment), which are based on the results of the literature review through expert consensus. Then, the fuzzy analytic hierarchy process (FAHP) is applied to calculate the relative weights of the critical factors that impact creativity for college students. The concepts of fuzzy set theory, the related analytical tools, and data collection and questionnaire design are briefly illustrated in the following subsections.

3.1. Fuzzy set theory

Fuzzy set theory was first developed in 1965, when Professor L.A. Zadeh was trying to solve fuzzy phenomenon problems that exist in the real world, such as uncertain, incomplete, unspecific, and fuzzy situations (Zadeh, 1965). Fuzzy set theory has more advantages in describing set concepts in human language than traditional set theory. Fuzzy set theory shows

Table 2
Summary of influential dimensions and criteria of creativity with their main references.

Dimension/criteria	Description (explanations about what/how the criteria impact creativity)	References
Personal characteristics (I)		
Personality (IP)	Individual creativity can be affected by personality. People who have positive personality (e.g., independent and decisive) may have higher creativity.	Torrance (1988); Sternberg and Lubart (1996); Cropley (1999); Moss (2002); Zhou and George (2003); Shalley, Zhou, and Oldham (2004)
Motive (IM)	Creative behavior sometimes involves high risks and failure. Only a person whose intrinsic motivation is high will take those risks without giving up easily.	Amabile, Hill, Hennessey, and Tighe (1994); Amabile (1997); Cann, Calhoun, and Banks (1997); Conti, Amabile, and Pollak (1995); Amabile (2003)
Knowledge (IK)	Knowledge is the basis of thinking. Creativity needs to have knowledge as its foundation.	Mumford and Gustafson (1988); Feldhusen and Goh (1995); Williamson (1998); Sternberg (2003)
Family background (F)		
Parental rearing style (FP)	Parents that teach children with low authoritativeness will encourage the development of creativity.	Siegelman (1973); Torrance (1975); Amabile (1996); Cropley (1999); Sternberg (2003)
Family environment (FL)	In a democratic and open family, children can enjoy the most interesting and creative activities.	Siegelman (1973); Olszewski, Kulieke, and Buescher (1987); Torrance and Goff (1990); Piirto (1992); Feldhusen and Goh (1995); Zhou and George (2003)
Subject identity of children (FC)	Parents are learning models and identifiable role models for children; the best way to learn and develop creativity is to observe and follow models.	Mansfield and Busse (1981); Pohlman (1996); Snowden and Christian (1999)
School element (S)		
Peer relations (SC)	Peer relations are social relationships within student groups based on a common interest or attitude.	Torrance (1988); Mumford and Gustafson (1988); Williamson (1998); Ministry of Education (2003); Clegg (2008)
Teacher–student interaction (ST)	When a teacher presents creativity in teaching and provides a support attitude while interacting with students, students' creativity can be further improved.	Osborn (1953); Siegelman (1973); Mansfield and Busse (1981); Woodman et al. (1993); Siau (1997); Csikszentmihalyi (1999); Moss (2002)
School environment (SS)	Schools need to create a creative environment to shape a creativity commitment and develop a learning environment that is good for innovation.	McDonough and McDonough (1987); Csikszentmihalyi (1999); Chandler, Keller, and Lyon (2000); Ministry of Education (2003); Dodds et al. (2002); Chen and Chen (2010a, 2010b)
Community (C)		
Social education environment (CE)	Various types of social education use creativity education at every civilian level and highlight the importance of the enhancement of creativity knowledge	Mumford and Gustafson (1988); Amabile (1996); Sternberg and Lubart (1996); Csikszentmihalyi (1999); Ripple (1999); Ministry of Education (2003)
Social cultural environment (CC)	Government synthesizes the relationship between creativity and social culture, provide cultural characteristics that are good for creativity development, respect differences, maintain a happy and active learning and innovative environment, and provide adequate stimuli for the environment to develop creativity.	Arieti (1976); Mellou (1996); Runco and Walberg (1998); Moss (2002); Ministry of Education (2003)

unspecific and fuzzy characteristics of language through evaluation and uses a membership function concept to represent the field in which a fuzzy set can permit situations, such as "incompletely belonging to" and "incompletely not belonging to." The concept of fuzzy number and primary operations of the two triangular fuzzy numbers (TFN) employed in the study is provided in Appendix A.
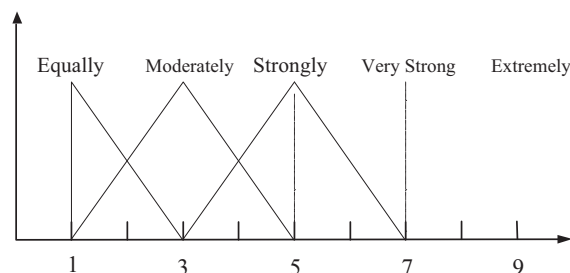
3.1.1. Fuzzy linguistic variable

The linguistic variable is a variable whose value is word or sentence in a natural or artificial language. Linguistic variables regarding human words or sentences can be evaluated in terms of importance using ratings such as "equally important," "moderately important," "strongly important," "very strongly important," and "extremely important," as shown in Fig. 2. The evaluators are asked to conduct their judgments, and each linguistic variable can be indicated by a TFN as shown in Table 7. Since the above variables could be made quantifiable by applying triangular fuzzy numbers from a range of 1 to 9 (as Table 7), they are thus called the fuzzy linguistic variables. For the purpose of the present study, a 5-point scale

Table 3
Summary of influential criteria and sub-criteria of Personal characteristics (I) on creativity.

Criteria/sub-criteria	Description of sub-criteria (explanations about what/how the criteria impact creativity)
Personality (IP)	
1. Challenge acceptance	A creative personality has three primary characteristics: confidence, inventiveness, and challenge solving.
2. Expressiveness	People who are adventuresome, humorous, and have a strong sense of self-expression are full of creativity.
3. Independent thinking	A person who can think and judge things independently has high creativity.
4. Curiousity	The need and motivation of creativity includes curiosity, facing difficulties, and pursuing truth.
Motive (IM)	
1. Self-satisfaction	Intrinsic motivation pushes the individual to pursue self-satisfaction
2. Personal interest	Intrinsic motivation is a stimulus, personal interest, from oneself regarding his future behavior such as.
3. Reward history	An organizational reward has a great effect on the creativity behavior of employees, which can be seen as a crucial tool for employees to understand that a certain reward will be given for a certain objective.
4. Opportunity for development	Enabling extrinsic motivation can authorize an individual to perform self-interested works within a freely performing environment.
5. Understanding self-potential	Understanding self-potential for creativity can help people perform self-evaluation on the objectives of one's existence, education, and work and encourage self-confidence and an adventurous spirit.
Knowledge (IK)	
1. Professional knowledge	Both formal and informal professional knowledge influence the development of creativity and its outcome
2. Reading	Development of reading hobbies can break through the original learning bottleneck and enhance a person's knowledge basis.
3. Lifetime learning	Lifetime learning is essential to maintaining creativity. Creativity is key to maintaining a competitive advantage in today's knowledge-based economy.

Table 4
Summary of influential criteria and sub-criteria of family background (F) on creativity.

Criteria/sub-criteria	Description of sub-criteria (explanations about what/how the criteria impact creativity)
Parental rearing style (FP)	
1. Strictness	Parents who utilize strict, despotic, indifferent, and resistance as resistant teaching methods may have impact on children's creativity development.
2. Creative thinking potentials	Creative thinking is the process of generating creative ideas within a creative-oriented activity. It is a synthesized presentation of multiple thinking styles and a core of creativity.
3. Communication skills	Communication is an essential process for new and creative thinking.
4. Avoiding over discipline	Parents give children suitable development opportunities.
5. Freedom to act	A creative family can shape a free developmental space for the creativity of children.
Family environment (FL)	
1. Liberal and open climate	An open and democratic family environment and a liberal and loving climate are critical conditions for children to produce creative motivation.
2. Parent–child communication	Communication between parents and children can encourage and motivate creativity of children and further develop their independent personalities, which is helpful for the development of the creativity of children.
3. Family caring for each other	Care for each other in a family can help build creativity of children indirectly because ideas can be supported and respected.
4. Stimulating imagination	Imagination is the process of using past perceptions of experiences as material to revise and recombine them in a novel form in mind.
5. Expectation for their children	Parents who have high expectations of their children can better provide opportunities, supportiveness, and other ways to promote creativity of children.
Subject identity of children (FC)	
1. Parent's occupation	Parents' jobs have a high impact on the learning development of their children.
2. Parent's hobby	Parents' hobbies and interests can guide the life development of their children.
3. Parent's characteristics	Parents' characteristics have a key influence on the development and improvement of creativity of children.
4. Role model for learning	Parents are role models for their children. To learn and develop creativity is to absorb and follow their models.

Fig. 2. Fuzzy membership function for linguistic variables for attributes.

Table 5
Summary of influential criteria and sub-criteria of school element (S) on creativity.

Criteria/sub-criteria	Description of sub-criteria (explanations about what/how the criteria impact creativity)
Peer relations (SC)	
1. Friends caring for each other	Students cherish their friendships; they take care of and help each other.
2. Exchange of opinions	By using brainstorming and free discussions, people are encouraged to exchange ideas and opinions.
3. Participation in activities	In a group, an individual who has a higher ability has more possibility to participate in more creative activities and tends to have a more positive attitude toward school.
4. Competitive environment	If parents want to fully develop creativity in their children, then the best way is to place them in a highly competitive environment in which everyone pursues rewards and commitments.
5. Proactive learning	Students utilize self-thinking for active learning; in classes, they actively participate in and produce novel ideas, thoughts, and opinions.
Teacher–student interaction (ST)	
1. Creative teaching	Teachers provide creative education and training styles to promote students' creative thinking skills.
2. Creating positive learning atmosphere in class	Teachers should motivate students' learning interests and create a climate in which students can feel free to participate.
3. Encouraging creative thinking	Teachers need to give students more time to think to promote their thinking style and imagination space.
4. Developing learning abilities	Teachers encourage students to brainstorm, actively accept knowledge, and train their thinking ability.
5. Harmonious learning environment	Teachers provide a diverse, open, and free learning environment, where every idea and creativity is welcomed.
School environment (SS)	
1. Providing creative courses	Schools develop policies regarding the promotion of creativity and creativity-related courses, graduate school, and college.
2. Teaching resources	In terms of teaching, schools create creativity research centers to involve creativity in each subject.
3. Emphasis on creativity	Several critical educational and economic policies reveal the importance of creativity.
4. Safe learning environment	A learning environment of a school where students and teachers can remain safe is a basis for developing creativity.

Table 6
Summary of influential criteria and sub-criteria of community (C) on creativity.

Criteria/sub-criteria	Description of sub-criteria (explanations about what/how the criteria impact creativity)
Social education environment (CE)	
1. Social education	Diverse social education (e.g., lifelong education, adult education, and supplementary education) has a function in promoting creativity development of people.
2. Integration of creative education	Governmental and private organizations are integrated to promote and conduct various policies of creativity and innovative education or reports at each civil level.
3. Expansion of professional knowledge	Creativity-related private organizations (e.g., associations, foundations, and websites) are established to encourage the formation of domestic creative culture.
Social cultural environment (CC)	
1. Cultural traits	Cultural traits that benefit the presentation of creativity (e.g., an adequate cultural condition, a stimulus that accepts creativity, change forces, and tolerance) are proposed to synthesize the connection between creativity and social culture.
2. Respect for intellectual properties	To shape a novel, diverse, and collective cultural phenomenon is suitable for constructing a protective domain of knowledge and creativity in knowledge-based economic era.
3. Oppressive environmental behavior	The development of creativity needs an adequate stimulus (pressure) from the external environment.

Table 7
Definition and membership function of fuzzy number.

Fuzzy number	Linguistic variable	TNF ($\tilde{a}_{ij}$)	Reciprocal of a TFN ($\tilde{a}_{ij}^{-1}$)
$\tilde{9}_{ij}$	Extremely important/preferred	(7, 9, 9)	(1/9, 1/9, 1/7)
$\tilde{7}$	Very strongly important/preferred	(5, 7, 9)	(1/9, 1/7, 1/5)
$\tilde{5}$	Strongly important/preferred	(3, 5, 7)	(1/7, 1/5, 1/3)
$\tilde{3}$	Moderately important/preferred	(1, 3, 5)	(1/5, 1/3, 1)
$\tilde{1}$	Equally important/preferred	(1, 1, 3)	(1/3, 1, 1)
$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	Intermediate value between two adjacent judgments		

Source: Mon, Cheng, and Lin (1994) and Hsieh et al. (2004).

(i.e., equally important, moderately important, strongly important, very strongly important and extremely important) for linguistic variables illustrated by triangular fuzzy numbers is used.

3.2. Fuzzy Delphi method

The traditional Delphi Method is a professional forecasting method and a type of nominal group technique aimed at arriving at a unanimous consensus among experts regarding a certain subject of forecast. A questionnaire is used to collect professional opinions from experts in the related field. The identity of the expert surveyed is hidden from all other experts participating in the same survey. The experts are not allowed to exchange opinions prior to the survey. A facilitator is appointed to summarize the opinions of all experts. Hence, experts participating in the survey may, based on their professionalism, express their opinions freely in an undisclosed environment. Therefore, this method is effective for drawing on the wisdom of the masses. Independent judgments of each expert can also be obtained.

The "consensus" achieved in the traditional Delphi method refers to the range of decisions that reach the median scores or are at the mid 50% scores of all opinions. Although all opinions that fall within such areas are considered a consensus, an exact point that determines one unanimous opinion cannot be decided. Therefore, ambiguity exists in the traditional Delphi method. However, the ambiguity is not considered in the analysis. Hence, the honest opinions of the experts are not truly reflected in the results, which is one of the major weaknesses of the Delphi method.

Ishikawa et al. introduced the fuzzy Delphi method in 1993, which is a combination of the traditional Delphi method and the fuzzy theory (Ishikawa et al., 1993). By using cumulative frequency and cumulative fuzzy scores, Ishikawa et al. (1993) consolidated the expert opinions into fuzzy numbers, and the method is called the fuzzy Delphi method (FDM). Noorderhaben (1995) proposed that the use of the FDM on nominal group technique can resolve the issue of ambiguity in the consensus of the expert opinion. Compared to the traditional Delphi method, its strengths are the following: (1) the number of times an expert is surveyed is reduced, and the expert's opinion can be expressed explicitly; and (2) the ambiguity that inevitably occurs during surveys is considered in the analysis. Therefore, this study initially applied the max–min FDM, proposed by Ishikawa, for assessment factor determination. The results will then function as the basis for weight assessment. The detailed steps of the max–min FDM proposed by Ishikawa et al. (1993) are given in Appendix B.

3.3. Fuzzy analytic hierarchy process

The analytic hierarchy process (AHP) was devised by Saaty (1980). It is a useful approach to solve complex decision problems. It prioritizes the relative importance of a list of criteria (critical factors and sub-factors) through pairwise comparisons amongst the factors by relevant experts using a nine-point scale. Buckley (1985) incorporated the fuzzy theory into the AHP, called the fuzzy analytic hierarchy process (FAHP). It generalizes the calculation of the consistent ratio (C.R.) into a fuzzy matrix. The procedure of FAHP for determining the evaluation weights are explained as follows:

Step 1: Construct fuzzy pairwise comparison matrices. Through expert questionnaires, each expert is asked to assign linguistic terms by TFN (as shown in Fig. 2 and Table 7) to the pairwise comparisons among all criteria in the dimensions of a hierarchy system. The result of the comparisons is constructed as fuzzy pairwise comparison matrices ($\tilde{A}$) as shown in Eq. (1).

Step 2: Examine the consistency of the fuzzy pairwise comparison matrices. According to the research of Buckley (1985), it proves that if $A = [a_{ij}]$ is a positive reciprocal matrix then $\tilde{A} = [\tilde{a}_{ij}]$ is a fuzzy positive reciprocal matrix. That is, if the result of the comparisons of $A = [a_{ij}]$ is consistent, then it can imply that the result of the comparisons of $\tilde{A} = [\tilde{a}_{ij}]$ is also consistent. Therefore, this research employs this method to validate the questionnaire.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \qquad (1)$$

Step 3: Compute the fuzzy geometric mean for each criterion. The geometric technique is used to calculate the geometric mean ($\tilde{r}_i$) of the fuzzy comparison values of criterion i to each criterion, as shown in Eq. (2), where $\tilde{a}_{in}$ is a fuzzy value of the pairwise comparison of criterion i to criterion n (Buckley, 1985).

$$\tilde{r}_i = [\tilde{a}_{i1} \otimes \cdots \otimes \tilde{a}_{in}]^{1/n} \qquad (2)$$

Step 4: Compute the fuzzy weights by normalization. The fuzzy weight of the ith criterion ($\tilde{w}_i$), can be derived as Eq. (3), where $\tilde{w}_i$ is denoted as $\tilde{w}_i = (lw_i, m_{w_i}, u_{w_i})$ by a TFN and l_{wi}, m_{wi}, and u_{wi} represent the lower, middle and upper values of the fuzzy weight of the ith criterion.

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} \qquad (3)$$

Table 8
Partial list of the FDM questionnaire.

Dimension/criteria/sub-criteria	Range (on a scale of 1–10) of importance									
I: Personal characteristics*	**1**	**2**	**3**	④	**5**	**6**	⑦	**8**	**9**	**10**
Personality (IP)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Challenge acceptance	1	2	3	4	5	6	7	8	9	10
2. Expressiveness	1	2	3	4	5	6	7	8	9	10
3. Independent thinking	1	2	3	4	5	6	7	8	9	10
4.Curiousity	1	2	3	4	5	6	7	8	9	10
Motive (IM)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Self-satisfaction	1	2	3	4	5	6	7	8	9	10
2. Personal interest	1	2	3	4	5	6	7	8	9	10
3. Reward history	1	2	3	4	5	6	7	8	9	10
4. Opportunity for development	1	2	3	4	5	6	7	8	9	10
5. Understanding self- potential	1	2	3	4	5	6	7	8	9	10
Knowledge (IK)	1	2	3	4	5	6	7	8	9	10
1. Professional knowledge	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2. Reading	1	2	3	4	5	6	7	8	9	10
3. Lifetime learning	1	2	3	4	5	6	7	8	9	10

Note: * indicates "the most possible range (on a scale of 1–10)" of importance for each item. For example, the most possible range of importance for the criterion, "I: Personal characteristics", is between 4 and 7.

Step 5: *Defuzzy*: The study finds the best crisp value, Best Nonfuzzy Performance (BNP), in accordance with the Center of Area (COA) or Center Index (CI) concept, which was developed by Teng and Tzeng (1993). The BNP value of the fuzzy number, the weight for each criterion, can be calculated by Eq. (4).

$$\text{BNP}_i = \frac{(U_i - L_i) + (M_i - L_i)}{3} + L_i, \quad \forall i \tag{4}$$

3.4. Data collection and questionnaire design

In this study, the surveys of questionnaires for the collection of experts' opinions were conducted by the researchers personally. All the participants were contacted by telephone in advance for making sure the visiting time. The important influential creativity factors (4 dimensions, 11 criteria, and 46 sub-criteria), as summarized in Tables 2–6, were synthesized from an extensive literature review. These factors were confirmed in consultation with relevant experts, adjusted, and then used to create formal questionnaires. The surveys were conducted in two stages. The questionnaire used in the first stage contains two parts: (1) Importance evaluation of factors affecting college students' creativity and (2) basic information regarding the experts' background. Partial list of the FDM questionnaire is shown in Table 8. The respondents were asked to suggest a "most possible range (on a scale of 1–10)" of importance for each item (criterion/sub-criterion) based on their professional judgments. For instance, if the expert considers the importance range (min–max) of the item, "I: Personal characteristics", can be rated between 4 (minimum) and 7 (maximum), then he or she marks these two numbers, 4 and 7, properly.

In the second stage, the FAHP questionnaire was constructed using the critical influential factors screened by the FDM analysis, the data culled from the first-stage questionnaires. Similarly, the FAHP questionnaire includes two parts: (1) pair-wise comparisons of importance among the factors and (2) basic information regarding the experts' background. A sample of the FAHP questionnaire (for "dimensions" in the first level) is given in Table 9. The experts were requested to estimate

Table 9
Partial list of the FAHP questionnaire (for the level of dimensions).

Dimension/Criteria/Sub-Criteria	Considering the dimensions (or criteria/sub-criteria) listed on the **left-hand** side and the **right-hand** side, please indicate the "**relative importance**" between them. 9:1 8:1 7:1 6:1 5:1 4:1 3:1 2:1 1:1 1:2 1:3 1:4 1:5 1:6 1:7 1:8 1:9	Dimension/Criteria/ Sub-Criteria
Personal characteristics (I)	☐ ☐ ☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	**Family background (F)**
Personal characteristics (I)	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	**School element (S)**
Personal characteristics (I)	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	**Community (C)**
Family background (F)	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	**School element (S)**
Family background (F)	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	**Community (C)**
School element (S)	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	**Community (C)**

Note: The descriptions of each scale: 1, "equal importance"; 3, "weak importance"; 5, "essential importance"; 7, "very strong importance"; 9, "absolute importance"; 2, 4, 6, and 8, intermediate values.

Table 10
Demographic results of expert group.

Variables Gender	No.	%	Variables Age	No.	%	Variables Occupation	No.	%	Variables Education	No.	%
Male	25	62.50	Under 30 years	2	0.05	Finance	4	10.00	Senior high	1	2.50
Female	15	37.50	31–40 years	10	0.25	Restaurant	4	10.00	Associate	3	7.50
Service year			41–50 years	17	0.43	Manufacturing	4	10.00	Bachelor	6	15.00
Under 5 years	3	7.50	Above 51 years	11	0.28	Service	4	10.00	Master	4	10.00
6–10 years	15	37.50				Cultural Education	24	60.00	Doctor	26	65.00
11–20 years	17	42.50				Others	0	0.00	Others	0	0.00
Above 21 years	5	12.50									

the relative importance between paired factors based on the Saaty's 9-point priority scale as shown in Table 7. For instance, if the expert considers the dimension, "Personal characteristics (I)," has "very strong importance" compared with "Family background (F)", then he or she marks "7:1". The same rules of pairwise comparisons are applied to the remaining criteria/sub-criteria.

4. An empirical study

In this study, we consulted 40 senior experts. Among them, 24 senior experts are from academics, and the rest are practitioners. The background of senior experts comprises finance, restaurant, manufacturing, service, and cultural educational industries. Because the study is focused on investigating the critical influential factors of creativity for university/college students, the majority of senior experts are professors (about 60%). All of them have experience with creativity-related education and paper publication in journals. The rest are senior managers of companies who have experience in participating in creativity-related activities (e.g., training, planning, seminar, etc.). Demographic results are summarized in Table 10. Most (about 71%) of the participants are more than 40 years old. The average service year of all senior experts is above 15 years, and there are five senior experts with more than 21 years of experience.

4.1. Extracting the critical creativity factors by FDM

Drawing on the literature, this research categorized factors influencing the creativity of college students into four major dimensions: "Personality (I)," "Family Background (F)," "School element (S)," and "Community (C)." Eleven influential criteria (main factors) and 46 influential sub-criteria (secondary factors) were also identified. The FDM was initially carried out based on the initially built hierarchy. Upon identification of factors with degree of importance above a certain level, hierarchical levels to evaluate key factors influencing creativity were established. After that, a FAHP questionnaire analysis was conducted to explore the weights of selected factors (i.e., dimensions, criteria, and sub-criteria).

As presented in Table 11, findings generated by using the max–min FDM (see Appendix B) illustrated that scores of all the factors X^* were distributed in the range of 6–7.5. In this study, the threshold value was set to 7 by the experts. The main factors (criteria) "IM: Motive," "IK: Knowledge," "FP: Parental rearing style," and "SS: School environment" had the highest scores, 7.5. The other main factors also scored above the threshold value. There were four secondary factors (sub-criteria) with an X^* value of 7.5, namely, "Freedom to act," "Family caring for each other," "stimulating imagination," and "role model for learning." There were 17 other secondary factors (sub-criteria) that scored below the threshold value, e.g., "Expressiveness," "Reward history," "Opportunity for development," "Reading," "Strictness," "Avoiding over discipline," and "Parent–child communication," etc.

Based on the findings, taking the example of the main factor "FP: Parental rearing style," we found that the degree of importance of its secondary factor "Strictness" did not reach 7, the threshold value set in this study. This result implied that its degree of importance was lower than the other secondary factors because experts believed that being strict with children was not beneficial to the stimulation of their creativity. Therefore, its degree of importance was lower than other secondary factors. The other secondary factor that failed to reach the threshold value was "Avoiding over discipline." This finding indicated that over discipline might cause children, for example, to be overly cautious, conservative, or to blindly follow the crowd's opinion for fear of making mistakes, being ridiculed or scolded, which gave little contribution to the positive development of creativity of college students. Among the main factors, "IM: Motive," "IK: Knowledge," "FP: Parental rearing style," and "SS: School environment" scored 7.5, which was the highest score. These were the factors experts believed to be constructive to the development of the creativity of college students. Therefore, these were listed as important factors in this study. After summarizing the experts' consensus by utilizing the FDM, the original 11 criteria (main factors) and 46 sub-criteria (secondary factors) were reduced to 11 criteria and 29 sub-criteria. The selected factors were then structured into a hierarchy to form the basis of the FAHP for weight analysis.

The influential criteria "IP: Personality" (main factor) was taken as an example in this part to illustrate the steps of analysis in the FDM:

Table 11
The analysis result of fuzzy Delphi method (FDM).

Dimension/criteria/sub-criteria	C_1	D_1	C_2	D_2	X^*
I: Personal characteristics					
Personality (IP)	8	10	4	6.5	7.25
1. Challenge acceptance	8	10	3	6	7
2. Expressiveness	7	10	3.5	6	6.5
3. Independent thinking	8	10	4	6	7
4. Curiousity	8.5	10	4.5	6	7.25
Motive (IM)	8	9.5	4	7	7.5
1. Self-satisfaction	8	9.5	4	6	7
2. Personal interest	8	9.5	3.5	6	7
3. Reward history	8	9	3	5.5	6.75
4. Opportunity for development	7	9	3	6	6.5
5. Understanding self-potential	8	10	3	6	7
Knowledge (IK)	8	9	4	7	7.5
1. Professional knowledge	8	10	4	6	7
2. Reading	7	9	4	6	6.5
3. Lifetime learning	8	10	3	6	7
F: Family background					
Parental rearing style (FP)	8	10	3	7	7.5
1. Strictness	7	9	3	5	6
2. Creative thinking potentials	8	9	4	6	7
3. Communication skills	8	10	4	6	7
4. Avoiding over discipline	7.5	9	3	5	6.25
5. Freedom to act	8	10	3.5	7	7.5
Family environment (FL)	8	10	4	7	7.5
1. Liberal and open climate	8	10	3.5	6	7
2. Parent–child communication	7	9	4	6	6.5
3. Family caring for each other	8	9	3	7	7.5
4. Stimulating imagination	8	10	4	7	7.5
5. Expectation for their children	7	9.5	3	6	6.5
Subject identity of children (FC)	8	10	4	6.5	7.25
1. Parent's occupation	7	9	3	6	6.5
2. Parent's hobby	7	9	3	6	6.5
3. Parent's characteristics	8	9	3.5	6	7
4. Role model for learning	8	10	4	7	7.5
S: School element					
Peer relations (SC)	8	10	4	6	7
1. Friends caring for each other	8	10	4	6	7
2. Exchange of opinions	8	10	4	6	7
3. Participation in activities	7.5	9	4	6	6.75
4. Competitive environment	8	10	4	6	7
5. Proactive learning	7	10	4	6	6.5
Teacher–student interaction (ST)	7	9	4	7	7
1. Creative teaching	7	9.5	4	6.5	6.75
2. Creating positive learning atmosphere in class	7	9	4	6	6.5
3. Encouraging creative thinking	8	9	3	6	7
4. Developing learning abilities	7	10	4	6	6.5
5. Harmonious learning environment	8	9	3.5	6	7
School environment (SS)	8	9.5	3.5	7	7.5
1. Providing creative courses	8	9	4	6	7
2. Teaching resources	7.5	10	4	6	6.75
3. Emphasis on creativity	8	9	4	6	7
4. Safe learning environment	8	9.5	3.5	6	7
C: Community					
Social education environment (CE)	8	9	4	6.5	7.25
1. Social education	8	9	4	6	7
2. Integration of creative education	8	10	4	6.5	7.25
3. Expansion of professional knowledge	8	10	4	7	7.5
Social cultural environment (CC)	7	9	6	7.5	7.25
1. Cultural traits	7	9	3	6	6.5
2. Respect for intellectual properties	7.5	9	4	7	7.25
3. Oppressive environmental behavior	7.5	9.5	5	6.5	7

Note: Sub-criteria with underline are deleted due to values below the threshold value ($X^* < 7$).

Table 12

The cumulative frequency of max–min evaluated values for personality (IP).

Evaluation value	1	2	3	4	5	6	7	8	9	10
Frequency of maximum score (Max)	0	0	0	0	0	0	3	11	11	15
F1: Cumulative frequency of max score	0	0	0	0	0	0	3	14	25	40
Frequency of minimum score (min)	0	2	7	6	10	5	6	1	3	0
F2: Cumulative frequency of min score	40	40	38	31	25	15	10	4	3	0

(1) Establish the cumulative distribution function $F_1(X)$ of the maximum degree of agreement and the cumulative distribution function $F_2(X)$ of the minimum degree of agreement. Based on the statistics of the returned questionnaires, the degree of importance of the main factor "IP: Personality," as deemed by all the experts, can be concluded. It included the "acceptable maximum value (max)" and the "acceptable minimum value (min)." The cumulative frequency of max- and min-evaluated values related to the main factors is listed in Table 12.

(2) Calculate the respective lower quartiles, medians, and upper quartiles of both $F_1(X)$ and $F_2(X)$ Use symbols (C_1, M_1, D_1) and (D_2, M_2, C_2) to represent the respective results. From the cumulative frequency of the respective max and min values of $F_1(X)$ and $F_2(X)$ in Table 12, the lower quartiles, medians, and upper quartiles of both $F_1(X)$ and $F_2(X)$ can be obtained. They were $F_1(X) = (C_1, M_1, D_1) = (8, 9, 10)$ and $F_2(X) = (D_2, M_2, C_2) = (6.5, 5.25, 4)$.

(3) The degree of importance of the subject X^* can be obtained by linking the point of intersection of (C_1, M_1, D_1) and (C_2, M_2, D_2). During calculation, the arithmetic mean of C_1 and D_1 was considered the point of intersection X^* of functions $F_1(X)$ and $F_2(X)$. Therefore, the X^* of the "personality" influential criteria (main factor) was calculated as $X^* = (C_1 + D_2)/2 = (8 + 6.5)/2 = 7.25$, indicating that the degree of importance of this influential criteria was 7.25. The same method may be repeated to calculate the degree of importance of other criteria in the hierarchy of the FDM (as shown in Table 11).

The threshold value will decide the number of factors to be selected. If the selected factors are too few, then the threshold value may be reduced to increase the number of factors. If the selected factors are too many, then the threshold value may be raised to reduce the number of factors. Therefore, the appropriate threshold value is solely the subjective determination of the researcher. This study drew on the recommendations of past related scholars (Bass & Kwakernaak, 1977; Chen, 1985; Tong & Bonissone, 1984) and set the threshold value at the median of the assessment value, i.e., 7. Therefore, factors with X^* more than 7 were selected to be the weight evaluation factors in the FAHP computation.

4.2. Weighting the selected critical creativity factors by FAHP

According to the analysis results of surveying senior experts by using FDM expert questionnaires in the first stage (in Table 11), the hierarchical evaluation structure of the selected critical influential factors for college students' creativity is thus developed as shown in Fig. 3. Tables 2–6 summarize the detailed description of each factor (criterion/sub-criterion) in the established structure.

With reference to the introduction of FAHP calculation in Section 3.3, in the second stage, the FAHP method was employed to compute the relative weights of the screened dimensions, criteria, and sub-criteria. The related analysis results of FAHP including the consistent ratios, relative weights, overall rankings of dimensions, criteria, and sub-criteria of creativity for college students are summarized in Table 13. The results show that "C: Community (0.3531)" is the most important influential dimension for college students' creativity, followed by "F: Family background (0.2299)," "S: School element (0.2093)," and "I: Personal characteristics (0.2077)." Furthermore, the importance ranking of criteria are "CC: Social cultural environment (0.1675)," "CE: Social education environment (0.1459)," "FC: Subject identity of children (0.0887)," "IP: Personality (0.0870)," "SS: School environment (0.0850)," "IM: Motive (0.0773)," "FP: Parental rearing style (0.0753)," "FL: Family environment (0.0726)," "ST: Teacher-student interaction (0.0708)," "SC: Peer relations (0.0680)," and "IK: Knowledge (0.0619)."

In addition, the top ten importance ranking of sub-criteria are "Oppressive environmental behavior (CC2) (0.0883)," "Respect for intellectual properties (CC1) (0.0680)," "Integration of creative education (CE2) (0.0519)," "Expansion of professional knowledge (CE3) (0.0517)," "Role model for learning (FC2) (0.0501)," "Social education (CE1) (0.0469)," "Independent thinking (IP2) (0.0391)," "Harmonious learning environment (ST2) (0.0362)," "Lifetime learning (IK2) (0.0352)," and "Personal interest (IM2) (0.0346)." In light of the ranking, it was found that the importance of criteria and sub-criteria basically reflect the importance of dimensions.

5. Discussions

As mentioned previously, unlike the past research that mainly used basic statistic analysis and greatly emphasized the relationships between creativity and other factors by sampling either firm employees or students, this study is attempted to investigate critical cause-factors (dimension/criteria/sub-criteria) affecting creativity for college students by adopting fuzzy MCDM. The current study makes contributions by proposing an analytical model to identify the most crucial factors that can be enhanced to help promote college students' creativity development.

Table 13
Summary of the weights and rankings of the critical influential dimensions, criteria, and sub-criteria on college students' creativity.

Dimension/criteria/sub-criteria	Local weight	Global weight	BNP	Normalized BNP	Ranking
I: Personal characteristics (C.R. = 0.0193)	**(0.0885, 0.2055, 0.4853)**		**0.2598**	**0.2077 (4)**	
IP: Personality (C.R. = 0.0148)	(0.1816,0.3807,0.8207)	(0.0161,0.0782,0.3983)	0.1642	0.0870 (1)	**4**
Challenges acceptance (IP1)	(0.1582,0.3196,0.6777)	(0.0025,0.0250,0.2699)	0.0992	0.0344 (2)	11
Independent thinking (IP2)	(0.1765,0.3928,0.7644)	(0.0028,0.0307,0.3045)	0.1127	0.0391 (1)	7
Curiousity (IP3)	(0.1506,0.2875,0.6182)	(0.0024,0.0225,0.2463)	0.0904	0.0314 (3)	16
IM: Motive (C.R. = 0.0144)	(0.1560,0.3559,0.7229)	(0.0138,0.0731,0.3508)	0.1459	0.0773 (2)	**6**
Self-satisfaction (IM1)	(0.1579,0.3196,0.6824)	(0.0022,0.0234,0.2394)	0.0883	0.0307 (2)	17
Personal interest (IM2)	(0.1727,0.3928,0.7626)	(0.0024,0.0287,0.2675)	0.0996	0.0346 (1)	10
Understanding self-potential (IM3)	(0.1503,0.2875,0.6346)	(0.0021,0.0210,0.2226)	0.0819	0.0284 (3)	21
IK: Knowledge (C.R. = 0)	(0.1319,0.2635,0.5863)	(0.0117,0.0541,0.2845)	0.1168	0.0619 (3)	**11**
Professional knowledge (IK1)	(0.2532,0.4103,0.6116)	(0.0030,0.0222,0.1740)	0.0664	0.0231 (2)	26
Lifetime learning (IK2)	(0.3906,0.5897,0.9419)	(0.0046,0.0319,0.2680)	0.1015	0.0352 (1)	9
F: Family background (C.R. = 0.0868)	**(0.0975, 0.2330, 0.5322)**		**0.2876**	**0.2299 (2)**	
FP: Parental rearing style (C.R. = 0.0133)	(0.1539,0.3237,0.6314)	(0.0150,0.0754,0.3360)	0.1422	0.0753 (2)	**7**
Creative thinking potentials (FP1)	0.1503,0.3144,0.6008	(0.0023,0.0237,0.2019)	0.0760	0.0264 (3)	24
Communication skills (FP2)	(0.1594,0.3361,0.6546)	(0.0024,0.0253,0.2200)	0.0826	0.0287 (2)	20
Freedom to act (FP3)	(0.1936,0.3495,0.7316)	(0.0029,0.0264,0.2459)	0.0917	0.0318 (1)	15
FL: Family environment (C.R. = 0.0124)	(0.1503,0.3137,0.6070)	(0.0147,0.0731,0.3230)	0.1369	0.0726 (3)	**8**
Liberal and open climate (FL1)	(0.1503,0.3144,0.6008)	(0.0022,0.0230,0.1941)	0.0731	0.0254 (3)	25
Family caring for each other (FL2)	(0.1594,0.3361,0.6546)	(0.0023,0.0246,0.2115)	0.0795	0.0276 (2)	22
Stimulating imagination (FL3)	(0.1936,0.3495,0.7316)	(0.0028,0.0255,0.2363)	0.0882	0.0306 (1)	18
FC: Subject identity of children (C.R. = 0)	(0.1990,0.3626,0.7487)	(0.0194,0.0845,0.3985)	0.1675	0.0887 (1)	**3**
Parent's characteristics (FC1)	(0.2532,0.4103,0.6116)	(0.0049,0.0347,0.2437)	0.0944	0.0328 (2)	13
Role model for learning (FC2)	(0.3906,0.5897,0.9419)	(0.0076,0.0498,0.3753)	0.1442	0.0501 (1)	5
S: School element (C.R. = 0.0721)	**(0.0899, 0.2040, 0.4916)**		**0.2618**	**0.2093 (3)**	
SC: Peer relations (C.R. = 0.0041)	(0.1408,0.3112,0.6278)	(0.0127,0.0637,0.3087)	0.1283	0.0680 (3)	**10**
Friends caring for each other (SC1)	(0.2645,0.2827,0.2191)	(0.0033,0.0180,0.0676)	0.0297	0.0103 (3)	29
Exchange of opinions (SC2)	(0.3179,0.3353,0.2976)	(0.0040,0.0214,0.0919)	0.0391	0.0136 (2)	28
Competitive environment (SC3)	(0.3649,0.3820,0.5390)	(0.0046,0.0243,0.1664)	0.0651	0.0226 (1)	27
ST: Teacher-student interaction (C.R. = 0)	(0.1500,0.3225,0.6546)	(0.0135,0.0658,0.3218)	0.1337	0.0708 (2)	**9**
Encouraging creative thinking (ST1)	(0.2902,0.5015,0.7495)	(0.0039,0.0330,0.2412)	0.0927	0.0322 (2)	14
Harmonious learning environment (ST2)	(0.3326,0.4985,0.8561)	(0.0045,0.0382,0.2755)	0.1043	0.0362 (1)	8
SS: School environment (C.R. = 0.0151)	(0.1912,0.3653,0.7924)	(0.0172,0.0745,0.3896)	0.1604	0.0850 (1)	**5**
Providing creative courses (SS1)	(0.2074,0.3664,0.6804)	(0.0036,0.0273,0.2651)	0.0986	0.0343 (1)	12
Emphasis on creativity (SS2)	(0.1675,0.3078,0.5383)	(0.0029,0.0229,0.2097)	0.0785	0.0273 (3)	23
Safe learning environment (SS3)	(0.1795,0.3258,0.5854)	(0.0031,0.0243,0.2280)	0.0851	0.0296 (2)	19
C: Community (C.R. = 0)	**(0.1548, 0.3576, 0.8152)**		**0.4416**	**0.3531 (1)**	
CE: Social education environment (C.R. = 0.0955)	(0.3069,0.5065,0.7350)	(0.0475,0.1811,0.5972)	0.2753	0.1459 (2)	**2**
Social education (CE1)	(0.1656,0.2987,0.5743)	(0.0079,0.0541,0.3430)	0.1350	0.0469 (3)	6
Integration of creative education (CE2)	(0.1956,0.3683,06235)	(0.0093,0.0667,0.3723)	0.1494	0.0519 (1)	3
Expansion of professional knowledge (CE3)	(0.1851,0.3330,0.6328)	(0.0088,0.0603,0.3779)	0.1490	0.0517 (2)	4
CC: Social cultural environment (C.R. = 0)	(0.3081,0.4935,0.8910)	(0.0477,0.1765,0.7239)	0.3160	0.1675 (1)	**1**
Respect for intellectual properties (CC1)	(0.2726,0.4624,0.6813)	(0.0130,0.0816,0.4933)	0.1959	0.0680 (2)	2
Oppressive environmental behavior (CC2)	(0.3603,0.5376,0.8987)	(0.0172,0.0949,0.6506)	0.2542	0.0883 (1)	1

Note: (1) All comparisons are consistent (C.R. <0.1). (2) The numbers inside the bracket "( )" indicate ranking of criteria/sub-criteria by local weights.

The 1st level Goal	The 2nd level Dimension	The 3rd Criteria	The 4th level Sub-criteria

Constructing Critical Evaluation Criteria of Creativity for College Students

- **Personal characteristics (I)**
  - Personality (IP)
    - Challenge acceptance (IP1)
    - Independent thinking (IP2)
    - Curiousity (IP3)
  - Motive (IM)
    - Self-satisfaction (IM1)
    - Personal interest (IM2)
    - Understanding self-potential (IM3)
  - Knowledge (IK)
    - Professional knowledge (IK1)
    - Lifetime learning (IK2)
- **Family background (F)**
  - Parental rearing style (FP)
    - Creative thinking potentials (FP1)
    - Communication skills (FP2)
    - Freedom to act (FP3)
  - Family environment (FL)
    - Liberal and open climate (FL1)
    - Family caring for each other (FL2)
    - Stimulating imagination (FL3)
  - Subject identity of children (FC)
    - Parent's characteristics (FC1)
    - Role model for learning (FC2)
- **School element (S)**
  - Peer relations (SC)
    - Friends caring for each other (SC1)
    - Exchange of opinions (SC2)
    - Competitive environment (SC3)
  - Teacher-student interaction (ST)
    - Encouraging creative thinking (ST1)
    - Harmonious learning environment (ST2)
  - School environment (SS)
    - Providing creative courses (SS1)
    - Emphasis on creativity (SS2)
    - Safe learning environment (SS3)
- **Community (C)**
  - Social education environment (CE)
    - Social education (CE1)
    - Integration of creative education (CE2)
    - Expansion of professional knowledge (CE3)
  - Social cultural environment (CC)
    - Respect for intellectual properties (CC1)
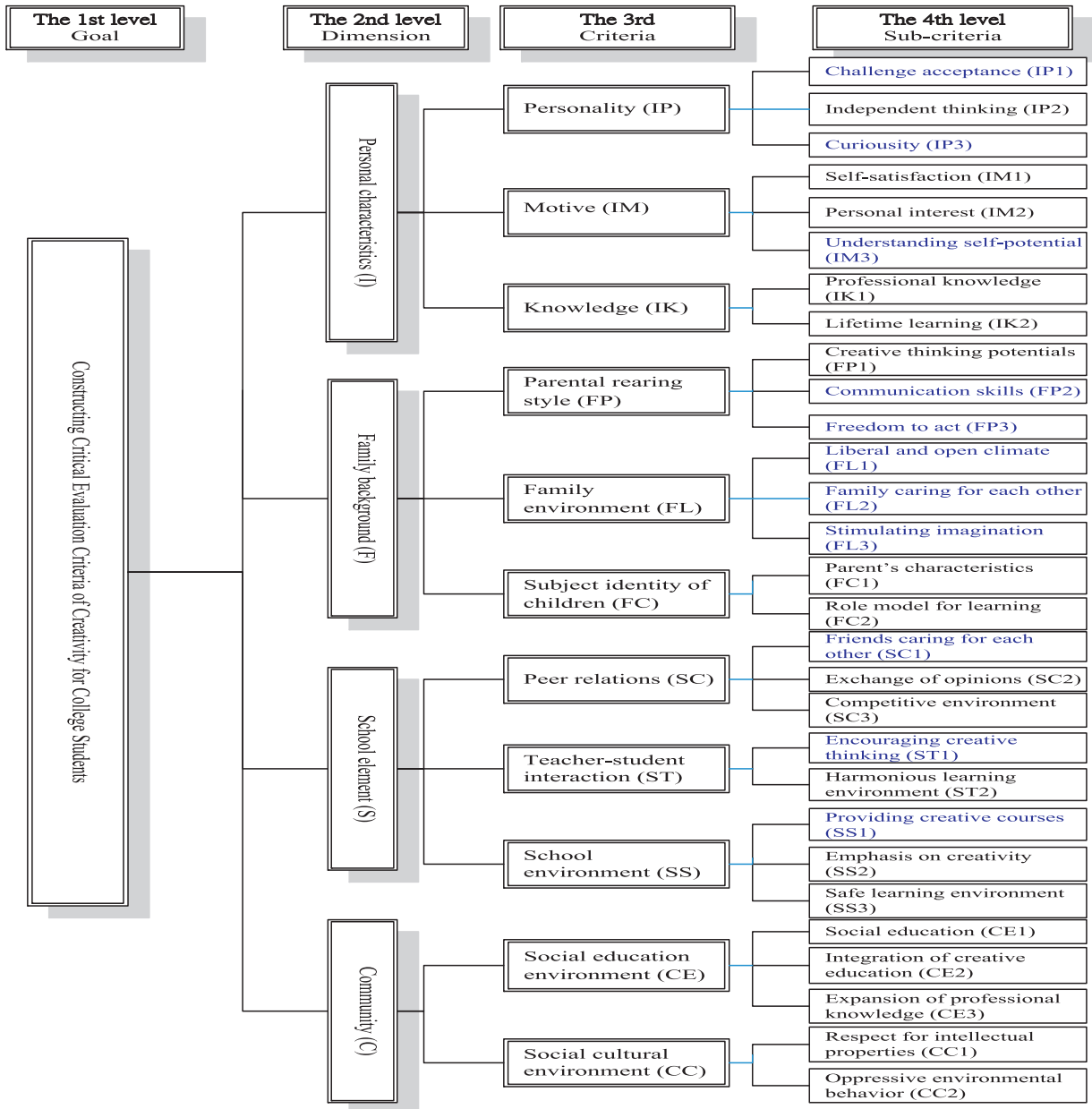   - Oppressive environmental behavior (CC2)

Fig. 3. The hierarchical evaluation structure of critical influential factors for college students' creativity.

The analytical process as well as the analytical tools adopted by the current study can be justified in dealing with the current research problem. The reasons why are as follows. First, basically, the classification of the factors contributing creativity is generalized from document analysis of an extensive literature review and consulting with related experts for appropriateness of college students. More specifically, some of the most common factors accepted by the major literature on creativity-related topics are compiled. Second, different form the traditional questionnaire analysis using statistical methods to test its reliability and validity, the current study conducts two-stage expert questionnaire surveys: (1) to screen out key factors (criteria/sub-criteria) based on the experts' consensus using FDM and (2) to prioritize the relative importance using FAHP along with consistent ratio checking (C.R. <0.1). Both of the analytical tools (FDM and FAHP) are confirmed as two of the popular MCDM approaches that have been successfully employed in expert questionnaire analysis by numerous studies. However, for the current study, like general studies, it is inevitable there are still inherent biases due to some restrictions. For example, bounded rationality may exist in document analysis. And the consulted expert groups limited in the same country may not be well representative of the whole.

Referring to the analysis results, the findings exhibited some controversies. The sequence of importance concluded by the FDM from the degree of importance X^* (as in Table 11) of the consensus conflicted with the conclusions from the relative weight values (as in Table 13) by the FAHP. For example, the former concluded that "Respect for intellectual property (CC1)" ($X^* = 7.25$) > "Oppressive environmental behavior (CC2)" ($X^* = 7$), whereas the latter concluded that "Respect for intellectual property (CC1)" (normalized BNP = 0.0680) < "Oppressive environmental behavior (CC2)" (normalized BNP = 0.0883). Generally, the sequence of importance of factors (dimensions, criteria, and sub-criteria) concluded from the FAHP should prevail over other findings due to the fact that the FDM only required the experts to give brief opinions on the importance of each factor. The objective of FDM was preliminary selection. However, the FAHP conducted pairwise comparisons, which were relatively more precise. The FAHP results were also confirmed by a consistency test (C.R. <0.1). Apart from that, this study included fuzzy theory so that the analysis has a closer proximity to human logical thinking. Thus, the findings of this study can best reflect the actual facts behind the complex reality (Zadeh, 1965).

The above findings demonstrated that the related experts unanimously consented that the community produced the major effects on the creativity of the college students. As listed in Table 13, looking at the detail, within the dimension of community containing two criteria (social education environment and social culture environment), the effects of oppressive environmental behavior ranked the highest, implying that to enhance creativity of the college students, a good place to start is in the community. Particularly, competition, harshness from the external environment, is inevitable stress in life and considered a factor unfavorable to the stimulation of creativity in the past. Nevertheless, healthy competition in oppressive environment can actually unlock potential, promote perseverance, and, in turn, foster the creativity of a person. Moreover, the prerequisites of doing this are the existence of an innovative, diversified, proactive, and unselfish cultural environment wherein differences are respected and a lively and joyful learning environment is created. In addition, concepts about respect for intellectual properties should also be integrated into the education system. Beyond these conditions, official policies or reports related to creativity or creative education may be promoted and implemented in all walks of life, through government institutions such as education, science and technology, communication, and arts. Likewise, non-governmental associations related to works of "creativity" should be established to assist in the development of professional knowledge of creativity and, in turn, encouragement of creativity of the people.

Apart from social environment (i.e., community) delivered through, the other dimensions affecting creativity of college students are, in sequence of importance, family, school, and personal characteristics. Therefore, creativity should be inspired from a young age, despite the differences in family backgrounds, meaning that parents should become role models for their children. The best way to learn and to enhance creativity is to observe and imitate a creative role model. Both learning at home and in school can develop creativity in students. Moreover, schools provide a harmonious learning environment, one of the essential factors of creativity development. Schools offer a safe environment, training and courses to sharpen thinking ability, creative role models via teachers, vision and confidence to the students to encourage them to create, and role models for learning via peers and fellow students. Especially, lifelong learning is one of the keys to survival in this competitive economy overloaded with information. As information increases exponentially, to express our creativity and add value to ourselves, we need to experience continuous education, be thorough in our thinking, and flexibly make use of what we learn.

Findings in this study showed that within the category of personal characteristics, the experts considered that college students who have independent and decisive personality may have higher creativity. This result is consistent with the findings of the abovementioned research by Montgomery et al. (1993) studying the key characteristics affecting the creativity of college students. Other factors such as personal hobbies and curiosity will interact with the knowledge learned and cultural stimulation from home, schools, community, or even the entire society. This interaction will enable the individual to experience creativity and understand the meaning of construction. Motives to pursue a hobby will cause a person to behave in a certain way, which is called an "internal motive." Individuals possessing such motives tend to be adventurous and prefer challenging jobs. This finding is consistent with the creative thinking process model proposed by Baker et al. (2001), which emphasized the pre- and post-relations of variables affecting the creative thinking process. Our study, however, emphasized the relative importance of factors affecting creativity.

Some findings in this study correlate with other related studies in the past. In this study, the overall importance ranking of "Oppressive environmental behavior (CC2)" was "1," indicating that it was the most critical factor affecting the creativity of the college students. This finding correlates with those of Mellou (1996), who argued that creativity arises from appropriate stimulations in the environment. Additionally, as shown in Fig. 3 and Table 13, the third level of evaluation hierarchy of this study contained 11 influential criteria. The "IK: Knowledge" criteria (with overall importance ranked as "11") were the least important criterion for college students' creativity, compared to the other criteria. However, interestingly, two out of the 29 sub-criteria within the forth level of evaluation hierarchy, i.e., "Professional knowledge (IK1)" (ranked as "26") and "Lifelong learning (IK2)" (ranked as "9"), have varying relative degrees of importance, implying that experts believe that developing creativity through lifelong learning is far more effective than through formal education. Attitude and desire to learn are stronger influential factors of creativity potential compared to the level of professional knowledge. Thus, it can explain the reason why individuals with low levels of education but good practice in learning knowledge through personal interest cultivation and continuous education may turn out to be inventors. Knowledge is the basis of creation, and "Professional knowledge (IK1)" may be acquired through informal learning channels, such as "Lifelong learning (IK2)." It implies that the two criteria may have cause and effect relations or may be "collinear." Therefore, the contribution and limitation of knowledge toward creativity should be given further consideration to avoid exaggeration or improper speculation.

6. Conclusions

In this economic era of rapid information growth, intellectual capital, as an intangible asset of an organization, is given increasing attention. Creative thinking, critical thinking, and problem-solving abilities are all important basic qualities for the future generation. Among these qualities, innovation capital reflects a staff's ability to innovate and create. Tertiary institutions, generating scholars and intellects, are responsible for training creative individuals suited to the demands of today's society. In response to the swiftly changing global economy and to adapt to the new information economy era, this study applied multiple criteria analysis to prioritize the factors affecting the creativity of college students. The FDM was used to effectively compile consensus among experts in the related field and determine the main influential factors. A FAHP was also employed to calculate relative weights of the criteria/sub-criteria from hierarchy levels and defuzzification using the synthesized experts' opinions. The sequence of importance of each factor was then determined. Being different from the former studies focusing on the assessment of creativity (measuring the degree of creativity) or examining the relationship between creativity factors, the current study contributes to the recent research on practical use in determining the most critical and influential factors of college students' creativity with an aim to establish priorities among criteria/sub-criteria, in line with the need for creative individuals in this era. More precisely, the prioritized weights analyzed by the proposed model can not only serve as a useful self-assessment tool for college students to better understand influential factors on their own creative abilities for enhancing their potential creativity, but also can provide an important reference for educational units and/or interested parties in policy making and strategies to help effectively enhance college students' creativity development.

Although efforts were devoted to making the results of this study precise, limitations are always present. First, like all the other professional questionnaires, both the expert questionnaire surveys using FAHP and FDM, responses are necessarily limited to human subjective consciousness due to the nature of decision making reflected in the subjective ability of human beings. Second, it is unavoidable that forming an expert panel may lead to a bias in the selection of criteria/sub-criteria since the elected expert groups may not stand for the whole. Third, the subjective judgments of related experts about the different perspectives may vary from each other. As illustrated earlier, in addition to make sure the consistency (C.R. <1), to reduce the variation of opinions, in this study, the results of the FAHP analysis, which is derived from an average of the inputs from the experts, were further confirmed by interviews with the committees of experts as part of an attempt to ensure consensus through a more complex perspective. And this is time-consuming work. Fourth, to fit the purpose of the current study, the selected influential factors (criteria/sub-criteria) with respect to creativity are primarily considered for appropriateness of college students. It may not be suitable to other people (e.g., students of different ages). Therefore, necessary precautions should be taken about the applicability of the results to other situations.

Some important recommendations for future work are summarized as follows. First, this study explored and analyzed the major literature related to creativity. The factors that commonly affect creativity are then referred in the current research. Since studies related to creativity are extensive and cover a wide domain, it is inevitable that there will be omissions and overly subjective views in this study. As market trends and demand changes with time, it is recommended that future studies involve other dimensions or related variables (e.g., age, gender, inheritance, and health conditions) in the analysis. Second, in this study, the influential factors were prioritized by FAHP without considering the interaction and feedback among the factors. To make the analytical model more complete and objective, the other analytical tools such as fuzzy integral and analytic network process can be applied. Third, based on the research findings of the current study, further work may include related strategy development for improvement and/or enhancing college students' creativity. Forth, a follow-up case study, along with in-depth analyses and comparisons, should be conducted for achieving more comprehensive insight about the factors that can shape college students' creativity. Finally, the proposed analysis model can be extended to other subjects of study (e.g., the working class in enterprises, institutions, or organizations).

Acknowledgements

Appendix A. Fuzzy number

Fuzzy numbers are a fuzzy subset of real numbers, and they represent the expansion of the idea of a confidence interval. According to the definition by Dubois and Prade (1978), the fuzzy number $\tilde{A}$ is of a fuzzy set, and its membership function is $\mu_{\tilde{A}}(x)R \to [0, 1]$ $(0 \leqq \mu_{A}(x) \leqq 1, x \in X)$, where x represents the criterion and is described by the following characteristics: (1) $\mu_{\tilde{A}}(x)$ is a continuous mapping from R (real line) to the closed interval [0,1]; (2) $\mu_{\tilde{A}}(x)$ is of a convex fuzzy subset; (3) $\mu_{\tilde{A}}(x)$ is the normalization of a fuzzy subset, which means that there exists a number x_0 such that $\mu_{\tilde{A}}(x_0) = 1$. For instance,
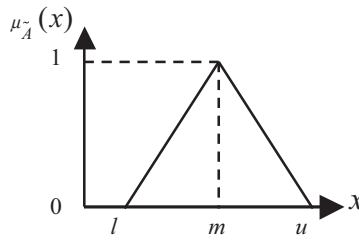
Fig. A1. Membership function of triangular fuzzy number (TFN).

the triangular fuzzy number (TFN), $\tilde{A} = (l, m, u)$, can be defined as Eq. (A1) and the TFN membership function is shown in Fig. A1.

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l), & l \leq x \leq m, \\ (u-x)/(u-m), & m \leq x \leq u, \\ 0, & \text{otherwise,} \end{cases} \tag{A1}$$

Given two positive triangular fuzzy numbers $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$, some algebraic operations of the triangular fuzzy numbers $\tilde{A}_1$ and $\tilde{A}_2$ can be expressed as follows (Eqs. (A2)–(A6)):

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{A2}$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \tag{A3}$$

$$\tilde{A}_1 - \tilde{A}_2 = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \quad l_i > 0, \quad m_i > 0, \quad u_i > 0 \tag{A4}$$

$$\tilde{A}_1 / \tilde{A}_2 = (l_1, m_1, u_1)/(l_2, m_2, u_2) = \left(\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2} \right) l_i > 0, \quad m_i > 0, \quad u_i > 0 \tag{A5}$$

$$\tilde{A}_1^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1} \right) l_i > 0, \quad m_i > 0, \quad u_i > 0. \tag{A6}$$

Appendix B. Fuzzy Delphi method

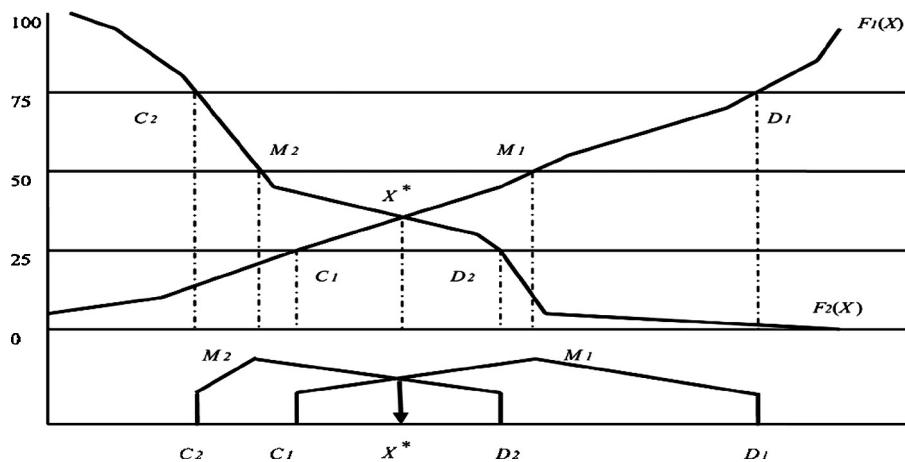Steps of the max–min FDM proposed by Ishikawa et al. (1993) are as follows.

Fig. B1. Max–min FDM forecasting.

Source: Ishikawa et al. (1993) chart.

Step 1: Calculate the cumulative distribution function $F_1(X)$ of the maximum degree of agreement and the cumulative distribution function $F_2(X)$ of the minimum degree of agreement for each assessment factor A_i.

Step 2: Calculate the respective lower quartile, median and upper quartile of both $F_1(X)$ and $F_2(X)$. Use symbols (C_1, M_1, D_1) and (D_2, M_2, C_2) to represent the respective results.

Step 3: The point of intersection between (C_1, M_1, D_1) and (D_2, M_2, C_2) is the degree of importance of the subject, i.e., the target value X^*.

As shown in Fig. B1, the cumulative distribution function $F_1(X)$ of the maximum degree of agreement and the cumulative distribution function $F_2(X)$ of the minimum degree of agreement both exhibit a gray area. Their respective gray areas are the overlapping areas of their respective lower quartiles, medians, and upper quartiles (C_1, X^*, D_2). The point of intersection X^* in each gray area is the target value.

From the above calculation, the predicated value X_i of the assessment factor A_i can be obtained. Then, a threshold value that varies with the requirement of different studies needs to be set for screening most important factors. The threshold value S shall define and determine the assessment factors suited to the study, i.e.:

If $X_i \geqq S$, then A_i will be accepted as the assessment factor.

If $X_i < S$, then A_i will be rejected.

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