Assessment Model for Improving Educational Curriculum Materials Based on the DANP Technique with Grey Relational Analysis

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Received 15 March 2011; received in revised form 18 April 2011; accepted 4 May 2011

ABSTRACT

The core objective of the integrated curriculum of compulsory education is to “enable students to demonstrate their network-talents instead of just scoring high on independent exams.” The key to determining education reform strategies in the e-era is to establish network-competence indicators for educational behavior in primary schools. We propose a MCDM means for evaluating, comparing and improving the effectiveness of network-competence indicators in various publications that are used for teaching at the primary school level. The Mandarin Chinese teaching curriculum based on this system is provided to verify the effectiveness of our method, which may extend to other subject areas.

Keywords: Teaching Curriculum Materials, Multiple Criteria Decision Making (MCDM), DEMATEL-based ANP (DANP), Grey Relational Analysis (GRA).

1. INTRODUCTION

Most countries have made the cultivation of human talent a priority in the twenty-first century. As other advanced countries propose education reform, Taiwan also views education as the bedrock of national development. Taiwan has implemented various education reforms, such as preschool education reform, curriculum reforms for grades 1-9, the restructuring of secondary education, the enhancement of higher education, and projects to promote lifelong learning. This study proposes a set of techniques and evaluation methods to improve, reconfigure and select the most appropriate Aspiring Intelligent Grey Relational Assessment System (AIGRAS) to improve the teaching materials in our education system.

Four British educational reform projects have been implemented since 1990 (DfE, 1991). The report of the Mayer Committee advised the Australian Education Council and the Ministers for Vocational Education, Employment and Training on employment-related key competencies for post-compulsory education and training (Mayer, 1992). The Education Commission of Hong Kong proposed “Learning is the key to one’s future, and education is the gateway to our society’s tomorrow” (EC, 2000).

Regardless of the style of educational reform, key competencies are generally the major concern for national

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reforms at the beginning of the twenty-first century.

The core objective of the Nine-Year Integrated Curriculum of compulsory education in Taiwan is to “enable students to demonstrate their network-talents instead of just scoring high on independent exams.” The key to determining education reform is to establish network-competence indicators of targeted educational standards in primary school and junior high school (MOE, 2002).

Therefore, in this study, we propose a MCDM (multiple criteria decision making) method for evaluating, comparing and improving the effectiveness of competence indicators in the various publications used for curriculum materials in primary school and junior high school. The DANP (DEMATEL-based ANP) (decision making trial and evaluation laboratory, DEMATEL; analytic network process, ANP) weights are based on getting the total relationship/influence-related matrix by DEMATEL method, using an MCDM approach to solve and address the network-relational problems of dependence and feedback involving various criteria. Next, a grey relational analysis (GRA) technique with DANP weights is proposed to determine and implement the best performance indicator related to each criterion for improving, reconfiguring and selecting AIGRAS for the development of curriculum materials. An empirical study involving three publishers based on this system design is provided to verify the effectiveness of the proposed methods. This design may improve the efficiency and quality of Mandarin Chinese teaching curriculum materials; moreover, our work may also apply to other subject areas.

The remainder of this paper is organized as follows. In Section 2, AIGRAS for teaching curriculum materials with MCDM are introduced. In Section 3, a MCDM method based on the DANP method is proposed. In Section 4, an empirical study involving AIGRAS for Mandarin Chinese teaching materials is presented to demonstrate our proposed method, and we discuss the results. Finally, in Section 5, we offer concluding remarks.

2. AIGRAS FOR TEACHING CURRICULUM MATERIALS WITH MCDM

In recent decades, competency-based education has become a major trend, influencing the educational reform strategies of most governments worldwide. In the following subsection, we review the related literature describing core competencies (CCs) and the intertwined effects of an assessment system for teaching materials as a foundation for the development of a theoretical framework.

2.1 Educational Reform in Taiwan (MOE, 2002, 2008)

Taiwan must engage in educational reform to meet the needs of the twenty-first century, respond to global education reform trends, foster national competitiveness and boost the overall quality of our citizens’ lives.

The Ministry of Education (MOE) of Taiwan has initiated curricular and instructional reforms in primary school and junior high school education. These reforms are based on the Action Plan for Educational Reform approved by the Executive Yuan in Taiwan. Because the curriculum represents not only the core of schooling but also the foundation on which teachers plan learning activities, the MOE places the greatest emphasis on the development and implementation of curriculum reforms for grades 1-9. These timely reforms are necessary to meet: (1) national development needs and (2) public expectations with respect to the next generation.

A major goal of education is to nourish each student’s mind and character. Every legitimate government hopes that its school system will produce outstanding citizens with both a sense of patriotism and the ability to adopt a global perspective. In essence, education is a learning process that helps students explore their potential and develop their capacity to adapt to and improve their living environments. In this new century, the following five basic aspects are emphasized and included in the curricula for grades 1-9: (1) developing humanitarian attitudes, (2) enhancing the ability to integrate, (3) cultivating democratic literacy, (4) fostering both indigenous awareness and a global perspective, and (5) building a capacity for lifelong learning.

For both primary schools and junior high schools, the aim of national education is to teach students basic networking knowledge and to develop the capacity for lifelong learning. To cultivate able citizens, we hope to enhance mental and physical health, vigor and optimism, gregariousness and helpfulness, intellectual curiosity, reflection, tolerance, creativity, a positive attitude and a global perspective. To accomplish this, the curriculum design of primary school and junior high school education should focus on the needs and experiences of students and on developing CCs relevant to modern citizens. Such CCs are referred to as key competencies and, as defined by the Mayer Committee, should (1) collect, analyze and organize information; (2) communicate ideas and information; (3) plan and organize activities; (4) cooperate with others and help sustain the group’s ability to work; (5) use mathematical concepts and technologies; (6) solve problems; and (7) use technology (Mayer, 1992).

In Taiwan, the CCs applicable to curriculum reforms in grades 1-9 (MOE, 2002) can be categorized as follows: (1) self-understanding and exploration of potential; (2) appreciation, representation, and creativity; (3) career planning and lifelong learning; (4) expression, communication, and sharing; (5) respect, care and teamwork; (6) cultural learning and international understanding; (7) planning, organizing, and putting plans into practice; (8) use of technology and information; (9) active exploration and study; and (10) independent thinking and problem solving.

With reference to curricular principles, CCs can be organized into four basic categories: (A) physical, mental
This evaluation framework consists of four main phases. In summary, finally, the assessment system for obtaining the best teaching materials (Chen et al., 2010). A MCDM method based on the DEMATEL technique for assessing Mandarin Chinese teaching curriculum materials was first proposed by the authors (2009a, 2009b, 2011), and, extended for Science and Technology teaching curriculum materials (Chen et al., 2010). MCDM frameworks exist for teaching curricula so that we can judge the quality of the teaching materials, but these frameworks are vague, even if clear CCs are used as the basis for the criteria. In this paper, we propose an AIGRAS technique in which the grey relational grade is used to rank the indices between the performance ratings of various curriculum materials.

2.2 AIGRAS with the MCDM Method

“Decision-making is as old as man.” The MCDM method may be applied for computer-aided learning (Quaddus, 1997). Most research has concentrated on evaluating the quality of web-based learning by the MCDM method (Hwang et al., 2004; Shee & Wang, 2008; Lin, 2010).

A MCDM method based on the DEMATEL technique for evaluating a private university of science and technology in Taiwan has been proposed by Tseng (2010). A MCDM method based on the DEMATEL technique for assessing Mandarin Chinese teaching curriculum materials was first proposed by the authors (2009a, 2009b, 2011), and, extended for Science and Technology teaching curriculum materials (Chen et al., 2010). MCDM frameworks exist for teaching curricula so that we can judge the quality of the teaching materials, but these frameworks are vague, even if clear CCs are used as the basis for the criteria. In this paper, we propose an AIGRAS technique in which the grey relational grade is used to rank the indices between the performance ratings of various curriculum materials.

3. A MCDM METHOD BASED ON THE DANP TECHNIQUE

The structure of the MCDM problem will be derived using the DEMATEL technique. The priorities of each determinant are based on the structure derived by using ANP. The GRA technique will be leveraged to calculate the rankings of alternatives to achieve the aspiring levels. Finally, the assessment system for obtaining the best teaching curriculum materials will be derived. In summary, this evaluation framework consists of four main phases (see Fig. 1).

3.1 The DEMATEL Technique for Developing NRM

The DEMATEL technique was developed by the Battelle Geneva Institute to analyze complex “world problems” dealing mainly with interactive man-model techniques. A second goal was to evaluate qualitative and factor-linked aspects of societal problems (Gabus & Fontela, 1972). The applicability of the method is broad, with applications ranging from industrial planning and decision-making to urban planning and design, regional environmental assessment, the analysis of global problems, and so forth. This technique has also been successfully applied in many situations and contexts, such as creating marketing strategies, control systems and safety solutions and developing the competencies of global managers and group decision-making (Chen et al., 2010; Chiou et al., 2006; Lee et al., 2009; Li & Tzeng, 2009; Lin & Wu, 2008; Ou Yang et al., 2008; Wu & Lee, 2007). Furthermore, a hybrid model combining the two methods has been widely used in such fields as e-learning evaluation (Tzeng et al., 2007), airline safety measurement (Liou et al., 2007, 2008), and innovation policy portfolios for Taiwan’s SIP Mall (Huang et al., 2007).

In this paper, we use DEMATEL not only to detect complex relationships and build a network relation map (NRM) of the criteria but also to calculate the inter-relational influence levels of each element. We adopted these influence level values as the basis of the normalization supermatrix for determining ANP weights to obtain the relative importance criteria. To apply DEMATEL, we refined the definitions based on the above references and produced new essential definitions, as indicated below. We based the DEMATEL method on graph theory so that we could divide multiple criteria into cause and effect groups. Directed influence graphs on graph theory so that we could divide multiple criteria into cause and effect groups. Directed influence graphs (also called digraphs) are more useful than directionless graphs. A digraph typically represents a communication network-relation or a domination relationship between individuals.

Suppose that a system contains a set of elements $S = \{s_1, s_2, \ldots, s_n\}$ and that particular pair-wise relationships are used for modeling with respect to a mathematical relationship (MR). Next, consider the relationship MR as a direct-relation matrix that is indexed equally in both dimensions using elements from set $S$. Then, extract the case for which the number appears in the cell $(i, j)$. If the

![Fig. 1. An analytical framework for the aspiring assessment systems of teaching materials](image-url)
entry is a positive integral, it means the ordered pair \((s_i, s_j)\) is in the relationship MR; and its relationship is such that \(s_i\) has an effect on \(s_j\). The digraph portrays a contextual relationship between the elements of the system in which a numeral represents the strength of influence (Fig. 2). The number between factors is the degree of influence. For example, an arrow from \(s_1\) to \(s_2\) represents the fact that \(s_1\) influences \(s_2\) and that its degree of influence is 2. The DEMATEL method can convert the relationship between the causes and effects of criteria into an intelligible network-structural model of the system (Chiu et al., 2006).

The method can be summarized as follows (Liou et al., 2007, 2008):

**Step 1. Calculate the initial average matrix by scores.**
In this step, respondents are asked to indicate the degree of direct influence each factor/element \(i\) exerts on each factor/element \(j\), as indicated by \(a_{ij}\), using an integer scale ranging from 0-4 (going from “no influence (0)”, to “very high influence (4)”). From any group of direct matrices of respondents, it is possible for experts to derive an average matrix \(A = [a_{ij}]_{n \times n}\), with each element being the mean of the same elements in the various direct matrices of the respondents. The average matrix \(A\) is represented as shown:

\[
A = \begin{bmatrix}
a_{11} & a_{12} & \cdots & a_{1n} \\
a_{21} & a_{22} & \cdots & a_{2n} \\
\vdots & \ddots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & a_{nn}
\end{bmatrix}
\]  

(1)

**Step 2. Calculate the initial influence matrix.**

The initial influence matrix \(N = [x_{ij}]_{n \times n}\) is obtained by normalizing the average matrix \(A\) (shown by degree, i.e., shown by membership and \(0 \leq x_{ij} < 1\), also called the “fuzzy cognitive matrix”)

\[ N = zA \]  

where

\[ z = \frac{1}{\max \left( \max_{1 \leq i \leq n} \sum_{j=1}^{n} a_{ij}, \max_{1 \leq j \leq n} \sum_{i=1}^{n} a_{ij} \right)} \]

in which all principal diagonal elements equal zero. Based on \(N\), the initial effect that an element exerts and receives from another is shown. The map portrays a contextual relationship among the elements of a system, in which the numeral represents the strength of influence (affected degree).

**Step 3. Derive the full direct/indirect influence matrix.**

A continuous decrease of the indirect effects of problems can be determined along the powers of \(N\), e.g., \(N^2, N^3, \ldots, N^n\), and \(N^N = [0]_{n \times n}\), \(0 \leq x_{ij} < 1\), \(0 \leq \sum_{i=1}^{n} x_{ij} \leq 1\), \(0 \leq \sum_{j=1}^{n} x_{ij} \leq 1\), and at least one column or one row of summation but not all, equals one.

**Step 4. Attaining the total-influence matrix \(T\).**

The total-influence matrix \(T = [t_{ij}]_{n \times n}\) can be obtained through

\[ T = N + N^2 + \ldots + N^n = N(I + N + \ldots + N^{n-1}) = \frac{N}{I - N}) \]

in which \(I\) denotes the identity matrix. If we define the sum of the rows and the sum of the columns separately expressed as vector \(r = [r_1 \ldots r_n]_{1 \times n}\) and vector \(c = [c_1 \ldots c_n]_{n \times 1}\) within the total-influence matrix \(T\), where the superscript ‘ denotes transpose.

If \(r_i\) denotes the row sum of the \(i\)th row in matrix \(T\), then \(r_i\) shows the sum of direct and indirect effects of factor \(i\) on the other factors/criteria. If \(c_j\) denotes the column sum of the \(j\)th column of matrix \(T\), then \(c_j\) shows the sum of direct and indirect effects that factor \(j\) has received from the other factors.

Furthermore, when \(j = i\) (i.e. the sum of the row and column aggregates), \((r_i + c_i)\) provides an index of the strength of influences given and received, that is, \((r_i + c_i)\) shows the degree that the factor \(i\) plays in the problem. In addition, the difference \((r_i - c_i)\) shows the net effect that factor \(i\) contribute to the problem. If \((r_i - c_i)\) is positive, then factor \(i\) is affecting other factors, and if \((r_i - c_i)\) is negative, then factor \(i\) is being influenced by other factors (Huang et al., 2007; Liou et al., 2007; Tzeng et al., 2007).

### 3.2 Combining DEMATEL and ANP to Find the Evaluation Weights

Consequently, the ANP method, a multi-criteria
theory of measurement developed by Saaty (1996), provides a general framework to deal with decision-making problems without making assumptions about the independence of higher-level elements from lower-level elements and about the independence of the elements within a level, as in a hierarchy. ANP is different from traditional MCDM methods (Saaty, 2005). For example, AHP (Analytic Hierarchy Process), TOPSIS, ELECTRE, et al. usually assume independence between criteria. ANP is a new theory that extends AHP to address dependence in feedback and utilizes the supermatrix approach (Saaty, 2003). ANP is a more reasonable tool for dealing with complex MCDM problems in the real world. ANP features two parts. The first consists of a control hierarchy or network of criteria and sub-criteria that control all interactions. The second is a network of influences among the elements and clusters. A control hierarchy is a hierarchy of criteria and sub-criteria for which priorities are derived in the usual way with respect to the goal of the system being considered. However, we build the hierarchical structure of the network relation map (NRM) with dependency and feedback problems in real situations, as shown in Fig. 3.

The analysis of priorities in a system can be considered in terms of a control hierarchy, with dependence among its bottom-level alternatives arranged as a network relation, as shown in Fig. 3. Dependence can occur both within and between components.

Therefore, a hierarchy structure of NRM for decision-makers (such as Fig. 3) can be derived by the DEMATEL technique. Based on NRM, a supermatrix $W$ for ANP as clusters $D_h$, $h = 1, ..., m$ can be obtained, where cluster $D_h$ resides in the $h^{th}$ dimension; we assume that $D_h$ has $n_h$ elements (determinants), which we denote as $C_{h1}, C_{h2}, ..., C_{hn_h}$. The influences of a given set of elements (determinants) in a component (dimension) on any element in the decision system are represented by a ratio scale priority vector derived from pair-wise comparisons of the relative importance of one criterion to another criterion, with respect to the interests or preferences of the decision-makers. This relative importance value can be determined using a scale of 1-9 to represent equal importance to extreme importance (Saaty, 1996).

In ANP procedures, the initial step is to compare the criteria in the entire system to form an unweighted supermatrix by pairwise comparisons. Then, the weighted supermatrix is derived by transforming each column to sum exactly to unity (1.00). Each element in a column is divided by the number of clusters, and thus each column will sum to unity exactly. However, using the assumption of equal weight for each cluster to obtain the weighted supermatrix appears irrational because there are different degrees of influence among the criteria (Ou Yang et al. 2008). Thus, we adopted the DEMATEL technique to determine the degrees of influence of these criteria and apply these to normalize the unweighted supermatrix in the ANP to mimic the situation in the real world. We named this improved ANP as DANP. The improved ANP is divided into the steps as follows:

**Step 1.** Develop an unweighted supermatrix. The total-influenced matrix will be obtained from DEMATEL. Each column will sum for normalization. We call the total-influenced matrix $T_C = [t_{ij}]_{n \times n}$, as shown:
obtained by criteria, and $T_D = [t_{ij}^D]_{m \times m}$ obtained by dimensions (clusters) from $T_C$. Then, we normalize the supermatrix $T_C$ for the ANP weights of dimensions (clusters) by using influence matrix $T_D$. Each column will sum for normalization. After normalizing the total-influence matrix $T_C$ by dimensions (clusters), we will obtain a new matrix $T_C^\alpha$ as shown as

$$
T_C^\alpha = \begin{bmatrix}
    t_{11}^\alpha & \cdots & t_{1n}^\alpha \\
    \vdots & \ddots & \vdots \\
    t_{m1}^\alpha & \cdots & t_{mn}^\alpha
\end{bmatrix} (5)
$$

In addition, an explanation for the normalization $T_C^{\alpha11}$ is shown as Eqs. (6)-(7), and other $T_C^{\alpha i mm}$ values are as above.

$$
d_C^{11} = \sum_{j=1}^{n_1} t_{ij}^{11}, \quad i = 1, 2, ..., n_1
$$

$$
T_C^{11} = \begin{bmatrix}
    t_{11}^{11} / d_C^{11} & \cdots & t_{1n_1}^{11} / d_C^{11} \\
    \vdots & \ddots & \vdots \\
    t_{m1}^{11} / d_C^{11} & \cdots & t_{mn_1}^{11} / d_C^{11}
\end{bmatrix} = \begin{bmatrix}
    t_{11}^{\alpha11} & \cdots & t_{1n_1}^{\alpha11} \\
    \vdots & \ddots & \vdots \\
    t_{m1}^{\alpha11} & \cdots & t_{mn_1}^{\alpha11}
\end{bmatrix}
$$

(7)

Let the total-influence matrix match and fill into the interdependence clusters. It will be called an unweighted supermatrix as shown as Eq. (8), which is based on transposing the normalized influence matrix $T_C^\alpha$ by dimensions (clusters), i.e.

$$
W = (T_C^\alpha)^T
$$

(8)
If the matrix $W^{11}$ is blank or 0 as shown in Eq. (9), this means that the matrix between the clusters or criteria is independent and with no interdependence, and the other $W^{mm}$ value are as above.

\[
W^{11} = \begin{bmatrix}
C_{11} & \ldots & C_{i1} & \ldots & C_{1n_i} \\
C_{i1} & \ddots & \vdots & \ddots & \vdots \\
\vdots & \ddots & \ddots & \ddots & \vdots \\
C_{in_i} & \ldots & C_{in_i} & \ldots & C_{nn_i}
\end{bmatrix}
\]  

Step 2. For obtaining the weighted supermatrix, each column will sum for normalization as shown in Eq. (10).

\[
T_D = \begin{bmatrix}
t_D^{11} & \ldots & t_D^{ij} & \ldots & t_D^{im} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
t_D^{ij} & \ldots & t_D^{jj} & \ldots & t_D^{jm} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
t_D^{im} & \ldots & t_D^{jm} & \ldots & t_D^{mm}
\end{bmatrix}
\]

We normalized the total-influence matrix $T_D$, and obtained a new matrix $T_D^\alpha$, as shown in Eq. (11) (where $t_D^{ij} = t_D^{ij}/d_i$).

\[
T_D^\alpha = \begin{bmatrix}
t_D^{11}/d_1 & \ldots & t_D^{ij}/d_i & \ldots & t_D^{1m}/d_1 \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
t_D^{ij}/d_i & \ldots & t_D^{jj}/d_j & \ldots & t_D^{im}/d_i \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
t_D^{im}/d_m & \ldots & t_D^{jm}/d_m & \ldots & t_D^{mm}/d_m
\end{bmatrix}
\]

Let the normalized total-influence matrix $T_D^\alpha$ fill into the unweighted supermatrix to obtain the weighted supermatrix.

\[
W^\alpha = T_D^\alpha \times W = \begin{bmatrix}
t_D^{11} \times W^{11} & \ldots & t_D^{ij} \times W^{ij} & \ldots & t_D^{1m} \times W^{1m} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
t_D^{1m} \times W^{1m} & \ldots & t_D^{jm} \times W^{jm} & \ldots & t_D^{mm} \times W^{mm}
\end{bmatrix}
\]

Step 3. Limit the weighted supermatrix. Limit the weighted supermatrix by raising it to a sufficiently large power $l$, until the supermatrix has converged and become a long-term stable supermatrix to obtain the global priority vectors, called DANP (DEMATEL-based ANP) influential weights, such as $\lim_{l \to \infty} (W^\alpha)^l$, where $l$ represents any number of power.

In brief, the overall weights are calculated by using the above steps to derive a stable limiting supermatrix. Therefore, a hybrid model combining the DEMATEL method with DANP methods can deal with the problems of interdependence and feedback.

3.3 Grey Relation for Evaluation

Since Deng (1982) proposed the grey theory, related models have been developed and applied to MCDM problems. Similar to fuzzy set theory, the grey theory is a
practical mathematical approach that can be used to deal with systems analysis characterized by inadequate information. Fields covered by the grey theory include systems analysis, data processing, modeling, prediction, decision-making, and control engineering (Deng, 1985, 1988, 1989; Tzeng et al., 2002; Tzeng & Tasur, 1994). In this section, we briefly review the calculation process for the grey relation model. This research modifies the definitions used by Chiou and Tzeng (2001). GRA is used to determine the relationship between two sequences of stochastic data in a grey system. The procedure bears some similarity to pattern recognition technology. One sequence of data is called the “reference pattern” or “reference sequence,” and the correlation between the other sequence and the reference sequence remains to be identified (Deng, 1986; Tzeng & Tasur, 1994; Wu et al., 1996). In this study, we use these concepts to determine how to improve the degree of grey relations from the performance values to reach the aspired values for various publishers (called alternatives) who create textbooks for Taiwanese school children.

Let the initial relationship matrix be a \( q \times n \) matrix, where there are \( q \) alternatives and \( n \) criteria, obtained by surveying the relationships following normalization, such as

\[
\begin{array}{cccc}
\text{Alternatives} & C_1 & \cdots & C_j & \cdots & C_n \\
G_1 & g_{11} & \cdots & g_{1j} & \cdots & g_{1n} \\
\vdots & \vdots & & \vdots & \cdots & \vdots \\
G_k & g_{k1} & \cdots & g_{kj} & \cdots & g_{kn} \\
\vdots & \vdots & & \vdots & \cdots & \vdots \\
G_q & g_{q1} & \cdots & g_{qj} & \cdots & g_{qn} \\
\end{array}
\]

Aspiring value \( g^* \)

\[
g_1^* \quad \cdots \quad g_j^* \quad \cdots \quad g_n^*
\]

Therefore, coefficients of grey relation for the aspiring values are

\[
\gamma(g_j^*, G_k) = \frac{\min_{i} \left| g_j^* - g_{ij} \right| + \zeta \max_{i} \left| g_j^* - g_{ik} \right|}{\left| g_j^* - g_{kj} \right| + \zeta \max_{i} \left| g_j^* - g_{ik} \right|}
\]

(13)

Then, the grade (degree) of the grey relation is obtained so that larger is better:

\[
\gamma(g^*, G_k) = \sum_{j=1}^{n} w_j \gamma(g_j^*, g_{kj})
\]

(14)

where the weight \( w_j \) can be obtained by DANP.

The Grey Relation for Evaluation algorithm has three steps according to the above mentioned factors:

**Step 1. Obtain an aspiring level.** We calculated the best \( g_j^* \) values (aspiring level) of all criterion functions, \( j = 1, 2, \ldots, n \). Suppose the \( j^{th} \) function denotes benefits; \( g_j^* = \max_{i} g_{ij} \) or these values can be set by decision makers (i.e. \( g_j^* \) is the aspiring level).

**Step 2. Calculate the coefficients of grey relation for the aspiring values.** The value can be counted by

\[
\gamma(g_j^*, G_k) = \frac{\min_{i} \left| g_j^* - g_{ij} \right| + \zeta \max_{i} \left| g_j^* - g_{ik} \right|}{\left| g_j^* - g_{kj} \right| + \zeta \max_{i} \left| g_j^* - g_{ik} \right|}
\]

where \( k = 1, 2, \ldots, q \), and setting \( \zeta = 0.5 \) (Mon et al., 1995; shown the difference \( \zeta \), the rankings have not changed in alternatives; so this paper are using the compromise parameter \( \zeta (\zeta = 0.5) \) is presented as the weight of the strategy of the maximum group utility.

**Step 3. Calculate the grade (degree) of the grey relation for each alternatives.** The larger is the better.

\[
\gamma(g^*, G_k) = \sum_{j=1}^{n} w_j \gamma(g_j^*, g_{kj})
\]

where \( G_k \) is the the \( k^{th} \) alternative, and \( w_j \) can be obtained by DANP.

4. AN EMPIRICAL STUDY OF AIGRAS FOR MANDARIN CHINESE TEACHING MATERIALS

In this Section, an example modified from a real case will be presented to demonstrate the effectiveness of the proposed MCDM framework with the DANP technique including the grey relational assessment. One empirical example focuses on the experiences of three leading textbook publishers.

In this case study, we look at Mandarin Chinese curriculum materials (six textbooks) for primary school children in grade 1.

4.1 Background (MOE, 2002, 2008)

In the twenty-first century, major changes have taken place in social, political, economic and cultural arenas. These changes are both national and global. Given the drastic changes brought about by the e-era, most countries have become aware of the importance of education and culture. Educational reform in these countries has been carried out to foster personal potential, to modernize, and to promote social progress.

After six decades of post-war development, Taiwan (also called Formosa) has transitioned from a traditional agricultural society into a modern industrial society.
Political, economic, and cultural arenas are facing modernization, industrialization and the technological influences of structural adjustment and reconstruction in the e-era. Among the major arenas of reform, the impact of education reform is one of the most far-reaching and has extensive implications. It affects national pride, impacts social consciousness, establishes a new culture and develops the nation’s competitiveness in the new century.

With the spread of education and enhancements in quality of life, Taiwan is becoming an educational community. However, many problems have emerged in the development of education over the years, and delays in solving these problems have made them even more complex. In light of this, the Council on Education Reform of Taiwan was established in September 1994. The Commission’s report on educational reform and the development of educational research was presented in December 1996.

In Taiwan, certain issues were addressed to enable reform. The influence of educational reform at both social and personal levels is significant. It is important to ponder the impact of social change and carefully consider how the value of the benchmarks of socio-cultural development may be determined. This is especially true in the context of educational reform.

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The Council has proposed a comprehensive proposal for education reform. Given the need to provide proper education for every student, it is clear that schools have not paid adequate attention to disadvantaged students. This has been mainly due to inappropriate compulsory education in Taiwan, where an excessively rigid system and curriculum is coupled with a lack of long-term investment in resources. As a result of weak educational practices, many disadvantaged students fail to build a solid foundation for learning; they are then exposed to large class sizes and a general lack of timely and adequate care. Consequently, their performance falls even further behind that of other students, causing them to feel insecure about school.

At the convening of the Education Reform Committee, the MOE of Taiwan proposed curriculum reforms for grades 1-9 (compulsory education) (MOE, 2002, 2008). A more detailed description is in Subsection 2.1.

The Mandarin Chinese curriculum is one of the curricula included in Language Arts. It is divided into three stages: grades 1-3, grades 4-6, and grades 7-9.

Based on curricular goals and CCs for grades 1-9, the goals of the Mandarin Chinese curriculum included listening, speaking, reading and writing of languages, as well as developing basic communication competencies.

Based on the requirements for children’s intellectual development, the numbers of competence indicators of the Mandarin Chinese curriculum for each stage are presented below (see Table 1).

![Table 1. Competence indicators for the Mandarin Chinese curriculum at each stage](image)

<table>
<thead>
<tr>
<th>CCs</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical, mental and spiritual mold</td>
<td>24</td>
<td>19</td>
<td>18</td>
<td>61</td>
</tr>
<tr>
<td>Self-understanding and exploration of potential</td>
<td>20</td>
<td>17</td>
<td>17</td>
<td>54</td>
</tr>
<tr>
<td>Appreciation, representation, and creativity</td>
<td>9</td>
<td>13</td>
<td>10</td>
<td>32</td>
</tr>
<tr>
<td>Career planning and lifelong learning</td>
<td>8</td>
<td>9</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>Cultural learning and international understanding</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Planning, organizing and putting plans into practice</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Interpersonal and social relations</td>
<td>4</td>
<td>11</td>
<td>8</td>
<td>23</td>
</tr>
<tr>
<td>Expression, communication, and sharing</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>Respect, care and teamwork</td>
<td>9</td>
<td>9</td>
<td>13</td>
<td>31</td>
</tr>
<tr>
<td>Cultural learning and international understanding</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Planning, organizing and putting plans into practice</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>The use of life science and technology</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>Using technology and information</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>24</td>
</tr>
<tr>
<td>Logical thinking and reasoning</td>
<td>104</td>
<td>108</td>
<td>106</td>
<td>318</td>
</tr>
</tbody>
</table>

International Journal of the Information Systems for Logistics and Management (IJISLM), Vol. 6, No. 2 (2011)

4.2 Structuring NRM and Calculating the Weights of Determinants Using

DANP The relationships between determinants involving assessment systems for Mandarin Chinese teaching materials were surveyed based on the opinions of teachers in Taiwan who write Mandarin Chinese textbooks (1/3), have taught Mandarin Chinese in primary school (1/3), or have taught other subjects in primary school (1/3). All of the surveyed teachers were familiar with the assessment protocols for Mandarin Chinese in schools.

Our proposed assessment system for Mandarin Chinese will assist publishers in creating better textbooks and will help to determine which assessment strategies can best achieve the aspiring levels of quality of textbooks. Detailed procedures and results are given below.

The interrelationships between the ten determinants were deduced using the DANP method in Subsection 3.1. First, the direct relation matrix $A$ was introduced (see Table 2). After that, the direct relation matrix $A$ was normalized based on Equation (1). The total relationship matrix was then deduced based on Equation (2) (see Table 3).

Finally, the strength of the influence for each determinant was deduced (see Table 4 and Fig. 4).

With an appropriate assessment system as the goal, pair-wise comparisons of the determinants were calculated based on the total relationship matrix, as deduced by DEMATEL. Note the interrelationships between the goals and the directions of arrows, indicating the dimensions of various assessment-system determinants (Fig. 4). The total relationship matrix serves as a set of inputs for ANP. By implementing ANP, the limit supermatrix $W$ can be calculated.

Weights corresponding to each determinant (Table 5) are derived accordingly and may be used to calculate both weighted averages and GRA scores.

4.3 Compromise Rankings Calculated Using GRA

After the determinants’ weights were calculated using DANP, the GRA technique introduced for compromise ranking was applied. Weighted averages of the six Mandarin Chinese textbooks for grade 1 of primary school, which were edited by three leading publishers (Table 6),
were also calculated as comparisons. In general, the calculation results (Table 7) demonstrated that the same conclusions are apparent at both the global and local levels: publisher A > publisher C > publisher B.

4.4 Discussions and Implications

Authoring teaching materials is not an easy task. There are no straightforward answers to the question of how teaching materials should be designed to meet particular criteria and determinants, considering that textbooks should generally take into account the relevant curriculum.

In this study, a MCDM framework that combined the DANP technique and GRA was proposed to address the aforementioned problems. We consider the results satisfactory. This MCDM framework was created to (a) overcome the issue of defining the assessment system for teaching materials, (b) use innovative but traditional MCDM approaches to resolve the problem of how to define an assessment system for textbooks, (c) explore the vague correlations between the determinants of teaching materials, (d) create target priorities for the resulting teaching materials, and (e) shape vague semantic processing issues, such as defining ‘good’ and ‘very good’ assessments.

CCs were selected as determinants for the assessment system. CCs were then categorized into four groups and used as criteria for the assessment. These groups were as follows:
Table 5. Weights of the determinants derived by DANP

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Criteria</th>
<th>Local</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1: Physical, mental and spiritual mold</td>
<td></td>
<td>0.3015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C1: Self-understanding and exploration of potential</td>
<td>0.3376</td>
<td>0.1018</td>
</tr>
<tr>
<td></td>
<td>C2: Appreciation, representation, and creativity</td>
<td>0.3312</td>
<td>0.0998</td>
</tr>
<tr>
<td></td>
<td>C3: Career planning and lifelong learning</td>
<td>0.3312</td>
<td>0.0998</td>
</tr>
<tr>
<td>D2: Interpersonal and social relations</td>
<td></td>
<td>0.4054</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C4: Expression, communication, and sharing</td>
<td>0.2656</td>
<td>0.1077</td>
</tr>
<tr>
<td></td>
<td>C5: Respect, care and teamwork</td>
<td>0.2455</td>
<td>0.0995</td>
</tr>
<tr>
<td></td>
<td>C6: Cultural learning and international understanding</td>
<td>0.2335</td>
<td>0.0947</td>
</tr>
<tr>
<td></td>
<td>C7: Planning, organizing and putting plans into practice</td>
<td>0.2554</td>
<td>0.1035</td>
</tr>
<tr>
<td>D3: The use of life science and technology</td>
<td></td>
<td>0.0895</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C8: Using technology and information</td>
<td>1.0000</td>
<td>0.0895</td>
</tr>
<tr>
<td>D4: Logical thinking and reasoning</td>
<td></td>
<td>0.2037</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C9: Active exploration and study</td>
<td>0.4959</td>
<td>0.1010</td>
</tr>
<tr>
<td></td>
<td>C10: Independent thinking and problem solving</td>
<td>0.5041</td>
<td>0.1027</td>
</tr>
</tbody>
</table>

Table 6. Satisfaction of grade 1 textbooks

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Criteria</th>
<th>11a</th>
<th>12b</th>
<th>11</th>
<th>12</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>C1</td>
<td>6.0000</td>
<td>5.7500</td>
<td>5.5000</td>
<td>5.2500</td>
<td>6.2500</td>
<td>6.2500</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>6.5000</td>
<td>6.7500</td>
<td>5.5000</td>
<td>7.0000</td>
<td>5.7500</td>
<td>7.2500</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>5.7500</td>
<td>4.7500</td>
<td>4.2500</td>
<td>4.5000</td>
<td>6.2500</td>
<td>4.7500</td>
</tr>
<tr>
<td>D2</td>
<td>C4</td>
<td>6.7500</td>
<td>7.5000</td>
<td>6.0000</td>
<td>6.5000</td>
<td>6.2500</td>
<td>7.2500</td>
</tr>
<tr>
<td></td>
<td>C6</td>
<td>5.2500</td>
<td>4.0000</td>
<td>4.2500</td>
<td>4.2500</td>
<td>4.0000</td>
<td>4.0000</td>
</tr>
<tr>
<td></td>
<td>C7</td>
<td>5.0000</td>
<td>5.0000</td>
<td>4.5000</td>
<td>4.7500</td>
<td>4.5000</td>
<td>4.2500</td>
</tr>
<tr>
<td>D3</td>
<td>C8</td>
<td>3.7500</td>
<td>3.7500</td>
<td>4.0000</td>
<td>4.7500</td>
<td>4.5000</td>
<td>4.5000</td>
</tr>
<tr>
<td>D4</td>
<td>C9</td>
<td>5.0000</td>
<td>5.2500</td>
<td>4.2500</td>
<td>4.2500</td>
<td>4.7500</td>
<td>4.5000</td>
</tr>
<tr>
<td></td>
<td>C10</td>
<td>5.2500</td>
<td>4.7500</td>
<td>4.7500</td>
<td>4.5000</td>
<td>5.0000</td>
<td>6.0000</td>
</tr>
</tbody>
</table>

Note: a: 11: the 1st Semester of grade 1; b: 12: the 2nd Semester of grade 1.

D1: Physical, mental and spiritual mold
C1: Self-understanding and exploration of potential
C2: Appreciation, representation, and creativity
C3: Career planning and lifelong learning

D2: Interpersonal and social relations
C4: Expression, communication, and sharing
C5: Respect, care and teamwork
C6: Cultural learning and international understanding
C7: Planning, organizing and putting plans into practice

D3: The use of life science and technology
C8: Using technology and information

D4: Logical thinking and reasoning
C9: Active exploration and study
C10: Independent thinking and problem solving

Through application studies, we found the MCDM model to be relevant and helpful. DANP establishes a reasonable assessment structure for dealing with the influence of various criteria. The influence relationships pertaining to the results (see Fig. 4) were quite reasonable.

(1) The goal of education is to nurture each student’s mind and character. First, enhancing “the use of life science and technology” may strengthen “logical thinking and reasoning” for students, which then improves “interpersonal and social relations” and becomes the ultimate goal; finally, this gives students “the physical, mental and spiritual dimensions”;

(2) For logical thinking and reasoning, “active exploration and study” is better than “independent thinking and problem solving,” consistent with the well-known point of view of knowledge management;

(3) For interpersonal and social relations, starting from “cultural learning and international understanding” may shorten the mental distance for the individual; sharing “expression, communication” should then naturally lead to improvement in “respect, care and teamwork,” and “planning, organizing and putting plans into practice” should be thoroughly examined;

(4) For physical, mental and spiritual mold, “self-understanding and exploration of potential” is the bench-
mark of “career planning and lifelong learning” and “appreciation, representation, and creativity”.

DANP suggests a general framework for dealing with decisions without making assumptions about the independence of higher-level elements from lower-level elements and about the independence of the elements within a typical hierarchy. Therefore, by defining the assessment system for teaching materials as illustrated in the paper, DANP is apparently a more reasonable tool for analyzing network structures with feedback.

The GRA technique uses a grade of the grey relation function \( \gamma(x^*, x_i) \) that represents “closeness to the aspiring level.” The GRA approach in this paper simply measures the grey relationship of the alternatives with the aspiring level.

In Table 7, globally, the six volumes for \( \gamma(x^*, x_i) \) are 0.7603, 0.7467, 0.6941, 0.7260, 0.7368, and 0.7628, and the sequences are 5, 4, 1, 2, 3, and 6, respectively. This means that Book 11 of Publisher B \( \prec \) Book 12 of Publisher B \( \prec \) Book 11 of Publisher C \( \prec \) Book 12 of Publisher A \( \prec \) Book 11 of Publisher A \( \prec \) Book 12 of Publisher C.

However, if Publisher B were to improve Book 11, for example, the sequences would be (1) the use of life science and technology \( (D_3) \), (2) logical thinking and reasoning \( (D_4) \), (3) physical, mental and spiritual mold \( (D_1) \), then (4) interpersonal and social relationships \( (D_2) \).

5. CONCLUDING REMARKS

This paper advances work in the field of teaching material assessment. In response to current concerns, we began with Mandarin Chinese. First, a MCDM framework was proposed to define the determinants of any set of teaching materials (not exclusively for Mandarin Chinese). Second, the traditional problem of the difficulty of defining an assessment system for teaching materials was resolved using the MCDM approach. An important conclusion was that the most important determinants may be the least influential determinants. We concluded that the sequence of influence among determinants is as follows: the use of life science and technology \( (D_3) \), logical thinking and reasoning \( (D_4) \), interpersonal and social relations \( (D_2) \), physical, mental and spiritual mold \( (D_1) \) (see Fig. 4). However, the weighting sequence of determinants is as follows: interpersonal and social relations \( (D_2, 0.4054) \), physical, mental and spiritual mold \( (D_1, 0.3015) \), logical thinking and reasoning \( (D_4, 0.2037) \), the use of life science and technology \( (D_3, 0.0895) \) (see Table 5). Finally, the challenge of selecting “rotten apple(s)” when using the traditional MCDM approach was also addressed based on our conceptual advances in achieving the aspiring level for each of the criteria.

REFERENCES


