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Prioritizing the teaching methods of ESD using an integrated fuzzy entropy–SAW algorithm (case study: technical and vocational schools)

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\section*{ABSTRACT}
The current environmental crisis has mainly a human-induced origin. In this regard, technical and vocational (T&V) graduates have an important role in the optimal use of environment and resources. Therefore, this research intends to find the best teaching method of education for sustainable development (ESD) in order to improve the behavior of those graduates toward the environment. For this purpose, the fuzzy entropy method was used to introduce and weight the sustainable development competency criteria of the T&V graduates. Then, the teaching methods were prioritized by applying a fuzzy Simple Additive Weighted (SAW) model. According to the results of the present paper, performance-based learning was the most appropriate method of ESD.

\section*{Introduction}
Considering the important role of education in disseminating sustainable development (SD) principles, the attention to education for sustainable development (ESD) has increased (Cotton, Warren, Maiboroda, & Bailey, 2007; Michalos et al., 2012; Olsson, Gericke, & Chang, 2016; Tilbury, 2012). SD has three main dimensions including the environment, the economy, and the community dimension (UNESCO\textsuperscript{1}, 2005a). Transversal to these SD dimensions, education is a fundamental component of SD and of the UNESCO mission and is a core aspect of Agenda 21 (UNESCO, 1992).

In ESD, the environment refers to the development of awareness of resources and physical environment vulnerability. The economy concerns awareness of limits, the potential for economic growth, and how they impact the environment and society. Society is considered as a democracy-based system that gives citizens the possibility to actively participate in
policy life, express different views, and elect governments (Olsson et al., 2016; Walshe, 2008). The education refers to educational programs and experiences that are designed to allow people to acquire the knowledge, skills, and values that are necessary to shape a sustainable future (UNESCO, 1992). In fact, the main role of education is to shape self-reliant minds able to make decisions, check information, and think critically (Hadzigeorgiou, Fokialis, & Kabouropoulou, 2012).

In this regard, technical and vocational (T&V) education focuses on the acquisition of knowledge, practical skills, and attitudes relating to occupations in various sectors of economic and social life (UNESCO, 2005b). Currently, an important indicator of each country’s success is the development of three sectors including industry, agriculture, and services. Moreover, it requires the training of skilled and efficient human resources in technical and professional fields related to the labor market (Navidi, Esmaeili, Senobari, & Barzegar, 2004). In contrast, environmental quality has decreased as a result of human activities, especially economy and industry.

Therefore, by considering the role of T&V graduates in the optimal use of environment and resources, this study attempts to select a teaching method that improves the SD competency criteria in T&V graduates. The present research was performed in four steps: (a) SD competency criteria of T&V graduates were identified, (b) the SD competency criteria of T&V graduates were prioritized through a fuzzy entropy algorithm, (c) six methods of SD teaching including speech, group discussions, e-learning, conceptual map, problem-solving-based learning, and performance-based learning were evaluated based on SD competency criteria, and (d) the most appropriate teaching method of ESD was presented applying the fuzzy Simple Additive Weighted (SAW) model.

Understanding SD competency criteria: The need for a consistent teaching method with SD

Education, as an essential component of supporting SD and improving people’s perception of environmental subjects, is as important as other dimensions of SD (Biasutti, 2015; McNaughton, 2012; Scoullos, 2013). T&V education is T&V education contributes fundamentally to the SD process by improving peace and reducing poverty (Pavlova & Chunlin, 2009). T&V education is a source of the skills, knowledge, and technology needed for competitiveness in the global economy. Enhanced global competitiveness can lead to a better economic and political balance of power that will support global peace and stability. As social equity is associated with peace
and political stability at a national level, the aggregate effect is possible at a
global level (Marope, Chakroun, & Holmes, 2015; World Bank, 2005).

T&V graduates must be equipped with SD competency to cope with
environmental degradation. SD competency is defined as awareness of the
physical environment and its effects on individual activities as well as the
ability to use or change the environment appropriately and according to
determined goals and activities (Lackney, 2008). De Haan (2006) defined
the formation of SD competency as a specific capacity to modify and direct
economic, social, technological, and ecological changes toward the
SD process.

The main teaching methods in T&V schools are Lecture method, Group
discussion method, E-learning method, Conceptual map method, Problem-
solving-based learning method, and Performance-based learning method.
The main characteristics of the SD teaching method are interdisciplinary,
comprehensive, learner-centered, collaborative, and value-based. Such
methods improve critical thinking, future-oriented thinking, and high-
thinking skills. SD teaching methods examine all interested progressing
parties with medium- and long-term planning processes. In this regard,
such processes involve the encouragement of multilateral cooperation
among local schools, local authorities, academic population, the private sec-
tor, and nongovernmental organizations and contribute to the understand-
ing of global issues and communications as part of daily life, whether in a
small village or a large city (Biasutti & Frate, 2017; Scoullos, 2013).

**Background research**

Sherren (2005) and Cotton et al. (2007, Cotton, Bailey, Warren, & Bissell,
2009) demonstrated pedagogies and teaching methods that are appropri-
ate for ESD. According to these authors, although rhetorical supports are
seen for student-led pedagogies in higher education, these methods are
not practically supported in education environments. Lan (2008) high-
lighted the need for environmental awareness and SD in T&V institu-
tions. Sofoluwe (2013) stated that T&V education significantly affects SD
process. In another study, Christie, Kelly, Cooke, and White (2013)
reported the views of 6% of Australian instructors on the teaching
method of ESD in higher education systems. Accordingly, the results sug-
gested that academics prefer lecture methods, critical thinking, and dis-
cussion, while various other teaching methods have not been used in
teaching ESD. In a case study conducted by Draper, Oltean-Dumbrav,
Kara-Zaitri, and Newbury (2014), three environmental education pro-
grams were investigated for T&V courses. The results indicated that
work-based factors, teaching, and personal parameters affect individual
learning and transfer of learning to the workplace. Rieckmann (2013) contributed to the internationalization of the ESD competence debate by presenting a joint discourse of European and Latin-American experts. He proposed 12 key competencies for ESD. Systemic thinking, anticipatory thinking, and critical thinking are on the top of the competencies list; these were primarily justified through reference to the challenges of complexity, uncertainty, risks, and the high velocity of societal (global) change. Molderez and Fonseca (2018) demonstrated that sustainability competencies in each learning activity are of relatively varying levels. To ensure the wide audience of sustainability competencies, teachers are advised to combine different learning activities or include a variety of characteristics to foster as many competencies as possible, especially because of the interplay and interactions between different competencies.

Previous studies in the literature have addressed the need for entering ESD into T&V training systems and evaluated environmental education programs and challenges for SD integration into T&V institutions. However, no research has been conducted in this field to prioritize and select teaching methods of ESD. In addition, the use of integrated methods such as entropy and SAW algorithms with a fuzzy approach is a less noted attempt in the literature, which can properly address uncertainty in data and analyses and provide reliable results. Therefore, the present research offers innovative dimensions in both the subject of the study and the implemented methodology in the field of SD education.

**Research question**

In the present study, we seek to answer the following three questions:

- What are the SD competence criteria of T&V graduates to improve behavior consistent with SD?
- Which SD competence criteria are more important?
- Which teaching methods are more appropriate for enhancing the SD competence criteria in T&V graduates?

**Methodology**

The present research adopts a descriptive-survey approach (Edeh, Ezegbe, Onwurah, Dike, & Uzodinma, 2018; Vanderpuye, Obosu, & Nishimuko, 2018) in terms of its methodology, and it is mainly applied to provide a teaching methodology for ESD in T&V schools. Such an approach also improves SD competency criteria of individuals in the best possible way and establishes a sense of responsibility toward the environment. The
The statistical population of this research is a collection of 15 specialists in the fields of SD and T&V education selected by convenience sampling method. This study was conducted based on four main steps as follows. Also, Fig. 1 demonstrates the overall steps undertaken in this study:

1. Identification of SD competency criteria of T&V graduates: In this regard, a comprehensive literature review was undertaken to investigate competency criteria of SD and the environment (Corral-Verdugo, 2002; De Haan, 2006; Eggert & Bögeholz, 2006; Gräsel 2001; Jensen & Schnack, 1997; Lackney, 2008; Roczen, 2011; Roczen, Kaiser, Bogner, & Wilson, 2014), the SD competency criteria of T&V graduates (Chinien, Bouti, & Karen, 2009; Dentoni, Blok, Lans, & Wesselink, 2012; Plane, 2007; Rauner, 2011; Rauner, Haasler, Heinemann, & Grollmann, 2009; Wiek, Withycombe, & Redman, 2011), and SD competency criteria of engineering (due to the close proximity of engineering to the T&V
field) (ABET, 2011; CEAB, 2016; EUA, 2007; Lapina & Aramina, 2011; Wright, 2014). Then, using the Delphi method (Musa, Yacob, & Abdullah, 2018; Sourani & Sohail, 2015), the SD competency criteria of T&V graduates were screened to a smaller set.

2. Questionnaire Designing: The questionnaire of the present research was developed based on multicriteria decision-making methods with a scale of seven values to provide input data for the SAW model and Shannon entropy algorithm. In this way, by placing criteria (the SD competency criteria of T&V graduates) in the column and the options (teaching methods) in the row, a square matrix was formed. Then, a set of experts were asked to determine the extent to which each of the criteria was strengthened with each option by rating from 1 to 7. Cronbach’s $\alpha$ coefficient was calculated in order to determine the reliability of the questionnaire for evaluating options. The obtained coefficient (i.e., 0.96) indicates the coordination and reliability of the data. The qualitative validity of the questionnaire was also confirmed by experts and specialists.

3. Weighing the SD competency criteria of T&V graduates using the Shannon entropy method: The SD competency criteria of T&V graduates were evaluated in the Excel software environment. For this purpose, the questionnaires (matrices derived from the experts’ view) were distributed and collected based on the fuzzy entropy method, and fuzzy triangular numbers were used for weighting purposes.

4. Ranking SD teaching methods in T&V using the SAW model: Considering the criteria weights, the ranking of teaching methods of ESD was performed using the fuzzy SAW model and fuzzy triangular numbers.

A brief description of each method implemented in this research is as follows:

- **Fuzzy logic**: The theory of fuzzy sets was proposed by Professor Lotfi Zadeh in 1965. He made an attempt to solve the uncertainties associated with human cognitive processes, such as thinking and reasoning. One of the most important features of the fuzzy set is its ability to describe set concepts in human language. It allows us to address unspecific and fuzzy characteristics using a membership function that partitions a fuzzy set into subsets of members that “incompletely belong to” or “incompletely do not belong to” a given subset. Triangular fuzzy numbers that have been implemented in this study are a set of means to portray uncertainty in analysis and such numbers formulated as follows:
\[ u_{\sim A}(x) = \begin{cases} \frac{(x-L)/(M-L)}{L}, & L \leq x \leq M \\ \frac{(U-x)/(U-M)}{M}, & M \leq x \leq U \\ 0, & \text{otherwise} \end{cases} \] (1)

Fuzzy numbers \( \sim A \) is mapped onto \( U \) such that a random \( x \to U \) is appointed a real number, \( U_{\sim A}(x) \to [0, 1] \). If another element in \( U \) is greater than \( x \), we call that element under \( A \). The universe of real numbers \( R \) is a triangular fuzzy number (TFN) \( \sim A \), which means that for \( x \in R, u_{\sim A}(x) \in [0, 1] \).

Note that \( \sim A = (L, M, U) \), where \( L \) and \( U \) represent fuzzy probabilities between the lower and upper boundaries (Chen & Chen, 2010), respectively.

- **Shannon entropy method**: Shannon entropy is a method to quantify the relative weight of importance for a set of criteria implemented in multicriteria decision-making problems (Andreica, Dobre, Andreica, & Resteanu, 2010). The main idea of this method is that the higher levels of dispersion in a criterion’s values indicate the more relative weight of importance for that corresponding criterion. Entropy steps are as follows (Karami & Johansson, 2014):

  **Step 1**: Calculate \( P_{ij} \) to eliminate anomalies with different measurement units and scales

  \[ P_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}}; \quad \forall ij \] (2)

  **Step 2**: Calculate the entropy of \( E_j \)

  \[ E_j = \left( \frac{-1}{\ln(m)} \right) \sum_{i=1}^{m} [p_{ij} \ln p_{ij}]; \quad \forall j. \] (3)

  **Step 3**: Calculate the uncertainty \( d_j \) as the degree of diversification

  \[ d_j = 1 - E_j; \quad \forall j. \] (4)

  **Step 4**: Calculate weights (\( W_j \)) as the degree of importance of attribute \( j \)

  \[ w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}; \quad \forall j \] (5)

- **SAW model**: SAW model is one of the most widely used multicriteria decision-making techniques. Based on this model, the weight of the criteria must be multiplied by the normalized value of the criteria for the
options. Then, the ranking is obtained based on the score of options, and the most appropriate option has the highest score (Janic & Reggiani, 2002). The analytical structure of the SAW model for \( N \) options and \( M \) attributes can be summarized as (Karami & Johansson, 2014):

\[
S_i = \sum_{j=1}^{M} w_j r_{ij} \quad i = 1, 2, \ldots, N
\]

(6)

\( S_i \) is the overall score of the \( i \)th option (alternative); \( r_{ij} \) is the normalized rating of the \( i \)th option for the \( j \)th criterion; \( r_{ij} = x_{ij}/\max_i x_{ij} \) represents an element for the normalized matrix; \( x_{ij} \) is an element of the decision matrix, which represents the original value of the \( j \)th criterion of the \( i \)th option; \( w_j \) is the importance (weight) of the \( j \)th criterion; and \( N \) and \( M \) are the number of options and criteria, respectively.

Findings
The findings provided based on research questions in three steps are as follows:

**What are SD competency criteria of professional and technical graduates to improve behavior consistent with SD in them?**

After a comprehensive literature review and using the Delphi method, the SD competency criteria of T&V graduates criteria are given in Table 1. These criteria are classified into four dimensions (i.e., knowledge, skill, attitude, and growth and eloquence), eight groups (knowledge of the state-of-art science, creativity and problem-solving skill, vocational and practical skills, teamwork and communication skills, sense of obligation and responsibility, transcendental motivation, lifelong learning, and self-motivated teaching), and 24 criteria. These competency criteria have acceptable integrity and include the competencies of a person in several roles such as being a T&V graduate or a concerned citizen (e.g., environmental issues) or as a valuable human being.

**Which SD competency criteria are more important?**

In order to answer the second question, the SD competency criteria of T&V graduates were weighted using the fuzzy Shannon entropy method. In this regard, matrices derived from expert’s view (questionnaires) were firstly fuzzified using fuzzy triangular numbers (Table 2). Then, for weighting the SD competency criteria, fuzzified numbers were combined by the
averaging arithmetic method, and, consequently, the fuzzy decision-making matrix was formed. This matrix was defuzzified using the CFCS\(^2\) method (Opricovic & Tzeng, 2003). Next, the weights of the competency criteria were calculated by Equations (2)–(5).

As shown in Table 3, the set of criteria including skill for working with specialized tools, creative thinking, practical skill of converting professional environmental knowledge into an environmentally friendly activity, and

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\(^2\)Converting Fuzzy data into Crisp Scores.
critical thinking received the highest weights (the most dispersion of values), in the order of their appearance, while the criteria of knowledge of Iranian norms, values and culture, self-directed learning skill, and improving other people’s performance were of the lowest weights (the least dispersion of values), in the order of their appearance. In fact, the weighting method is based on the numerical analysis of the information contained in the decision-making matrix, and the criterion with the highest distributed values receives the greatest weight of importance. In other words, if a criterion in all teaching methods is assigned with the value of 7 (the highest value), because its dispersion is 0, its weight is 0 as well.

**Which teaching methods are more appropriate for enhancing the competency criteria in T&V graduates?**

Teaching methods are ranked according to Table 4 using the SAW model (Equation (6)). This was done also after fuzzification of the decision-making matrix through fuzzy triangular numbers (Table 2) and linear non-scaling of the fuzzy decision-making matrix. Based on SAW, the option with the highest score is selected as the most appropriate option.
According to Table 4 and the fuzzy SAW–entropy method, performance-based learning, group discussion, and problem-based learning received the highest scores, in the order of their appearance and consequently the highest priority. Comparing the obtained results reveals that the lecture method is of the least priority.

### Discussion and conclusion

In fact, current environmental crises have affected our planet worldwide, and such a phenomenon is mainly rooted in unsustainable activities of modern humans, especially in agricultural and industrial sectors. Referring to the fact that major graduates of T&V systems enter these sectors of economy and industry, the consequences of their behaviors can deeply disturb the maintenance and protection of environmental systems. Accordingly, the most important issue in this regard is the choice of an appropriate method for transferring and improving environmental knowledge and ultimately enhancing the environmental responsibility of graduates.

Based on the findings of the current paper, prioritization and selection of the most appropriate teaching methods have been addressed according to a set of SD competency criteria for T&V graduates. These competency criteria have acceptable comprehension. In this regard, all dimensions of knowledge, skills, and attitudes in addition to growth and eloquence have been considered in these criteria.

The fuzzy entropy method was used for criteria weighting. The results indicated a set of criteria, including skill for working with specialized tools (c33: weight = 0.1252), creative thinking (c22: weight = 0.0654), and the practical skill of converting professional environmental knowledge into an environmentally friendly activity (c31: weight = 0.0611), which are the most important SD competency criteria, in the order of their appearance. However, other criteria (such as the analytical skill of economic, social and environmental characteristics (c32: weight = 0.0325), and environmental knowledge mastery related to a particular T&V major (c12: weight = 0.0267)) obtained the highest scores in relation to teaching methods in the questionnaires. The reason why the entropy method generates somewhat

<table>
<thead>
<tr>
<th>Teaching methods of SD education</th>
<th>A*</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture</td>
<td>0.63</td>
<td>6</td>
</tr>
<tr>
<td>Group discussion</td>
<td>2.18</td>
<td>2</td>
</tr>
<tr>
<td>Conceptual map</td>
<td>2.01</td>
<td>4</td>
</tr>
<tr>
<td>E-learning</td>
<td>1.22</td>
<td>5</td>
</tr>
<tr>
<td>Performance-based learning</td>
<td>2.29</td>
<td>1</td>
</tr>
<tr>
<td>Problem-solving-based learning</td>
<td>2.14</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4. Prioritizing the teaching methods of SD education using the hybrid fuzzy SAW–entropy model.
unexpected weights is that in this method, a given criterion with variable scores for different teaching methods receives a higher weight of importance.

The fuzzy SAW model has been used to prioritize teaching methods, and it is one of the most commonly used multicriteria decision-making methods. The results indicate that lecture ($A^* = 0.63$) is the most inappropriate teaching methods of SD in T&V schools; however, the lecture is the most common teaching method in educational environments. Performance-based learning ($A^* = 2.29$), group discussion ($A^* = 2.18$), and problem-solving-based learning ($A^* = 2.14$) are the most appropriate teaching methods of SD, in the order of their appearance. In fact, the main advantages of multicriteria decision-making methods are their capability to model real problems, their simplicity, and their comprehensiveness for most users, simultaneous consideration of the quantitative and qualitative variables and situations of the problem as well as the capability of these models to consider all aspects of the problem. The fuzzy logic was also used to reduce ambiguity and uncertainty in human judgments.

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**Appendix**

CFCS method was developed by Opricovic and Tzeng (2003). CFCS can generate defuzzified numbers corresponding to the fuzzy weights using a similar approach that finds left and right scores through fuzzy min and fuzzy max, and the total score is determined as a
weighted average according to the membership functions. Let \( f_{ij} = (l_{ij}, m_{ij}, u_{ij}) \) be triangular fuzzy numbers, where \( J \) is the number of alternatives. The crisp value of the \( i \)th criterion could be determined by the following four-step CFCS algorithm:

1. **Normalization:**
   \[
   R = \max_j u_{ij}, \quad L = \min_j l_{ij}, \quad \text{and} \quad \Delta = R - L
   \]
   
   \[
   x_{ij} = (l_{ij} - L) / \Delta, \quad x_{mj} = (m_{ij} - L) / \Delta, \quad x_{uj} = (u_{ij} - L) / \Delta.
   \]

2. **Compute left (ls) and right (rs) normalized values:**
   
   \[
   x_{j}^{ls} = x_{mj} / (1 + x_{mj} - x_{ij}) \quad \text{and} \quad x_{j}^{rs} = x_{ij} / (1 + x_{ij} - x_{mj})
   \]

3. **Compute total normalized crisp value:**
   
   \[
   x_{j}^{\text{crisp}} = \left[ x_{j}^{ls} \times \left( 1 - x_{j}^{ls} \right) + x_{j}^{rs} \times x_{j}^{rs} \right] / \left[ 1 - x_{j}^{ls} + x_{j}^{rs} \right]
   \]

4. **Compute crisp values for**
   
   \[
   f_{ij} : \quad f_{j}^{\text{crisp}} = L + x_{j}^{\text{crisp}} \times \Delta
   \]