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Are You Up To The Mark? - A Grading Certification Guideline Of Reference For Vocational College Students' Sustainable Development Competencies

Bohong Li[1*], Mahyuddin Arsat[2], Mengmeng Zhong[3], Nei[4], Wang[4,] Duan, Yongzhou[5]

[1*,2,3]Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia, Skudai, Johor 81310, Malaysia, Malaysia,
[1,24,5]Xinxiang University, Henan 453000, China
[1]Bohong@graduate.utm.my, [2]Mahyuddin@utm.my, [3]Zhongmengmeng@graduate.my [4]2023Wang0503@gmail.com, [5]Thundorson@gmail.com

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ABSTRACT

This study introduces a Sustainable Development Competency Grading Assessment Guideline tailored for learners in higher vocational colleges. It categorizes essential competencies into four main areas: Systems and Critical Thinking, Strategic Action and Implementation, Social Interaction and Synergy, and Self-management and Personal Growth. Each area is further divided into basic, intermediate, and advanced levels, providing a structured approach to assess and enhance students' competencies in sustainable development. It aims to construct a comprehensive assessment tool in sustainability assessment. Through a Delphi study involving 17 experts from diverse backgrounds, the research validates the guideline's applicability and relevance. The experts' insights contribute to refining the competency categories and defining the proficiency levels required at each stage of sustainable development problem-solving. The Sustainable Development Competency Grading Assessment Guideline provides a systematic method for assessing and enhancing vocational college learners' competencies in sustainability. It supports educators in tailoring instruction to meet individual and collective learning needs, thereby contributing to the broader goal of equipping students with the necessary skills and knowledge for addressing global sustainability challenges.

Index Terms—sustainable development, competency guideline, vocational education, Guidelines.

I. INTRODUCTION

A. Background

UNESCO, (2017, 2020) points out that education plays a vital role in the development of student competencies for sustainability and in achieving the Sustainable Development Goals (SDGs). Adopted by the European Commission, the European Green Deal, in addition to achieving a just and inclusive green transformation in coordinated policy areas, also necessitates that education and training take action to address the green crisis. This is to ensure that learners of all ages have the ability to achieve sustainable living (EC, 2022). In June 2022, the European Council (EC) adopted a policy statement on learning to promote the green transition. It calls on members to prioritize green transition and sustainable development learning in education and training policies and plans. This includes providing opportunities for all learners to understand the climate crisis and sustainability in formal education (such as schools and higher education) and informal education (such as extracurricular activities, youth work) (EC, 2022).

Universities need to establish an organized reflective process to address sustainability issues and engage both teachers and students in an ongoing and institutionalized transformative learning journey (Loorbach & Wittmayer, 2023). The campus, as a socially responsible entity, should project an image of ethics, fairness, and environmental stewardship, aligning its actions with institutional values. The identification and generation of meaningful and conscious learning experiences prompt students and stakeholders to adopt a proactive stance on environmental issues (Ali et al., 2021). This cognitive alignment corresponds to the

fundamental and intentional educational preparation of future professionals. Therefore, universities are strategically positioned to enhance students' potential and elevate the sustainable and responsible competencies of each learner. Researchers argue that higher education institutions function as Complex Adaptive Systems (CAS), not rigid entities that simply respond and evolve based on feedback and societal demands (Priyadarshini et al., 2022). Consequently, the definition and development strategies of students' sustainability competencies vary, leading to pronounced differences in sustainability competencies among students from different disciplines (Elmassah et al., 2020).

Although environmental sustainability in all education and training policies and processes is vital to build the skills and competences needed for the green transition. However, the widespread adoption of Whole-institution approaches that integrate sustainability into all management aspects has not yet been achieved. Educational institutions need tools to monitor the effectiveness of sustainable development initiatives (EC, 2022)

The prior studies do not explicitly grade these competencies into levels. The major focus is on the types of competencies needed rather than on the proficiency levels within each competency. While the concept of grading sustainability competencies by proficiency level is a valuable approach for educational design and assessment, explicit models doing so are not prominently featured in sustainability education literature. The grading should be reasonable, and the grading standards should be established based on the characteristics and requirements of vocational skills to ensure that the grading standards can accurately reflect the vocational skill level of the assessed subjects. When selecting assessment methods, the actual situation and assessment objectives of the assessed subjects should be fully considered to ensure the scientific nature of the assessment methods (Darling-Hammond, 2005; Holdsworth et al., 2020).

The necessity of grading assessment of college students' sustainable development competencies is crucial to align educational practices with the goals of sustainable development. Education is recognized as a key means to achieve sustainable development, and appropriate teaching, learning, and assessment strategies are essential in this pursuit (Bramwell-Lalor, 2019). Sustainable assessment can help bridge the gap between assessment and learning, equipping students for the challenges of future learning and practice, fostering their sustainability consciousness, and encouraging their engagement in global sustainable development (Boud & Soler, 2016). Grading assessment plays a vital role in ensuring that students acquire the knowledge, skills, values, and attitudes related to sustainable development, ultimately contributing to the achievement of the Sustainable Development Goals (HESI, 2021).

B. Research Questions

The study aims to prove a critical analysis for the items of sustainability competencies in the assessment to the vocational college students, locating the key ones in the steps of the solvation of sustainable development issues. This paper furtherly makes the conclusion of competencies guideline for the rating assessment through an in-depth exploration of research findings.

C. Research Methodologies

This study develops a grading assessment guideline for vocational college students' sustainable development competencies through a multi-step process. Initially, a literature review identified 29 specific competencies related to sustainable development, laying a theoretical foundation for competency categorization. An international expert survey then refined these into four core competency categories, ensuring global relevance and practical applicability. In-depth expert interviews further clarified essential competencies required for addressing sustainable development challenges, emphasizing the guideline's practicality.

Cluster analysis, also known as clustering, is pivotal in identifying underlying patterns and trends within a dataset by analyzing the characteristics of the data and grouping similar items together. Sometimes, due to the similarity of data, different clustering analysis algorithm models may lead to variations in analysis results. Therefore, this study utilizes two algorithm models for analysis, aiming to achieve clearer and more accurate results.

II. LITERATURE REVIEW

A. Literature Review

In recent literature, key sustainability competencies for college students have been increasingly scrutinized, reflecting a growing recognition of the multifaceted skills required to navigate the complexities of sustainable development. These competencies span various domains, from theoretical knowledge to practical application, underpinned by a deep understanding of systemic interconnections and forward-thinking approaches.

Systems Thinking: Central to this is the competency in systems thinking, emphasized by scholars such as Molderez & Ceulemans (2018) and Davelaar (2021) (The latter one highlighted the competency, following the theoretical framework created and revised by Meadows, (2008).). This competency involves recognizing and understanding the interconnectedness of ecological, social, and economic systems within the biosphere, as highlighted by (Costello, 2023).

Future Orientation: Anticipatory or futures thinking, as discussed by Glasser & Hirsh (2016) and Wiek et al. (2011, 2016), is another critical competency. It encompasses considering long-term consequences and aiming for intergenerational equity and well-being, aligning with the insights from Wiek et al. (2022).

Normative Competency: The normative or values thinking competency, explored by researchers like Lambrechts et al. (2013), revolves around being guided by ethical values such as social justice, ecological responsibility, and participatory decision-making.

Critical Thinking and Problem-Solving: Critical thinking and problem-solving competencies are vital in applying knowledge to analyze and develop solutions for complex sustainability challenges. Kopnina, (2020) have delved into this aspect, highlighting the need for decision-making capacity within complexity.

Communication and Collaboration: Effective communication and collaboration, particularly in diverse groups, are competencies underscored by researchers like Wiek et al. (2011, 2015, 2022) and Thornhill-Miller et al. (2023). These skills are essential for communicating complex sustainability information and working with various stakeholders.

Project Management and Policy Development: Competencies in project management, policy analysis, and development, as noted by Donald et al. (2023), are crucial for planning, implementing, and evaluating sustainability interventions. They also play a significant role in designing and implementing policies supportive of Sustainable Development Goals (SDGs).

Intercultural Competence and Lifelong Learning: Understanding diverse cultural perspectives on sustainability and continuously seeking new knowledge are competencies discussed by Richter et al. (2023) and Leal Filho et al. (2021). These skills are indispensable in an increasingly interconnected and culturally diverse world.

The literature from various scholars, including Rieckmann (2012), Hanisch et al. (2023), and others, provides a comprehensive overview of these competencies. Their collective research underscores the importance of an integrated approach to sustainability education, which not only focuses on theoretical understanding but also on practical application, policy development, and the cultivation of a mindset oriented towards lifelong learning and intercultural competence. This holistic perspective is essential for effectively equipping students to contribute meaningfully to sustainable development. Wiek et al. (2011) concluded core SD principles, which are widely accepted, from the ocean of tags : systems thinking, future orientation, normative compass, contextual sensitivity, and actionable knowledge.

This study selected the key competency framework for sustainable development proposed by Wiek et al. (2011, 2022), which synthesizes a comprehensive literature review and a set of detailed learning objectives within an operational framework (Wiek et al. 2016). We summarize the following relational framework that constitutes the basic elements of sustainability competencies (Table 1 Segmented Items of Sustainability Competencies & Relevant Research).

B. Research Gap

Students are unlikely to have ability to rate their own capacity in an activity they have never practiced (Holdsworth et al. 2020）; Results are based on the unknowable way in which each student (inconsistently) interprets the prompt and the scale or understands the competency (Cebrián et al. 2019). Therefore, statements may fall into the trap of structured trap of narratives.

The study of sustainable development (SD) competencies in educational settings faces several significant challenges and gaps, which collectively highlight the need for a unified grading assessment guideline. These challenges include:

(a) Contextual Differences: Sustainability challenges and priorities differ widely across regions, cultures, and socioeconomic conditions, leading to variations in what is considered essential in terms of sustainable competencies.(Leal Filho, et al., 2021) (Ardoin, et la., 2023).

(b) Disciplinary Perspectives: The interdisciplinary nature of sustainability means that different academic disciplines approach it from diverse angles, complicating efforts to develop a unifying model of competencies. (Kopnina, 2020; Wiek et al., 2011, 2016)

(c) Lack of Universal Definition: There is a lack of consensus on core competencies for sustainable development, which can be attributed to the diversity of contexts and disciplines, as well as varying interpretations of what a grading assessment guideline should entail. (Beagon et al., 2023) (Chinedu et la., 2023)

(d) Balancing Knowledge and Intangible Skills: There is a need to strike an effective balance between assessing knowledge acquisition and practical skills necessary for addressing real-world sustainability challenges, including Assessing intangible skills such as attitudes, values, and behaviors related to sustainable development (Saleem et al.,2023).

Given these challenges, it becomes evident that the absence of a unified grading assessment guideline is a critical gap in sustainable development education. This gap hinders the ability to effectively evaluate and enhance the development of sustainability competencies among students. While specific authors who have directly addressed this precise issue were not identified in the provided context, the collective insights from the literature underscore the need for such a guideline in educational settings. Developing a unified grading assessment guideline that accommodates diverse contexts, disciplines, and the dynamic nature of sustainable development would be a significant step forward in advancing sustainability education.

III. METHODOLOGIES

A. Delphi Method

The Delphi method was initially used by the RAND Corporation in the 1950s for qualitative forecasting (He et al., 2016). Scholars are increasingly using the Delphi technique to identify indicators and assess the sustainability of projects (Tseng et al., 2023). The Delphi Method is a research approach that involves collecting expert opinions through anonymous surveys and group discussions to reach a consensus on a particular issue. The Delphi Method is a cost-effective and time-efficient way of gathering opinions and insights from experts, making it an invaluable tool for complex decision-making and problem-solving (Markmann, 2021). The Delphi Method is most commonly used when there is a lack of agreement or an absence of knowledge, and it is well suited to situations in which the experts are geographically dispersed and/or have limited time, With the advantages: anonymity, expert group consensus, and flexibility, making it an invaluable tool for various applications across different domains (Beiderbeck et al., 2021). The Delphi Method is also beneficial for developing a well-rounded view of an issue and gaining insight from experts without the need for face-to-face meetings. (Drumm et al., 2022). The study uses Delphi method because:

(a) This method is widely applied in the study of learners' sustainability competencies;
(b) Its participatory approach allows respondents to freely explore extended concepts and viewpoints, ensuring that researchers receive authentic feedback;
(c) Through repeated discussions and communication, a consensus is reached, enhancing the authority of the conclusions (Hsu & Sandford, 2019).

The Delphi methodology, complemented by cluster analysis, forms the backbone of this research. The Delphi method, renowned for its application in gathering expert consensus through iterative rounds of surveys (Hsu & Sandford, 2019), is paired with cluster analysis to discern patterns within data, highlighting its versatility across fields like data mining and pattern recognition (Fleischmann, 2023; Ikotun et al., 2023). This combination serves as an exploratory tool, enabling a nuanced understanding of sustainable development competencies.

A selected panel of 17 experts from diverse geographical and academic backgrounds, including China, ASEAN countries, South Korea, and Nigeria, contributed to this study (Table 2). Each expert, holding a doctoral degree with at least five years of relevant experience, provided insights into the competency frameworks, vocational education training, and sustainable development in vocational education. The study prioritized anonymity and informed consent, ensuring a respectful and ethical approach to data collection. The research employed semi-structured interviews, initiated by a preparatory notification to experts, followed by a survey conducted via an open-ended questionnaire comprising four critical questions related to sustainable development competencies (Table 3). This approach allowed for a flexible exploration of expert opinions, facilitated through both face-to-face and multi-rounds virtual meetings, ensuring comprehensive coverage of sustainable development competencies.

To uphold the integrity of the research, interviews were audio-recorded, with subsequent transcription and detailed analysis. A systematic method was applied to organize and analyze the data, involving coding responses and identifying themes relevant to the research questions. A member checking process further validated the findings, confirming the accuracy of interpretations with the participants (Table 4). The survey aimed to refine the understanding of sustainable development competencies, drawing from a meticulously developed questionnaire informed by extensive literature review and preliminary research. This process sought to elicit detailed expert insights into the competencies necessary for addressing sustainable development challenges effectively.

This study's scope is distinctly focused on developing a grading description of sustainable development competencies for students in higher vocational colleges. It aims to establish a foundational framework for future assessments, deliberately excluding the integration of competency dimensions with professional and technical domains. The research underscores the importance of a practical and implementable assessment guideline, facilitating the development of relevant teaching content and clear competency benchmarks for learners (Hammer & Lewis, 2023; Venn et al., 2022; Redman & Wiek, 2011; Corres et al., 2020).

In summary, this research methodologically combines the Delphi technique with cluster analysis to engage a diverse group of experts in defining and categorizing sustainable development competencies. Through a structured interview and survey process, it seeks to contribute a nuanced guideline for assessing and grading these competencies, tailored to the needs of vocational college students, and aligned with current educational demands in sustainable development.

Table 3: Questionnaire (1st Round-3rd Round)

	Questionnaires
	Round 1 Sustainable development competencies elements
1	What is your understanding of Sustainable Development Competencies?
2	What do you think are the essential elements in the construction of sustainability issues
3	What do you think is the logical relationship between these elements?
4	What elements do you think are included in sustainable development competencies?
	Round 2 Sustainable development competencies in key steps
1	What do you think are the key steps to solving sustainability issues? (Please list and briefly explain your reasons)
2	What indicators do you think should be included in the sustainable development competency framework at different stages of development?
	Round 3 Sustainable development competencies indicator system at various development stages
1	What indicators do you think should be included in the sustainable development competency system at different stages of development? (Please list the indicators for primary, intermediate and advanced stages respectively)
2	Please rate the following sustainable development competency indicators at different stages of development: Primary Stage/Intermediate stage/Advanced stage
3	Do you have any other comments or suggestions about this survey?

B. Cluster Analysis

Based on inviting experts to score each sub-item of competencies (in terms of their relevance to the steps of solving sustainable development issues), this study conducted a cluster analysis on the related data (Table 5). The purpose is to categorize the subdivided competencies into broader categories with significantly distinct attributes, to meet the needs of competency assessment and certification practices.

The code first loads the data, then uses the KMeans algorithm to cluster the data. The clustering algorithm employs the Elbow Method, which is a heuristic method used to determine the optimal number of clusters: by analyzing the relationship between the number of clusters (k value) and the clustering effect (usually measured by the Sum of Squared Errors, SSE), to find the best number of clusters. As the number of clusters increases, the distance from each point to its cluster center decreases, thus SSE decreases. After a certain point, the reduction in SSE brought by increasing the number of clusters will significantly drop, and the final number of clusters and interpretation need to be determined in conjunction with actual situations and professional knowledge.

The limitation of this study is that the participating experts are limited and distributed in local areas, and the views of individual interviewees cannot represent the cognitive or policy trends of the entire region. However, this study will make up for this shortcoming by incorporating a discussion of previous research.

The reason why the scatter plot of Python clustering analysis may group various competency items into one category is possibly due to the clustering algorithm grouping them based on the similarity between the data. Even though the competency items may not appear to belong to the same category on the surface, they might exhibit similar characteristics in some feature space, leading to their clustering into the same category. There are three potential reasons for the occurrence of cross-category data in the clustering analysis presented in this paper.

a) Data similarity: Despite describing different aspects of competency, the scores of various competency items might be very close in a certain feature space. If the data are not preprocessed and the values are relatively close, the algorithm may consider them similar data points and classify them into the same category.
b) Algorithm selection: Some clustering algorithms may tend to form larger categories, resulting in data points that should belong to different categories being mistakenly grouped into the same one.
c) Feature selection: The features chosen in clustering analysis have a significant impact on the results. The sustainability problem-solving step features selected in this study may lead to unclear data discernibility.

Therefore, after determining the grading indicators of the competency guideline, this study reassessed the clustering degree of each competency by adjusting the algorithm (Gaussian Mixture Model).

IV. RESULTS

The descriptions of various competencies were merged and categorized in the cluster analysis. Through testing, in this study, when the number of clusters is 4, the ability to differentiate groups becomes relatively clear (Figure 3). Next, PCA is used for dimensional reduction and the clustering results are visualized through a scatter plot, indicated by python programming (Figure 4). Finally, each cluster is iterated through, printing out all the subdivided competencies that belong to that cluster (Figure 5).

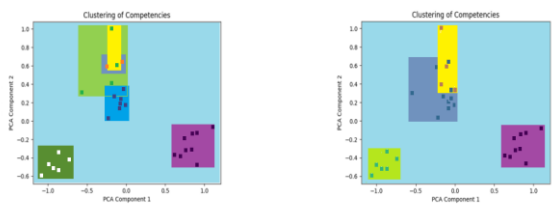
However, some competency items were also attributed to categories beyond those divided in the expert discussions. Competence for communication is attributed to another cluster group while the participation competency is organized into Cluster 2, regarding both items are used to describe learner's competency in the category of social interaction competency. The current explanation for the discrepancies caused by scoring and textual descriptions is that these competencies are used in multiple steps, and the scores given by experts' personal subjective opinions do not need to be considered as grounds for doubting their fundamental attributes. Of course, for the classification of competency items involved in the discrepancies, this study conducted a special discussion in the third round of the survey. Following the detailed discussions and refinements conducted in the third round of interviews, comprehensive assessment of how experts rated the importance of various sustainability competencies in practical operational procedures is presented, highlighting the critical competencies necessary for effective sustainability practices (Table 7). Despite this, we can still discern that the differentiation of subdivided competencies projects is quite apparent at the levels of systems thinking, strategic thinking and implementation. Additionally, expertshave also noted the necessity of separately listing competency indicators for individual growth.

Table 5: The Importance rating of competency indicators in operational procedures (1st Rating)

Competency	S1	S2	S3	S4
Systems/ Systemic Thinking Competence	5.0	5.0	3.5	4.8
Anticipatory / Futures Thinking Competence	5.0	4.9	3.5	4.7
Normative Competency	4.9	4.8	3.5	4.9
Competency for Evaluation	4.8	4.6	3.3	5.0
Values Thinking Competency	5.0	5.0	3.6	4.6
Strategic Action Oriented Competency	4.8	5.0	4.6	3.2
Acting Fairly and Ecologically Competency	4.7	5.0	4.5	3.4
Action-oriented Leadership &	5.	4.8	4.	4.5

Change Agency Skills	0		6	
Interpersonal/ Cooperation / Collaboration Competency	4.9	4.7	4.4	4.4
Problem Solving/ Implementation Competency	5.0	4.8	4.6	3.3
Political Competency	5.0	5.0	4.6	4.6
Intrapreneurial Competency	4.9	4.8	4.5	3.3
Planning & Realizing Innovative Projects Competency	4.8	5.0	4.5	3.6
Sustainability Research Competency	5.0	4.9	3.5	4.6
Community Science Competency	4.9	4.7	4.5	4.6
Competency for Ambiguity and Frustration Tolerance	4.9	5.0	3.3	4.7
Critical Thinking / Decision-Making Capacity within Complexity	5.0	4.9	3.6	4.9
Participation Competency	4.3	4.8	4.8	4.2
Competency for Stakeholder Engagement / Community	5.0	4.9	4.5	4.3
Integrated Learning Competency	4.7	3.9	4.8	4.7
Interdisciplinary Work Competence	4.9	4.8	4.6	3.5
Competency for Empathy and Change of Perspective	4.8	4.8	4.4	4.5
Intellectual Humanity Competency	4.8	3.8	4.4	4.4
Understanding of Different Worldviews and Relationships	4.8	4.7	3.5	4.7
Competence for communication and use of media	4.6	4.4	4.5	4.4
Growth Mindset	4.9	4.7	4.8	4.8
Intercultural Competence	5.0	4.8	4.5	4.5
Self-regulation Competence	4.8	4.8	4.9	4.7
Evolutionary Thinking	4.2	4.3	4.2	4.4

This study explores the core element structure and the universal operational steps for achieving sustainability in the dimensions of the subjective and objective worlds through inquiries with experts in higher education assessment and sustainable development. The experts showed a high level of consensus on the existing frameworks for sustainability development competencies.



K=6 K=4

Figure 3 (K=6 / 4) Cluster Analysis of Sustainability Competencies (1st Test)

```
import pandas as pd

df = pd.read_csv("D:/python/my_dataframe.csv")
from sklearn.cluster import KMeans
import matplotlib.pyplot as plt
from sklearn.decomposition import PCA

K = 6
kmeans = KMeans(n_clusters=K, random_state=0).fit(df.iloc[:,1:])
df['Cluster'] = kmeans.labels_

for i in range(K):
    print(f"Cluster{i+1};")
    print(df[df['Cluster'] == i]['Competency'],"\n")

pca = PCA(n_components=2)
df_pca = pca.fit_transform(df.iloc[:, 1:-1])

plt.scatter(df_pca[:, 0], df_pca[:, 1], c=kmeans.labels_)
plt.title("Clustering of Competencies")
plt.xlabel("PCA Component 1")
plt.ylabel("PCA Component 2")
plt.show()

for i in range(K):
    print(f"Cluster {i+1}:")
    cluster_members = df[df['Cluster'] == i]['Competency']
    for competency in cluster_members:
        print(f"- {competency}")
    print("\n")
```

Figure 4 Cluster analysis algorithm Python programming (K-means, K=4, 1st Test)

```
Cluster4:
19                    Integrated Learning Competency
22                 Intellectual Humanity Competency
24    Competence for communication and use of media
28                      Evolutionary Thinking
Name: Competency, dtype: object

Cluster 1:
- Systems/ Systemic Thinking Competence
- Anticipatory / Futures Thinking Competence
- Normative Competence
- Competency for Evaluation
- Values Thinking Competence
- Sustainability Research Competency
- Competency for Ambiguity and Frustration Tolerance
- Critical Thinking / Decision-Making Capacity within Complexity
- Understanding of Different Worldviews and Relationships

Cluster 2:
- Action-oriented Leadership & Change Agency Skills
- Interpersonal/ Cooperation / Collaboration Competency
- Political Competency
- Community Science Competency
- Participation Competency
- Competency for Stakeholder Engagement / Community
- Competency for Empathy and Change of Perspective
- Growth Mindset
- Intercultural Competence
- Self-regulation Competence

Cluster 3:
- Strategic Action Oriented Competency
- Acting Fairly and Ecologically Competency
- Problem Solving/ Implementation Competency
- Intrapreneurial Competency
- Planning & Realizing Innovative Projects Competency
- Interdisciplinary Work Competence

Cluster 4:
- Integrated Learning Competency
- Intellectual Humanity Competency
- Competence for communication and use of media
- Evolutionary Thinking
```

Figure 5 Grouping of competencies indicators demonstrated in the cluster analysis algorithm (1st Test)

Table 7: The Importance rating of competency indicators in operational procedures (2nd Rating)

Competency	S1	S2	S3	S4
Systems Thinking	5.0	5.0	3.5	4.8
Critical Thinking	5.0	4.9	3.5	4.7
Normative Competence	4.9	4.8	3.5	4.9
Evaluation & Research	4.8	4.6	3.3	5.0
Future Thinking	5.0	5.0	3.6	4.6
Strategic Action-Oriented Competence	4.8	5.0	4.6	3.2
Intra-preneurial Competence	4.9	4.8	4.5	3.3
Inter-disciplinary Work Competence	4.9	4.8	4.6	3.5
Problem Solving Competence	5.0	4.8	4.6	3.3
Innovative Competence	4.8	5.0	4.5	3.6

Interpersonal Competence	4.7	4.5	4.4	4.4
Communication Tools & Media Use Competence	4.6	4.4	4.5	4.4
Participation & Leadership	4.6	4.3	4.6	4.5
Cross-Cultural Competence	5.0	4.9	4.5	4.3
Self-Awareness	4.7	4.9	4.8	4.7
Self-Regulation & Motivation	4.9	4.7	4.8	4.8
Self-Efficacy Management	4.8	4.8	4.9	4.7
Values Thinking	4.8	4.8	4.7	4.8

The results of cluster analysis using the Gaussian Mixture Model (GMM) demonstrate a well-distributed pattern of points, which is utilized to examine the categories of competencies (Figure 7) through Cluster analysis in python coding (Figure 8, Figure 9). However, a noticeable conflict arises from the mistaken categorization of cross-cultural competency within the cluster of system thinking competencies. This discrepancy underscores the ongoing debate among experts regarding whether more emphasis should be placed on the origins of systemic thinking or on its application in communication and cooperation activities (R3:5; R3:7; R3:10; R3:14; R3:17). In this study, we advocate for categorizing it within the group of social-interaction and synergy competencies, considering the functional balance and application of assessments.

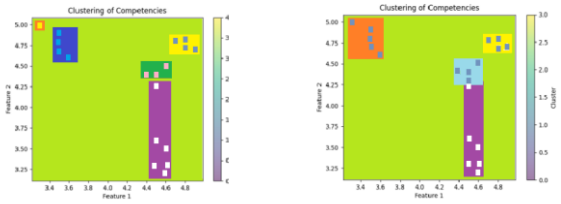


Figure 7 Cluster Analysis of Sustainability Competencies (2nd Test)

```
Cluster 1:
5      Strategic Action-Oriented Competence
6          Intra-preneurial Competence
7     Inter-disciplinary Work Competence
8          Problem Solving Competence
9              Innovative Competence
13          Cross-Cultural Competence
Name: Competency, dtype: object

Cluster 2:
0          Systems Thinking
1         Critical Thinking
2      Normative Competence
3    Evaluation & Research
4           Future Thinking
Name: Competency, dtype: object

Cluster 3:
10                  Interpersonal Competence
11    Communication Tools & Media Use Competence
12                Participation & Leadership
Name: Competency, dtype: object

Cluster 4:
14              Self-Awareness
15    Self-Regulation & Motivation
16       Self-Efficacy Management
17             Values Thinking
Name: Competency, dtype: object
```

Figure 8 Grouping of competencies indicators demonstrated in the cluster analysis algorithm (2nd Test)

```
import pandas as pd
import matplotlib.pyplot as plt
from sklearn.mixture import GaussianMixture

# Read Data
df = pd.read_csv("D:/python/my_dataframe.csv")

# Analysis through Gaussian Mixture Model
K = 4
gmm = GaussianMixture(n_components=K, random_state=0)
gmm.fit(df.iloc[:, 1:-1])
df['Cluster'] = gmm.predict(df.iloc[:, 1:-1])

# Output individual member from each cluster
for i in range(K):
    print(f"Cluster {i+1}:")
    print(df[df['Cluster'] == i]['Competency'], "\n")

# Generate Spots Figure
plt.scatter(df.iloc[:, -3], df.iloc[:, -2], c=df['Cluster'], cmap='viridis', s=5
plt.title("Clustering of Competencies")
plt.xlabel("Feature 1")
plt.ylabel("Feature 2")
plt.colorbar(label='Cluster')
plt.show()
```

Figure 9 Cluster analysis algorithm Python programming (GMM, K=4, 2nd Test)

V. FINDINGS

A. Essential Components

Sustainable development focuses on how to leverage the connection between people and nature from harmful transition to sustainable state (Barragan-Jason et al., 2022)

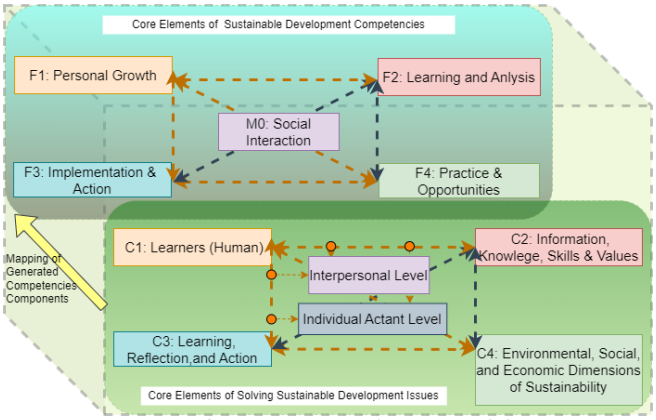


Figure 1: Core Components of Competencies to Address Sustainability Issues

From the survey to experts, the conclusion can be manifested in “Problem-Competency Cub” which contains 2 aspects: Core elements of sustainable development solution and core components in sustainability.

In this study, when notifying experts to participate in discussions, they were reminded to consider whether it is possible to examine sustainable development issues in a three-dimensional perspective from another dimension, as a complement to studies from a phenomenological perspective (from the viewpoints of social, economic, and human sustainable development) (Figure 1). During the discussions, some experts proposed viewing sustainable development capabilities as "the effectiveness of individuals (learners) mastering the behaviors to maintain the sustainability of things (affairs) through experience and patterns," which was agreed upon by the majority of experts. This concept aligns with broader themes in sustainability education and behavior change research. These fields emphasize experiential learning, pattern recognition, and behavior modification as crucial components in fostering sustainable practices. Subsequent framework discussions were conducted on this basis.

In the comprehensive framework of core components of competencies to address sustainability issues, 4 fundamental elements construct the basic structure of SD issues solutions. Firstly, in terms of the environmental dimension, there is sustainability, which may pertain to natural resources or communities. As actors (learners in the framework of this study), individuals need to acquire information and skills and take action under the guidance of certain attitudes and values. These actions may be a response to the loss of environmental sustainability or learning behaviors necessary to change the environment and grasp information. The key elements such as knowledge, skills, values, personal/interpersonal levels, environmental/social/economic dimensions, and the learning-reflection-action cycle - are intricately connected and manifest in co-reactive and related ways:

(a) C1 to F1:

Actants are the primary components in ultimately solving sustainability issues. Elements such as information, competencies, and actions are all generated through actors. In the process from acquiring intelligence and developing skills to enhancing problem-solving competencies, actors also need to achieve competency growth through self-management and a growth mindset. Among these, the perception of self-efficacy and the competency to self-regulate continuously have a significant impact on improving oneself in higher-order thinking skills and practical operational competencies (R2: 1-5; R2:8-12; R2:15-17).

(b) C2 to F2:

Knowledge manifests as a deep understanding of sustainability issues, principles, and global challenges. Skills are evident in the practical application of this knowledge through problem-solving, effective communication, and collaboration. Values manifest as internalized principles that guide decisions and

behaviors towards sustainability. These components represent the intellectual (knowledge), practical (skills), and ethical (values) dimensions of sustainability, forming a holistic educational foundation. Based on this, systematically processing information, and engaging in critical thinking, mastering the ability to work in the intersection of professional work and the field of sustainable development, can all become targets for assessing learning outcomes. The analytical ability that runs through all stages of solving sustainable development issues is directed not only towards the past but also towards the future, which is an important ability for strategic design and efficacy evaluation (R2: 1-2; R2: 4-6; R2:9-15).

(c) C3 to F3:

In the key factor of implementation and action, the competencies of utilizing soft resources and construct possible solution way between information and real problems present the importance, including integrated learning competency, strategic implementation competence, etc., Learners are supposed to be active engagement with sustainability knowledge, being capable of critical evaluation of personal and societal sustainability impacts. They are also expected to take concrete steps towards sustainable practices. This cycle encapsulates the transformative process of sustainability competence cultivation, where ongoing learning leads to reflective thinking, which in turn inspires meaningful action (R2: 1-8; R2: 10-16).

On a personal level, sustainability is manifested in individual choices and actions. Interpersonally, it comes through in collaborative efforts and communication aimed at promoting sustainability. Systemically, it is evident in the understanding and influence exerted on broader societal systems like policy and economics. This multi-level approach underscores the progression from individual awareness and action to collective and systemic change, emphasizing the interconnectedness of personal, social, and systemic transformations (R2:1; R2:4-9; R2:12-15; R17).

(d) C4 to F4:

Environmental dimensions manifest in addressing ecological challenges; social dimensions in efforts towards equity and justice; and economic dimensions in advocating for sustainable economic practices. All of these can be classified into “Objective world”, reflecting a comprehensive approach that reminding us to pay attention to the balance of energy flow between human subjective activities and the objective world (including the natural world and human socio-economic activities) (R2: 1-5; R2:10-15; R2:17).

In both aspects, Each of these core components is essential for the development of comprehensive sustainability competencies. They are interdependent, with each element reinforcing and complementing the others. The guideline’s effectiveness lies in its ability to facilitate a deep and nuanced understanding of sustainability, enabling learners to internalize concepts, develop practical skills, and embody the values necessary for championing sustainable development (R2: 1-8; R2: 10-17).

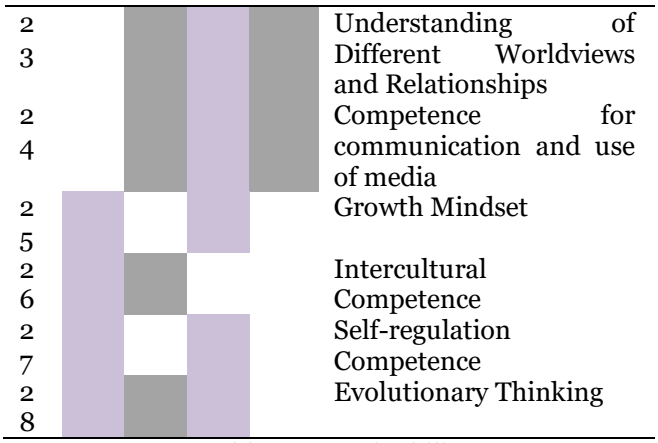
Some experts have provided different viewpoints in discussions. F1-Actors might need initiators, and this broader concept could replace it, but some interviewees believe that the carriers of executing sustainability development's technology, skills, and actions are more in line with the definition of this element (R2:6,7; R2:13-14). Other experts think that F2-Information should include norms and rules’ concepts, not just knowledge and skills. Considering the characteristics of F1 and the theme of this study being the sustainable development capabilities of students, some experts have made corrections (R2: 3; R2:17). In the discussion of F3-Action’s initiatives, some experts insist that thinking ability should belong to the nature of skills and experience (F2), of course, most participants believe that the inspection dimension of action lies in the attitude, cognition behind the action, F3 elements actually summarize the learners’ feedback on environmental information, and behavior is just the result of expression (R2:9; R2:17). F4-Sustainability is not recognized by individual experts, they think it should be the environment (subjective environment plus objective environment), so the correspondence of each element is balanced, and the individual's action not only makes the external environment obtain improvements in sustainability but also affects the subjective environment (R2:6-9; R2:16). However, after in-depth discussions, this study adopted the views of most experts and defined this element as the more specific “environmental sustainability.”

Considering the property of Factor one (Human), and M 0 (Individual level), which are the basic element for any observation to learners’ SD competencies, we only preserve the necessary Factors two to four and M 1, with various color to show the difference and degree of progression. The table is also concluded from analysis on the interviews with experts. The square marked with color only demonstrate the necessary but not sufficient conditions.If multiple combination schemes appear in the statistics, they will be marked only after reaching a consensus of more than 12 experts (70%) through discussion. At the same time, these sub-skills can be preliminarily merged during the discussion. For example, “Problem Solving” and “Implementation Competency” are considered as one item. A similar approach is taken for 6 items, and eventually, we obtain

the "Relationship between SD Competencies and Essential Components" (Table 6). The identified essential elements indicate that the weight of these competencies will be higher than those not identified during the evaluation.

Table 6 Relationship between SD Competencies and Essential Components

	F2	F3	F4	M1	**Key Sustainability Competency**
1					Systems/ Systemic Thinking Competence
2					Anticipatory / Futures Thinking Competence
3					Normative Competency
4					Competency for Evaluation
5					Values Thinking Competency
4					Strategic Action Oriented Competency
6					Acting Fairly and Ecologically Competency
7					Action-oriented Leadership & Change Agency Skills
8					Interpersonal/ Cooperation / Collaboration Competency
9					Problem Solving/ Implementation Competency
10					Political Competency
11					Intrapreneurial Competency
12					Planning & Realizing Innovative Projects Competency
13					Sustainability Research Competency
14					Community Science Competency
15					Competency for Ambiguity and Frustration Tolerance
16					Critical Thinking / Decision-Making Capacity within Complexity
17					Participation Competency
18					Competency for Stakeholder Engagement / Community
19					Integrated Learning Competency
20					Interdisciplinary Work Competence
21					Competency for Empathy and Change of Perspective
22					Intellectual Humanity Competency



Steps to Address Sustainability Issues

All experts highlight the competencies in solving practical issues should be performed effectively (The effectiveness of behaviors), which means that, whether exploring capabilities at the cognitive, skill, or thought level, ultimately, it is about examining problem-solving behaviors. Previous studies have varied in their emphasis on the division of steps. Starting with Wiek and Lang's study in 2017, subsequent research emphasizes distinct steps in addressing sustainable development issues. Raworth's "Doughnut Economics" highlights the balance between planetary needs and human well-being within ecological limits and social foundations. Rockström et al. (2023) identify critical transformations required for the SDGs, emphasizing analyzing past and current states, constructing sustainable visions, and scenario building during strategy development. Pereverza's research (2019) focuses on strategic planning for sustainable heating in cities and participatory backcasting, emphasizing problem analysis and refined implementation after strategy evaluation.While specific details about Siegel et al.'s research (2024) are unavailable, their work likely contributes to understanding sustainable development issues within the current timeframe. Sachs et al. (2023) integrate digital elements, focusing on data collection and analysis across all stages. Collectively, these studies underscore the importance of specific operational steps such as problem analysis, strategy evaluation, and refined implementation, complementing the broader research landscape established by Wiek and Lang.

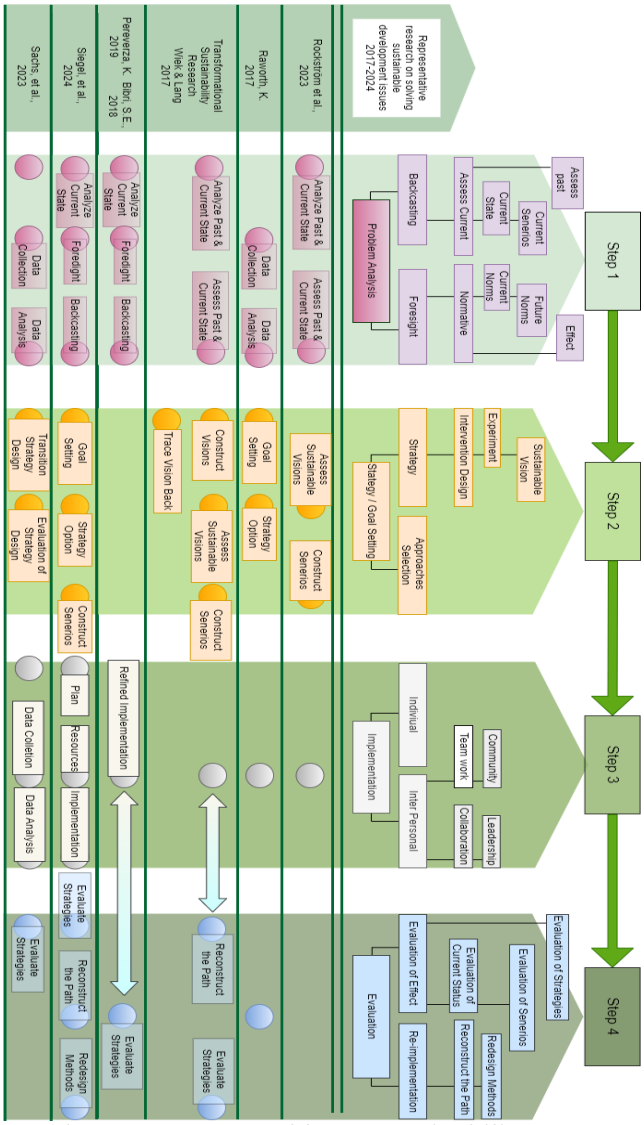


Figure 2: Steps to Address Sustainability Issues

Researchers believe that the steps to solve specific and complex sustainability issues are divided into four stages, including problem analysis, strategy formulation (goal setting), implementation and action, and impact assessment (Figure 2). Through the collected responses, experts have acknowledged these four steps and have also supplemented the operational aspects contained in each step.

In problem analysis, the main operational aspects are Backcasting and Foresight. Actors may need to assess the current scenario and state, and even compare earlier situations to predict what impact the changes in standards will bring. In the Strategy Setting section, actors need to consider a sustainable vision, make creative designs for solving strategies or intervention methods, and choose the appropriate solutions based on the set goals. In the implementation steps, experts emphasized the mutual influence between individual-level changes and growth, and the levels (collaboration / Leadership) and scope (Teamwork / Community) of group-level behavior. The effectiveness of the implementation needs to be evaluated (Strategies / Scenarios / Status). If necessary, it may be required to execute again after restructuring paths and reorganizing methods

B. Construct the grading competency assessment guideline

Through the third round of interviews, experts refined and explained the performance of each categorized competency at various action steps. In summarizing the experts' modification proposals, we discussed in detail with the expert group the distinction and attribution of competencies that span different classification concepts. For the convenience of assessing learning outcomes in practical operations, we ultimately consolidated the major categories of competencies into four types, each containing 5-8 subdivided competency indicators. After selective discussions with various experts, the subdivided competency indicators were condensed into 19 items, incorporated into the four categories of sustainable development competencies, and named these four key competencies as: Systems and Critical Thinking, Strategic Action and Implementation, Social Interaction and Synergy, Self-management and Personal, abbreviated as the 4S

competency guideline. Each subdivided competency indicator in the competency guideline was negotiated by experts to describe the competency standards from basic to advanced.

The core dimensions of college students' sustainable development are based on self-growth, forming basic self-judgment and thinking in solving green issues in a sustainable manner. This involves participating in the green process in professional technical fields and community life through individual or team efforts, utilizing existing tools, and leveraging their sustainable development competencies. In every step of solving green issues, the comprehensive application of various abilities is indispensable (Figure 6).

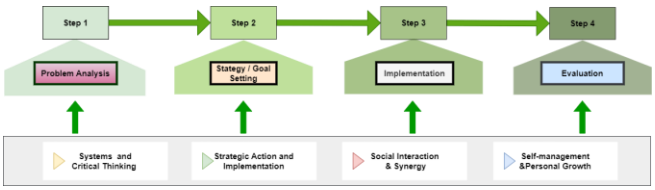


Figure 6: Relationships between sustainable development competencies and operational steps

These competencies are interconnected and facilitate achieving successful performance and a positive outcome that progresses sustainability in a range of contexts. The connotation of these competencies is that they enable students to deal critically, reflexively, and inclusively with various values, concepts, and solution approaches, contributing responsibly to overcoming real-world problems and opportunities (Cebrián, et al., 2020)(Hammer & Lewis, 2023). In this study, the sub-competencies of college students' sustainable development were consolidated three times, combining 29 sub-indexes into 4 categories with 19 items based on the core points observed in each project. Although experts strongly suggest complementing the sub-index in the category of "Individual Mindset Growth," considering the similarity of content, the study integrates the index of Self-discipline, Self-Regulation, and Self-Motivation into "Self-Regulation & Motivation; combines the descriptions of Tolerance for Ambiguity & Frustration with that from "Self-awareness," as both can be attributed to mindfulness management content. As for the descriptions in the Political Activity Competency index: identifying stakeholders related to the sustainable development political process, since it converges with the competency descriptions in Stakeholder Engagement and action-oriented leadership, it is adjusted to "identifying various stakeholders related to the sustainable development process" in the Community Participation Competency project, and the description of understanding basic political systems and governance structures in the Leadership competency index. Considering the scope of measuring college learners' learning outcomes, "using political strategies" is simplified to "able to navigate effectively within the community to support sustainable development goals" and is included as an advanced competency requirement in the combined competency index of "Community Participation" and "Action-oriented Leadership," while completely eliminating the "Political Competency" index. Community science projects belong to the community's sustainable development goals and community participation content; thus the Community Science Competence competency index description is adapted to the community activity participation project category. Based on similar attributes, Stakeholder Engagement competence, Community Participation Competence, and Action-oriented Leadership are combined into the Social-Interaction and Synergy category under the Participation and Leadership project. Similarly, in this category, Interpersonal / Cooperation / Collaboration Competence is consolidated into: Interpersonal Competence. Empathy and Perspective-Shifting Competence focus more on observing and evaluating learners' psychological states, emphasizing understanding and perspective shifting, and under expert advice, this item is ultimately eliminated and merged into the competency index of interpersonal abilities and cooperation abilities. Because it emphasizes actions for environmental protection within organizational systems, it integrates Acting Fairly and Ecologically Competence-related content into Strategic Action-Oriented Competence and cancels the overly broad description of the sustainable development competency requirements for vocational college students. Value thinking is an important part of self-management because it can help people reflect on their behavior and values and make more sustainable choices (Wahl, 2016; Sterling et al., 2021).

Based on the comprehensive and detailed descriptions collected from the interviews, here are the indicator points in the assessment to the competencies in sustainability (Appendix: Table 8). Furthermore, the descriptive definitions for the major types of competencies can be obtained, such as Systems and Critical Thinking, Strategic Action and Implementation, Social Interaction and Synergy, and Self-management and Personal Growth:

(a) Systems and Critical Thinking Competencies:

The Systems and Critical Thinking cluster encompasses subdivisions that require a profound understanding of the dynamics of complex systems, their components, and interconnections. This competency enables

individuals to systematically analyze, evaluate, and synthesize information from various fields to address multifaceted problems from a holistic perspective. It encourages critical assessment of systems' sustainability at ecological, social, and economic levels, fostering an inquiry environment. This competency equips individuals with the skills to navigate future uncertainties, identify intervention opportunities, and devise sustainable solutions. Critical thinking also involves scrutinizing underlying assumptions, critically assessing evidence, and embracing diverse viewpoints to make well-informed decisions.

(b) Strategic Action and Implementation Competencies Group:

The Strategic Action and Implementation competencies entail transforming sustainability insights and analytical skills into actionable strategies and interventions. Essential for crafting, executing, and overseeing initiatives that propel sustainable development, this competency set emphasizes the importance of defining clear objectives, developing strategic plans, mobilizing resources, and assessing outcomes. Learners in vocational education equipped with these competencies adeptly navigate complex systems, innovate impactfully, and apply solutions that are both inventive and pragmatic. They excel in initiating collaborative efforts towards shared sustainability objectives, demonstrating leadership and entrepreneurial spirit to steer transformative governance and sustainable ventures.

(c) Social Interaction and Synergy Competencies Group:

The Social Interaction and Synergy competencies are pivotal for successful collaboration and collective action towards sustainable solutions. This group highlights the importance of empathetic communication, understanding diverse perspectives, and fostering strong interpersonal relationships for effective team dynamics and community involvement. It accentuates proficiency in managing cultural differences, leading inclusive discussions, and leveraging collective intelligence across various social and cultural settings to address sustainability challenges. Additionally, it underscores the role of leadership in motivating change, promoting sustainability, and building partnerships for community and global sustainability endeavors. These competencies are crucial for leading and engaging in cross-cultural teams, using strategic communication to shape public opinion, and actively participating in shaping a sustainable future through participatory and leadership roles.

(d) Self-management and Personal Growth Competencies Group:

Self-management and Personal Growth competencies focus on the ongoing development of personal skills and fostering a mindset aligned with sustainable development. This competency set is marked by an in-depth self-awareness, stringent management of one's actions and motivations, and a dedicated pursuit of lifelong learning and self-betterment in line with sustainability principles. It involves adeptly managing personal emotions and behaviors, setting and actively pursuing personal and professional objectives, and adapting to various challenges and changes with resilience. Individuals proficient in these competencies are dedicated to their personal growth, acknowledging the significance of their well-being in contributing effectively to sustainable development. They are reflective practitioners who critically evaluate their actions and continually seek opportunities for self-enhancement, thus promoting personal development and sustainability.

C. Competencies Adjusted

These competencies are interconnected and essential for fostering the knowledge, skills, attitudes, and behaviors necessary for advancing sustainability in various contexts. Under each major category, there are sub-items for stakeholders' comprehensive application (Appendix: Table 9). Although the guideline facilitates individuals to engage critically and reflexively with sustainability challenges, and integral assessment from organizations, despite this, further research is needed to determine how to annotate scoring systems on each competency indicator item.

Some experts argue that the grading assessment competencies guideline should highlight personal development in sustainability according to common agreement at international level (UNESCO, 2020; Duraiappah, et al., 2021). External sustainability issues require individuals to change their behaviors and approaches, which also constitutes the possibility of personal sustainability (Parodi, 2018). The individual's self-awareness, self-motivation, and resilience in facing complex problems should all be reflected in the guideline of sustainable development (R3:2; R3:4; R3:13; R3:16). However, some argue that the guideline should focus more on addressing directly relevant skills for sustainable development. Yet, the basic literacy and qualities of individual learners can be seen as the background for the emergence of relevant skills. Although there is a possibility to strengthen or weaken these skill indicators, they should be excluded from the guideline (R3:1; R3:8).

Additionally, this grading guideline considers balance when specifying competencies, with each subdivided indicator involving levels from basic to advanced. Some experts expressed in interviews that some

competencies do not require requirements at the basic stage (R3:8, R3:15). Some experts also called for further discussion on the "research competency for sustainable development issues" listed in the guideline (R3:5, R3:12). Learners in vocational colleges also include students with backgrounds in informal learning outcomes certification, and some experts expressed concern about their risk of meeting the standards (R3:5, R3:9). Ultimately, most respondents approved of this guideline as a referential framework to be tried first in the assessment work of sustainable development competencies.

VI. AUTHOR CONTRIBUTIONS

Conceptualization, BL,MA & PB; methodology, BL and MZ; software, BL;formal analysis, BL and PB; investigation, BL and NW; resources, MA and PB; data curation, NW; writing - original draft preparation, BL; writing - review and editing, BL and NW; visualization, MZ; supervision, MA; project administration, MZ. All authors have read and agreed to the published version of the manuscript.

VII. CONFLICTS OF INTERESTS

The authors declare no conflict of interest.

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Appendix

Table 1 Segmented Items of Sustainability Competencies & Relevant Research

	Segmented Items of Sustainability Competencies	Relevant Research
1	Systems/ Systemic Thinking Competence	Molderez & Ceulemans, (2018); Ratinen et al., (2023); Sanneh, (2018); Davelaar, (2021); Glasser & Hirsh, (2016); Venn & Vandenbussche, (2022); Wiek et al. (2011,2015); Rieckmann, (2012)
2	Anticipatory / Futures Thinking Competence	Glasser & Hirsh, (2016); Venn & Vandenbussche, (2022); Wiek et al. (2011, 2015); Rieckmann, (2012); Eberz et al., (2023); Sierra et al., (2023); Hanisch et al., (2023)
3	Normative/ Values Thinking Competency/ Competence for Evaluation	Glasser & Hirsh, (2016); Venn & Vandenbussche, (2022); Wiek et al. (2011, 2015); Rieckmann, (2012); Sierra et al., (2023); Lambrechts et al., (2016); Hanisch et al., (2023)
4	Strategic / Action Oriented/ Acting fairly and ecologically Competence/ Action-oriented Leadership Skills and Change Agency Skills	Meza Rios et al., (2018); Glasser & Hirsh, (2016); Wiek et al. (2011, 2015), Faham et al., (2017); González-Salamanca et al, (2020); Annelin & Boström, (2022);
5	Interpersonal/ Cooperation (in (Heterogeneous Groups)/ Collaboration Competency	Glasser & Hirsh, (2016); Venn & Vandenbussche, (2022); Wiek et al. (2011, 2015); Rieckmann, (2012); Sierra et al., (2023); Hanisch et al., (2023)

6	Problem Solving/ Implementation Competency	Venn & Vandenbussche, (2022); Wiek et al. (2011); Boone et al., (2023)
7	Political Competency	Venn & Vandenbussche, (2022)
8	Intrapreneurial Competency/ Competency for Planning and Realizing Innovative Projects	Venn & Vandenbussche, (2022); Rieckmann, (2012)
9	Sustainability Research Competency / Community Science Competency	Venn & Vandenbussche, (2022); Hanisch et al., (2023)
10	Competency for Ambiguity and Frustration Tolerance	Rieckmann, (2012); Lambrechts et al., (2013)
11	Critical Thinking / Decision-Making Capacity within Complexity	Rieckmann, (2012); University of Calgary, (2018); Lambrechts et al., (2013)；Hanisch et al., (2023)
12	Participation Competency/ Competency for stakeholder engagement / Community	Rieckmann, (2012); University of Calgary, (2018); Sass et al., (2022); Hanisch et al., (2023)
13	Integrated Learning Competency/ Interdisciplinary Work Competence	Venn & Vandenbussche, (2022); Rieckmann, (2012); Lambrechts et al., (2013); Hanisch et al., (2023)
14	Competency for empathy and change of perspective/ understanding of different worldviews and relationships/ Intellectual Humanity	Rieckmann, (2012); University of Calgary, (2018); Lambrechts et al., (2013); Hanisch et al., (2023)
15	Competence for communication and use of media	Rieckmann, (2012)
16	Growth Mindset	Hanisch et al., (2023)
17	Intercultural Competence	Hanisch et al., (2023)
18	Self-regulation Competence	Hanisch et al., (2023)
19	Evolutionary Thinking	Hanisch et al., (2023)

Table 2: Form of Consultation Expert Profile Summary

Gender	Age	Highest Level of Education	Research Experience (Years)	Title	Research Area	Position Type	Country/Territory of Origin
Male	53	Doctorate	30	Professor	Education Policy	University	China
Male	37	Doctorate	25	Professor	TVET, Humanities	University	China
Female	37	Doctorate	18	Senior Researcher	Educational Economics	University	China
Male	39	Doctorate	22	Professor	Educational Management	University	China
Male	35	Doctorate	10	Associate Professor	Educational Governance	University	South Korea
Female	47	Doctorate	12	Professor	TVET, Sustainability	University	South Korea
Male	48	Doctorate	13	Professor	TVET, Sustainability	Government	Malaysia
Female	34	Doctorate	17	Senior Researcher	Educational Management	Official Think Tank	Malaysia
Male	49	Doctorate	17	Professor	Political Science	University	Hong Kong
Male	52	Doctorate	10	Professor	Educational Economics	University	Thailand
Male	51	Doctorate	10	Professor	Educational Management, Pedagogy	University	Thailand
Female	39	Doctorate	15	Associate Professor	Sustainability Education	NGO	Nigeria
Male	46	Doctorate	20	Senior Lecturer	Vocational Training	University	Nigeria
Female	41	Doctorate	19	Research Director	Educational Policy	Research Institute	Nigeria
Male	44	Doctorate	16	Senior Researcher	Technological Education	Official Think Tank	Singapore
Female	38	Doctorate	14	Lecturer	Educational Sociology	University	Philippines
Male	50	Doctorate	20	Professor	Educational Leadership	Government	Philippines

Table 4： Overview of questionnaires answered by the experts in the Delphi Study (From: Core Components of Sustainable Development Competencies towards an agreed-upon grading assessment guideline)

Round NO.	Topic	Instructions
Round 1	Competency definition	Review the definition of competencies Review the Simplified categories Review the core components contained in those competencies Ref list： UNESCO, (2017). Education Goal 4.7: Knowledge and Skills for Sustainable Development;

		UNESCO, (2014). United Nations Decade of Education for Sustainable Development (DESD, 2005-2014)" Wiek, A., Withycombe, L., & Redman, C. L. (2011). "Key competencies in sustainability: a reference framework for academic program development." Sustainability Science, 6(2), (203-218) Hammer, T., Lewis, A.L. (2023). Which competencies should be fostered in education for sustainable development at higher education institutions? Findings from the evaluation of the study programs at the University of Bern, Switzerland. Discov Sustain 4, 19. (doi.:10.1007/s43621-023-00134-w) University of Georgia, (n.d.) Sustainability Certification. (https://reurl.cc/2z77bE)
Round 2	Process of Solutions	Review the key steps in solving the sustainable development issues (offer reasons) Review the involved the competencies in each operational step Review the extra type of competencies according to contextualized practice, if necessary Ref: Comment on results from round 1
Round 3	Grading guideline	Review the descriptions of each sub-type of competency in various level Review the objectives in sustainable development education to vocational college students Comment on results from rounds 1 & 2 Comment on the basis of Cluster analysis by Python
Round 4 Final manuscript	Final review Co-authorship	Review and revise proposed synthesis, presented in form of draft manuscript Accept / decline invitation to co-author the manuscript If accept: comment on final draft draft of manuscript

Table 8: Targets of Competencies Indicators Assessment

Category		Targets of Competencies Indicators Assessment
Systems & Critical Thinking & Systems (SCT)	Systems Thinking (ST)	Interactions Between Simple Systems / Perceptions and Regulations / Concurrent Environmental Issues and Feedback Loops / Human Factor and Knowledge / Skills and Implementation / Values and Action / Environmental, Social, and Economic Dimensions
	Critical Thinking (CT)	Critical Thinking and Problem-Solving / Decision-Making Complexity / Argument Analysis and Evaluation / Comprehensive Planning and Implementation in Uncertain Contexts
	Normative Competence (NC)	Understanding and Application of Core Sustainability Concepts / Normative Competency in Sustainability / Ethical Judgment and Sustainability Standards / Development and Application of a Normative Framework for Sustainability
	Evaluation & Research (ER)	Knowledge Acquisition and Application / Skills Development and Utilization / Values Integration and Ethical Decision-Making / Action and Implementation in Sustainability Contexts
	Future Thinking (FT)	Identify/Evaluate Future Trends / Apply Futures Studies Tools / Develop Strategies Based on Scenarios
Action and Strategic Implementation (SAI)	Strategic Action-Oriented Competence (SA)	Design/Implement Interventions / Execute Strategic Action Plans / Balance Environmental, Social, Economic Benefits
	Intra-preneurial Competence (IP)	Identify Opportunities / Promote Innovative Projects / Lead Organizational Changes for SD Goals
	Inter-disciplinary Work Competence (ID)	Integrate Disciplinary Perspectives / Solve Complex Tasks / Effective in Interdisciplinary Teams
	Problem Solving Competence (PS)	Identify Essential Factors / Construct Practical Approaches / Utilize Resources for Solutions
	Innovative Competence (IC)	Manage Sustainability Projects / Drive Creative Solutions / Lead Innovative Projects
Social Interaction and Personal Synergy (SIS)	Interpersonal Competence (PC)	Understand Others / Communicate in Teams / Facilitate Collective Decision-making
	Communication Tools & Media Use Competence (TM)	Use Communication Tools / Adapt to Scenarios / Promote Sustainability Agendas
	Participation & Leadership (PL)	Drive Sustainability Changes / Design Participatory Processes / Lead Community Partnerships
	Cross-Cultural Competence (CC)	Facilitate Cultural Integration / Promote Understanding and Cooperation
Self-management and Growth (SPG)	Self-Awareness (SA)	Recognize Growth Potential / Adjust Behavior / Guide Others Through Uncertainty
	Self-Regulation & Motivation (SR)	Self-Regulate Under Pressure / Set and Achieve Goals / Maintain Execution Levels
	Self-efficacy Management (SE)	Belief in Success / High Confidence in Various Situations
	Values Thinking (VT)	Identify Values / Analyze Value Conflicts / Foster Shared Values

Table 9 Sustainable Development Competencies Grading Assessment guideline (for Vocational College Learners)

Competency Category	Basic Level (B-Level)	Intermediate Level (M-Level)	Advanced Level (A-Level)
Systems Thinking (ST)	● Comprehends the interactions between simple systems, perceptions, and regulations	● Comprehends the cause-effect relations, motives, and regulations in complex systems; ● Able to identify the	● Able to analyze complex systems involving multi-dimensional viewpoints and various fields with a global context;

	articulating cause and effect; ● Comprehends concurrent environmental issues, feedback loops in (non-) sustainability systems;	basic components of systems and their interrelationships. ● Able to analyze and explain the dynamics and interdependencies of complex systems across different domains within a regional or local context.	● Able to design and evaluate interventions in complex systems, predicting long-term impacts on the whole and parts.
Critical Thinking (CT)	● Able to identify arguments and evidence, performing basic logical reasoning; ● Comprehends the basic complexity in decision-making processes.	● Able to analyze and evaluate different arguments and evidence; ● Able to make well-informed decisions of moderate complexity across various contexts	● Able to perform deep critical thinking in complex and uncertain situations, formulating comprehensive plans and implementing complex decisions.
Normative Competence (NC)	● Comprehends key sustainability concepts; ● Comprehends the importance of these principles as the groundwork for further exploration and application in sustainability; ● Able to work in normative way; ● Able to identify and comprehend the foundational principles and values of sustainability.	● Able to apply sustainability principles and values within specific contexts, such as policies and official reports; ● Able to discern sustainability norms and standards; ● Able to make preliminary ethical judgments, demonstrating an enhanced competency to contextualize and interpret sustainability norms within real-world scenarios.	● Able to systematically evaluate and develop the normative framework of sustainability; ● Comprehends and creatively applies sustainability values, principles, goals, and targets, leading the creation and refinement of sustainability standards; ● Able to apply comprehensive and critical approach towards scrutinizing the sustainability of current and future states of social-ecological systems; ● Demonstrates a deep engagement with sustainability challenges and a commitment to contributing innovative solutions to the field.
Evaluation & Research (ER)	● Comprehends the basic concepts and methods of sustainability research; ● Able to make judgments in line with principles and theories based on technical common sense, basic ethical standards for sustainability	● Comprehend the edgy relevant research findings, independently conducts sustainability research projects, applying appropriate research methods and techniques. ● Able to use basic assessment , research tools and methods to evaluate general sustainability projects or policies.	● Able to perform comprehensive analysis on core factors and key steps in projects, including quantitative and qualitative methods, comprehensively; ● Able to participate sustainability research projects in team or community, contributing new knowledge and solutions to the field of sustainability.
Future Thinking (FT)	● Able to identify, describe and evaluate the possibilities of future trends and challenges; ● Able to consider qualitative and	● Able to consider sustainability problems quantitatively and qualitatively; ● Able to apply futures studies tools and methods, such as scenario analysis; ● Able to develop	● Comprehend the mechanisms, causes, and effects that craft complex future scenarios; ● Able to assess and reconstruct the work structure at the level of critical components;

	quantitative information related to sustainability issues.	strategies based on potential future scenarios.	● Able to guide participants in future planning and decision-making processes. ●
Strategic Action-Oriented Competence (SA)	● Comprehends the basic concepts and tools of strategic planning, recognizing the importance of goals and actions for sustainable development. ● Comprehends the basic principles of fair and ecological action, recognizing the impact of personal and organizational behavior on the environment and society.	● Able to comprehensively design and implement interventions, transitions, and management strategies. ● Develops and executes strategic action plans for specific sustainable development challenges, applying strategic thinking in complex contexts. ● Actively considers and balances environmental protection, social justice, and economic benefits in decision-making and actions.	● Able to creatively apply transformative governance plans toward sustainability; ● Able to construct strategic planning processes, setting long-term visions and systematic strategies for sustainability goals, considering feasibility and effectiveness; ● Able to leads and promotes cross-boundary cooperation to achieve fair and ecological sustainability goals.
Intra-preneurial Competence (IP)	● Comprehends the basic concepts of entrepreneurship and intrapreneurship; ● Able to identify opportunities for innovation within organizations.	● Able to initiate and promote innovative projects within organizations, demonstrating enterprising spirit.	● Able to function as an intrapreneur, leading and facilitating organizational culture and structural changes to achieve sustainable development goals.
Inter-disciplinary Work Competence (ID)	● Comprehends the basic connections between different disciplines; ● Able to identify the path of disciplinary work. ● Able to participate interdisciplinary projects.	● Able to promptly assemble and absorb necessary information from different domains; ● Able to construct effective implementational path across various fields;	● Able to work effectively in interdisciplinary teams, integrating different disciplinary perspectives and methods; ● Able to innovatively be combining knowledge and skills from different disciplines to solve complex tasks.
Problem Solving Competence (PS)	● Able to identify and define the essential factors of problems related to sustainability.	● Comprehend the fundamental relations of core factors and operational steps in progress; ● Able to construct practical approaches in solving sustainability problems based on reasonable implements strategies and solutions.	● Able to utilize necessary resources and opportunities in solving problems; ● Able to participate or support organizations to solve complex sustainability problems, implementing effective and practical solutions.
Innovative Competence (IC)	● Comprehends the basic principles and tools of project management, recognizing the role of innovation in sustainability.	● Plans and manages challenging sustainability projects, applying innovative thinking to solve problems.	● Participates , or leads effective innovative projects, driving creative solutions , even breakthroughs in the field of sustainability
Interpersonal Compe	● Able to recognize and understand others' emotions and	● Able to see issues from others' perspectives, showing deep empathy.	● Able to apply perspective-shifting in complex social and cultural

	tence (PC)	viewpoints., ● Able to effectively communicate within a team, understanding the basic principles of teamwork. ● Comprehends the importance of participation, able to contribute personal opinions in simple participatory activities.	● Able to collaborate within diverse teams, resolve conflicts, and enhance team effectiveness. ● Actively participates in more complex discussions and activities, facilitating collective decision-making processes.	environments, fostering understanding and cooperation, ● Able to manage interdisciplinary or cross-cultural teams, creating a collaborative work environment to achieve common goals.
	Comm unica-t ion Tools & Media Use Compe tence (TM)	● Able to use basic communication tools and technologies; ● Comprehend the role of media in solving sustainability issues.	● Able to effectively use various media and technologies for communication, adapting to different communication scenarios.	● Creatively uses media for strategic communication, influencing public opinion, and promoting sustainability agendas.
	Partici pation & Leader ship (PL)	● Comprehends the importance of stakeholders and community participation, ● Able to identify the impact of personal and organizational behavior on the environment and society. ● Comprehends the basic concepts of leadership, and change agency, recognizing the role of leadership in sustainable development. able to identify key stakeholders in any sustainability progress.	● Demonstrates leadership in teams or projects, driving sustainability changes. ● Comprehends the basic political systems and governance structures, , Able to design participatory processes, and implement effective stakeholder engagement plans, effectively promoting community participation. ● Effectively works in community science projects, promoting knowledge sharing.	● Able to lead complex stakeholder engagement projects, establishing lasting community partnerships and fostering shared value creation. ● Acts as a leader and agent of change, designing and implementing strategies to empower communities and promote sustainability actions. inspiring and guiding large-scale sustainability transformations; ● Able to navigate effectively within community to support sustainability goals.
	Cross-Cultur al Compe tence (CC)	● Comprehends the basic worldviews and basic differences in cultural backgrounds, showing cultural sensitivity.	● Able to communicate and collaborate effectively in cross-cultural environments; ● Comprehend cultural conflicts, adapting to and respecting diversity.	● Able to lead cross-cultural teams, facilitating cultural integration, addressing cultural differences, and promoting cross-cultural and cross-sectoral understanding and cooperation.
Self-management	Self-A warene ss (SA)	● Recognizes personal growth potential, aware of one's emotional and behavioral patterns. ● Able to recognize and accept	● Deep understanding of one's emotions, thoughts, and behaviors, identifying areas for growth. ● Able to maintain adaptability and flexibility in decision-making and	● Profound self-understanding, able to anticipate personal growth directions and challenges; ● Able to proactively adjust behavior to foster growth. ● Able to guide others

	uncertainty and challenges in life and work.	actions when faced with uncertainty and frustration.	through uncertainty, using setbacks as opportunities for learning and growth.
Self-Regulation &Motivation (SR)	● Practices self-discipline in daily tasks, such as completing assignments on time, managing basic emotions and behaviors. ● Sets small goals, motivating oneself through their achievement.	● Effectively self-regulates under pressure or challenges, maintaining task continuity. ● Improves self-motivation by setting and achieving medium-difficulty goals.	● Excellently manages emotions and behaviors, self-motivates to maintain prominent levels of execution, stays healthy in challenging environments. ● Has clear motivation and relentless pursuit of personal goals and visions.
Self-efficacy Management (SE)	● Believes in one's ability to make progress in specific areas or tasks.	● Holds firm belief in one's success across broader areas.	● Possesses high confidence in one's ability to succeed in various situations.
Values Thinking (VT)	● Able to identify basic personal and societal values and understand how they affect sustainability issues.	● Analyzes and discusses value conflicts, Able to analyze the value background on which the proposed solutions to sustainability issues are based.	● Guides cross-cultural and multi-stakeholder value dialogues, fostering the formation of shared values, consensus-building for sustainability goals.