To know, feel and do: an instructional practice of higher education for sustainable development

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Abstract

Purpose – The importance of multidimensional and engaging instruction for sustainable development goals (SDGs) in higher education cannot be overstated. Such instructions should motivate students not only to memorize and contemplate these goals but also to actively participate in addressing SDG-related challenges. Consequently, this study aims to develop practical and appropriate instructional approaches to education for sustainable development (ESD) in higher education to enhance students' knowledge, attitudes and behaviors concerning sustainability.

Design/methodology/approach – By using a quasi-experimental design, this ESD study was conducted at a university in central Taiwan. A total of 121 students from diverse academic backgrounds participated in the 16-week experiment, which was divided into three groups. Lecturing, thematic teaching and design-thinking strategies were applied to these respective groups.

Findings – The thematic-teaching and design-thinking groups displaying improved cognitive performance. However, the quantity results revealed that the design-thinking group surpassed the other two groups in sustainability knowledge, attitudes, behaviors and mind map tasks. The qualitative findings further indicated that design thinking – through multiple practical problem-solving activities – guided college students to think independently and sustainably, as well as enabled them to internalize the value of sustainable development.

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By implementing these effective approaches, the core goals of ESD-related personal and societal transformations may be realized.

Practical implications – This study proposed a goal-oriented ESD instructional model for educators, demonstrating the efficacy of design thinking in cultivating higher-order thinking and affection for ESD in students. Additionally, this study introduced an innovative evaluation approach – mind mapping – to the ESD domain, which may compensate for the limitations of the survey method.

Originality/value – This study provides empirical evidence for the effectiveness of design thinking and thematic-based pedagogies in sustainable development higher education. Additionally, it also offers a practical ESD instructional model with reference value for scholars and multi-domain instructors. Moreover, the study highlights that by examining organizational governance from the perspectives of design thinking and higher-order affection, sustainable and economic development need not be mutually exclusive concepts. Instead, pursuing SDGs can be viewed as investment opportunities for organizations rather than mere costs.

Keywords Sustainable development goals, Education for sustainable development, Design thinking, Thematic teaching, Mind mapping, Cross-domain, Affective goal

Paper type Research paper

1. Introduction

"Without us, Earth will abide and endure; without her, however, we could not even be" (Weisman, 2008). In 2015, the United Nations proposed a five-dimensional agenda for sustainable development (SD) targeting "people," "prosperity," "planet," "peace" and "partnership." The agenda includes 17 sustainable development goals (SDGs) and 169 targets for SD. The aim is for humanity to collaboratively implement a plan to achieve SD on Earth by 2030 by realizing its targets.

Education has been recognized as a vital element in promoting the SDGs (Hogan and O'Flaherty, 2022). Education for sustainable development (ESD) refers to the achievement of SDGs through education and should be valued at each stage of education. Although the literature has suggested introducing sustainability into higher education (Sandri, 2014; Ruiz-Mallén and Heras, 2020), this topic is often overlooked in university teaching, where academic autonomy and highly autonomous teaching are maintained (Ruiz-Mallén and Heras, 2020). The focus is either on SD in a narrow sense (i.e. environmental issues) (Lin and Li, 2017) while neglecting its multi-faceted nature or on integrating SDGs into professional courses but remaining at the level of knowledge transfer (Hsieh, 2020).

The core objective of ESD is to educate global citizens about their knowledge and actions regarding SD. In other words, while relevant knowledge about SD is essential, the direction of students' attitudes, feelings and actions should not be neglected (Shu *et al.*, 2020). Compared to traditional knowledge-centered teaching methods, learner-centered and action-oriented teaching methods are perceived as more effective in improving learners' critical thinking and continuously producing sustainable behaviors (Rieckmann *et al.*, 2017). The learner-centered strategy views students as autonomous learners, and the teacher's role is to facilitate learning and encourage students to reflect on their own learning. Examples include design thinking, known for people-oriented creative problem-solving (Buhl *et al.*, 2019), and thematic teaching, focusing on critical thinking training based on themes and issues (Finch *et al.*, 1997). These innovative teaching strategies are well-known among teachers in various fields and have been applied in practice. However, little research on ESD explores its effect on student learning.

In addition, innovative teaching strategies should be combined with innovative evaluation methods. Regarding ESD evaluation, the traditional paper-and-pencil assessment is a teacher-centered test emphasizing logical thinking and accuracy (Greenstein, 2012). ESD is an educational field that emphasizes affection, imagination and practice (Fuertes-Camacho *et al.*, 2019). Traditional knowledge tests categorize students into different grades through

standardized evaluations and focus on relative positions. In recent years, drawing mind maps, among other multivariate assessments, has emerged as an assessment strategy orientation (Keleş, 2011; Rowell *et al.*, 2021). Drawing mind maps is a student-centered learning and assessment, in the form of visual and graphical activity, that helps learners present their thoughts freely, creatively and fully. Every mind map, with the time and effort invested in it, will be recognized, and teachers can set qualitative or quantitative evaluation criteria for mind maps according to their research needs. In other words, drawing mind maps is more consistent with the objectives of ESD than traditional paper-and-pencil assessments.

Accordingly, the objectives of this study include the following:

- to explore the impact of three teaching strategies (thematic teaching, design thinking and traditional narrative teaching) on students' SD knowledge, attitudes and behaviors;
- to analyze the structure of mind maps on SD drawn by three groups of students who were instructed in thematic teaching, design thinking and traditional narrative teaching; and
- to explore students' feelings and satisfaction for the course by introducing the concept of SD using various teaching strategies.

2. Literature review

2.1 Sustainable development and education for sustainable development goals (ESDG)

In 2015, the United Nations launched the "2030 Agenda for Sustainable Development," an action plan to advance the prosperity of humankind and the planet (Assembly, 2015). The agenda consisted of 17 SDGs and 169 targets, covering 5Ps: "people" for social value, "prosperity" for economic value, "planet" for environmental value, "peace" and "partnership" for the executive level (Ho and Goethals, 2019), and are expected to be achieved by 2030.

The UN announced the Decade of Sustainable Education (2014–2015) to ensure education's role in SD. ESD drives high-quality education and SD (Glavič, 2020). The goal is for all to gain knowledge, skills, attitudes and values for a sustainable future. This improves life quality without endangering the planet (Leicht *et al.*, 2018), considering future societal issues (economics, environment, equity).

2.2 The educational instructional approaches for sustainable development goals

The United Nations-funded Sustainable Development Solutions Network (SDSN, 2021) states SDGs can be achieved through diverse educational activities such as courses, professional training, online learning and student-led sustainable actions (Fuertes-Camacho *et al.*, 2019). Effective ESD curricula should include interactive and experiential pedagogical innovations tied to real-world contexts (Brundiers *et al.*, 2010; Wang *et al.*, 2022). SDGs can be pursued through teaching, research, community engagement and sustainability-focused courses, stimulating learners to consider and solve sustainability issues (Leal Filho *et al.*, 2019). Consequently, curricula, learning methods and teaching behaviors need to be reformed to help students become active sustainability advocates (Olsson *et al.*, 2016), indicating traditional lecture-based teaching may be insufficient for SDGs (Maher, 2017).

Student-centered teaching better promotes interaction and experiential learning than lecture-based teaching. Thematic teaching combines various skills across disciplines into a theme-based framework (Finch *et al.*, 1997), encouraging students to apply their knowledge to real-life situations (Alm *et al.*, 2022). Petillion *et al.* (2019) used SDGs themes to enhance students' emotional learning about social and environmental facets.

Active learning methods in SD curricula have been proposed, leveraging design thinking to foster creative problem-solving skills (Halpern and Walther, 2022; Hsieh, 2020; MacVaugh and Norton, 2012). Design thinking's five phases – empathizing, defining, ideating, prototyping and testing – can stimulate creativity and quick prototyping, facilitating different perspectives on "changes" (Massari *et al.*, 2021; Friis, 2019). Given their shared emphasis on creativity and problem-solving, design thinking and SD can contribute to SDGs and ESD (Kagan *et al.*, 2020).

Despite these insights, few studies have compared different instructional approaches' learning outcomes. Thus, this study investigates if thematic teaching and design thinking can improve students' understanding of SD in higher education.

2.3 Assessment in education for sustainable development goals: Introducing mind maps

The ESD assessment method is in the developmental stage. Prior studies used qualitative interviews, class attitude scales, SD knowledge scales and work evaluations (Petillion *et al.*, 2019; Olsson *et al.*, 2016). However, self-report scales suffer from subject bias, potentially leading to self-deception bias (Ajzen, 2002; Armitage and Conner, 1999). To address this, a comprehensive sustainability consciousness questionnaire and mind maps were adopted as evaluation tools for ESD learning effectiveness.

The mind map, proposed by Buzan in 1974 (Buzan and Buzan, 2006), converts complex knowledge into visually rich presentations. Learners create theme-specific mind maps using an artistic visual approach (Bawaneh, 2019; Buzan and Buzan, 2002). Studies showed mind maps improved student grades and were effective in higher education (Akinoglu and Yasar, 2007; Mento *et al.*, 1999; Keleş, 2011). Mind mapping fosters unique creative thinking, problem-solving and aids the design process (Dong *et al.*, 2021). Drawing mind maps allows learners to present their thoughts comprehensively and individually through visual images, respecting their subjective learning experiences and aligning with experience-centered teaching strategies.

3. Method

This study adopted three teaching strategies to examine the feasibility of introducing the concept of SD into higher education courses: design thinking (Experimental Group I), thematic teaching (Experimental Group II) and traditional didactic teaching (Control Group). This study aimed to understand the learning outcomes of SD in higher education. The research framework was based on pre- and post-test experimental methods. Further, scales, mind mapping and qualitative feedback were used to collect and analyze the data.

3.1 Research participants

The study included 121 Taiwanese college students – 64 males (53%) and 57 females (47%) – divided into Group I (43 participants), Group II (40 participants) and the Control Group (38 participants). All adult participants provided informed consent. Personal information was replaced with unique alphanumeric codes for anonymity. Data was securely stored in encrypted files and only accessed by the research team. No individual-level data was disclosed in any study results, ensuring privacy and compliance with ethical standards.

3.2 Research tools

The research tool used was the Scale for the SD Concept, which is subdivided into SD, SD, SD, SD and post-course feedback forms. Detailed descriptions of each measurement scale and mind map assessment tool are provided below.

3.2.1 The sustainable development concept scale. The scale for this study was revised using the Sustainability Consciousness Questionnaire (SCQ) designed by Gericke *et al.* (2019). It consists of the full-length scale (SCQ-L) and short-form scale (SCQ-S), which serve as pre- and post-test scales, respectively. The final revised version included content on SD knowledge, attitude and behavior, and the analysis was based on the five dimensions of humankind, prosperity, Earth, peace and partnership. The scale contained eight questions, each on SD knowledge, attitude and behavior. For each question, the participants were asked to tick on a Likert five-point scale representing "strongly disagree" to "strongly agree."

3.2.2 Analysis of pre-test reliability and validity. As mentioned previously, the scale proposed by Gericke *et al.* (2019) was used as the basis for this study, and three questions were deleted from and added to the SCQ-S and SCQ-L.

After distributing the pre-test scale, the researchers retrieved 120 copies; nine were deleted because they were invalid, and the remaining 111 valid pre-test samples were analyzed. A statistical software (SPSS 25.0) was used for item analysis of the questions on SD knowledge, attitude and behavior in the scale for the SD concept. These included extreme group comparisons, homogeneity tests and internal consistency tests. The groups were compared using an independent sample *t*-test. The critical ratio (CR) value of each item was greater than 0.3 and reached significance (Wolman, 1973). Correlation was the indicator for homogeneity testing, and the results indicated that it was greater than 0.3 (Eisen *et al.*, 1979). A reliability analysis was also used to test internal consistency, and the results showed that Cronbach's α coefficients (as seen in Table 1) of the three facets of SD knowledge, attitude and behavior were greater than the recommended value of 0.7 (Nunnally, 1994). The formal scale of this study was finalized after the aforementioned analyses were completed in sequence.

3.2.3 Rating scale for the mind-map structure. Reference was made to The Scoring Framework for Concept Maps on SD published by Shallcross (2016), and the Mind-Map-Scoring Rubric (MMSR) published by Hua and Wind (2019) was used to determine the criteria for evaluating the mind-map structure for the SD concept. The three scoring criteria were "structure," "accuracy" and "visualization." The rating scale for the mind-map structure prepared according to the descriptions above is presented in Table 2.

Three raters individually scored the rating scale for the mind map structure according to the evaluation criteria. The reliability of the three facets of structure, accuracy and visualization was 0.788, 0.800 and 0.838, respectively, with all three values within 0.7–0.9. The overall Cronbach's α was 0.887. Thus, the raters determined that the scale had good reliability (Table 3).

3.2.4 Rating scale for mind-map knowledge. The evaluation criteria for the mind-map knowledge of the SD concept were developed with reference to Shallcross's (2016) Scoring Framework for Concept Maps of SD. The scoring criteria for the conceptual keywords were based on five SD dimensions: humankind, prosperity, Earth, peace and partnership. The

Facet	No. of questions	Cronbach's α
SD awareness	8	0.714
SD attitude	8	0.710
SD behavior	8	0.711

Source: Author's own work

Table 1.
Reliability analysis

Table 2.
Rating scale for the mind map structure

Scoring criteria	0 point	1 point	2 points
Structure The participant arranged the presented concepts systematically and used the appropriate concepts to make connections between the different layers	The structure was simple with no connection between concepts	The structure was good with a few connections between concepts	The structure was complex with clear links between concepts
Accuracy (1) The participant constructed the categorization of the topics accurately (2) The participant used valid keywords to express their ideas	Unable to identify the categories and included many erroneous or inappropriate keywords	Identified some categories and included some inappropriate keywords, although most were correct	Identified all the categories correctly and included all the appropriate concepts and linkages
Visualization (1) The participant used patterns to present keywords (2) The participant used colored fonts and shapes to present keywords	None of the elements was clearly defined, and readers could not understand them	The definition of some elements could not be recognized	All the elements were clearly defined

Source: Author's own work

students received points based on the number of keywords mentioned for each dimension in their mind maps.

Three raters independently scored the rating scale for mind-map knowledge using the evaluation criteria, and inter-rater reliability was calculated. The reliabilities of the five dimensions – the social value of humankind, economic value of prosperity, environmental value of Earth, peace and partnership at the execution level – were 0.931, 0.881, 0.858, 0.815 and 0.862, respectively. All these values were between 0.8 and 1.0, indicating good reliability. The overall Cronbach's α was 0.955, further confirming the reliability of the evaluation criteria for mind map knowledge of the SD concept (Table 4).

3.3 Teaching and experimental designs

The teaching design for the study involved the same teacher planning and implementation of different teaching strategies for the three experimental groups: teaching by design thinking (Group I), thematic teaching (Group II) and traditional didactic teaching (Control Group). The teaching activities for all three groups lasted 18 weeks, with two 50-min lessons per week. The experimental process is illustrated in Figure 1.

In Weeks 1–6 of the course, the students were taught about the previous SD situation. Before the scale and mind map for the SD concepts were used for the pre-test in Week 6, they learned about issues related to college education and the environment. In the middle of the course (Weeks 7–16), a ten-week SD course was conducted using three different strategies: teaching by design thinking, thematic teaching and traditional didactic teaching. Four steps were adopted in the teaching-by-design thinking strategy: seeing convergence, in-depth exploration, developing strategies and feasibility assessment. Thematic teaching involved displaying SD-related videos. Traditional didactic teaching is a standard lecture method. The learners presented short SDG reports when the course ended in Week 17. In Week 18, the researchers conducted the post-test, which consisted of a scale and mind map for the SD concept. Post-course feedback forms were used to collect qualitative data from learners.

Regarding the research design, the three groups with different teaching strategies were treated as independent variables, whereas SD knowledge, attitude and behavior were the dependent variables.

Facet	Range of scores	Cronbach's α	
Structure	0–2	0.783	0.887
Accuracy	0–2	0.800	
Visualization	0–2	0.838	

Source: Author's own work

Table 3. Reliability analysis for evaluation of the SD structure

5 SD dimensions	Range of scores	Cronbach's α	
Social value of "humankind"	0–4	0.931	0.955
Economic value of "prosperity"		0.881	
Environmental value of "Earth"		0.858	
Peace		0.815	
"Partnership" at the execution level		0.862	

Source: Author's own work

Table 4. Reliability analysis for evaluation of mind map knowledge on the SD concept

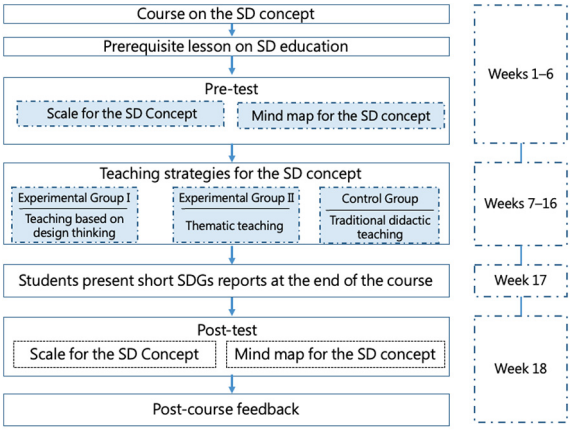

Figure 1.
Flow chart for the teaching experiment

Source: Author's own work

The measurement results for the scale and mind map of the SD concept were treated as covariates. The research framework and design are illustrated in Figures 2 and Table 5.

4. Results

4.1 Effects of design thinking, thematic teaching and traditional lectures on sustainability knowledge, attitudes and behaviors

To explore the differences in pre- and post-learning of various teaching strategies, three groups of students were administered a pre-test and post-test on their knowledge of

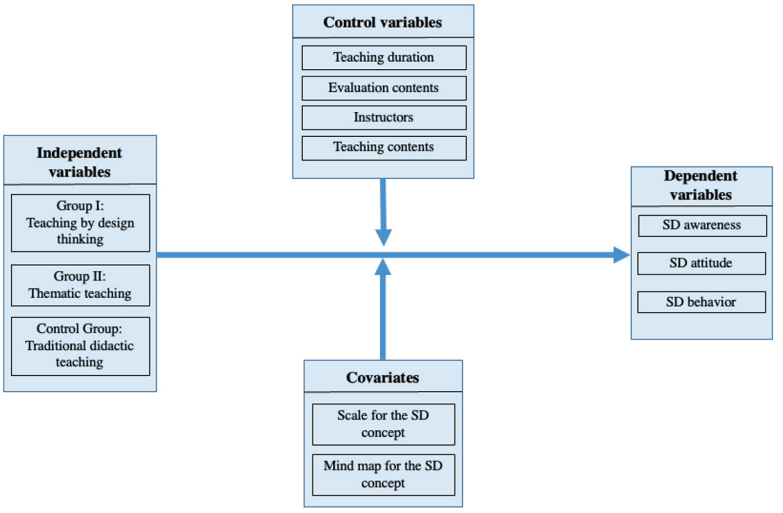

Figure 2.
Research framework

Source: Author's own work

sustainability, and a one-way analysis of covariance (ANCOVA) was used to analyze the three groups' sustainability knowledge. The pre-test scores for sustainability knowledge, attitudes and behaviors for all three groups met the assumption of homogeneity of variance ($F = 1.007$, $p = 0.369 > 0.5$; $F = 1.010$, $p = 0.367 > 0.5$; $F = 1.760$, $p = 0.177 > 0.5$). The results of the ANCOVA are presented in Table 6. First, the differences in post-test scores for sustainability knowledge among the three groups ($F = 14.071$, $p = 0.001 < 0.5$) were significant; the *post hoc* comparison showed that the scores for Group I ($M = 4.55$, SE = 0.054) and Group II ($M = 4.46$, SE = 0.056) were higher than that for the Control Group ($M = 4.15$, SE = 0.058), and the differences were significant ($p = 0.001$). Second, the differences in the post-test scores for sustainability attitudes among the three groups ($F = 15.164$, $p = 0.004 < 0.5$) were significant. The *post hoc* comparison showed that the score was significantly higher for Group I ($M = 4.37$, SE = 0.065) than for the Control Group ($M = 4.06$, SE = 0.068), and the difference was significant ($p = 0.004$). Third, the differences in the post-test scores for sustainability behaviors among the three groups (F = 4.887, $p = 0.009 < 0.5$) reached statistical significance. The *post hoc* comparison revealed that the score for Group I ($M = 4.11$, SE = 0.058) was higher than that for the Control Group ($M = 3.84$, SE = 0.062), and the difference was significant ($p = 0.007$).

Independent variable (Group)	Covariate (Pre-test results for SD scale and mind map)	Experimental treatment	Dependent variable (Post-test results for SD scale and mind map)
Experimental Group I	O_1, O_4	X_1	O_7, O_{10}
Experimental Group II	O_2, O_5	X_2	O_8, O_{11}
Control Group	O_3, O_6	X_3	O_9, O_{12}

Notes: O_1, O_2, O_3: Scale for the SD Concept pre-test; O_4, O_5, O_6: Mind Map for the SD Concept pre-test; X_1: Design thinking method; X_2: Thematic teaching method; X_3: Traditional didactic teaching method; O_7, O_8, O_9: Scale for the SD Concept post-test; O_{10}, O_{11}, O_{12}: Mind Map for the SD Concept post-test
Source: Author's own work

Table 5. Research design

Variable	Source of variation	*SS*	*df*	*MS*	*F*	*P*
Sustainability awareness	Pre-test score	8.266	1	8.266	65.265	0.001
	Experimental group	3.564	2	1.782	14.071	0.001
	Error	14.819	117	0.127		
	Total	2,368.219	121			
Sustainability attitudes	Pre-test score	2.655	1	2.655	90.877	0.001
	Experimental group	2.003	2	1.002	15.164	0.004
	Error	20.488	117	0.175	5.72	
	Total	2,206.063	121			
Sustainability behaviors	Pre-test score	9.634	1	9.634	65.786	0.001
	Experimental group	1.431	2	0.716	4.887	0.009
	Error	17.134	117	0.146		
	Total	1,942.5	121			

Source: Author's own work

Table 6. ANCOVA results of sustainability

4.2 Assessment of the structure, accuracy and visualization of the sustainability mind map

An ANCOVA was conducted to analyze the scores of the three groups for structure, accuracy and visualization using the Mind Map Knowledge Scale (Table 7) to examine the effects of the three teaching strategies (design thinking, thematic teaching and traditional lectures) on sustainability learning. The pre-test scores for the structure, accuracy and visualization of the sustainability mind map for the three groups met the assumption of homogeneity variance ($F = 0.075$, $p = 0.928 > 0.5$; $F = 2.803$, $p = 0.054 > 0.5$; $F = 2.319$, $p = 0.103 > 0.5$). The differences in post-test scores for the structure of the sustainability mind map among the three groups ($F = 7.052$, $p = 0.001 < 0.5$) were significant, and *post hoc* comparisons showed that the scores for Group I ($M = 1.68$, SE = 0.06) and Group II ($M = 1.53$, SE = 0.06) were higher than those for the Control Group ($M = 1.36$, SE = 0.06), and the differences were significant ($p = 0.001$). Second, the differences in the post-test scores for the accuracy of the sustainability mind map among the three groups ($F = 6.0$, $p = 0.003 < 0.5$) were significant. The post hoc comparison showed that the score was higher for Group I ($M = 1.89$, SE = 0.047) than for the Control Group ($M = 1.66$, SE = 0.051), and the difference was significant ($p = 0.005$). Third, the differences in the post-test scores for the visualization of the sustainability mind map among the three groups [Group I ($M = 1.45$, SE = 0.075), Group II ($M = 1.46$, SE = 0.077), and Control Group ($M = 1.43$, SE = 0.080) were statistically significant ($F = 0.037$, $p = 0.964 > 0.5$).

These results indicate that both Experimental Groups I and II performed significantly better than the Control Group in terms of the structure and accuracy of the mind map, whereas the visual effects of the mind map did not vary with the teaching strategies.

4.3 Learning performance in sustainability knowledge as presented in the sustainability mind map

Based on the Mind Map Knowledge Scale developed in this study, we calculated the number of times students mentioned each of the five dimensions of sustainability (Rieckmann *et al.*, 2017) – people, prosperity, planet, peace and partnership – and plotted the distribution of the pre- and post-tests using a radar chart. This was done to gain insight into the qualitative learning effects of different teaching strategies on sustainability knowledge. Figure 3 shows the pre- and post-test distributions of learners in the 5P dimensions. Overall, each group of participants focused mostly on the planet dimension in the pre-test when drawing their mind maps (SDGs 6, 12, 13, 14 and 15).

Variable	Source of variation	*SS*	*df*	*MS*	*F*	*P*
Mind map structure	Pre-test score	1.430	1	1.430	133.724	0.001
	Experimental group	1.871	2	0.935	10.779	0.001
	Error	14.458	109	0.133	7.052	0.001
	Total	285.222	113			
Mind map accuracy	Pre-test score	0.230	1	0.230	238.732	0.001
	Experimental group	1.069	2	0.534	2.582	0.111
	Error	9.710	109	0.089	6.000	0.003
	Total	362.667	113			
Mind map visualization	Pre-test score	3.540	1	3.540	38.263	0.001
	Experimental group	0.016	2	0.008	15.939	0.001
	Error	24.210	109	0.222	0.037	0.964
	Total	265.778	113			

Table 7.
ANCOVA Results of sustainability mind map

Source: Author's own work

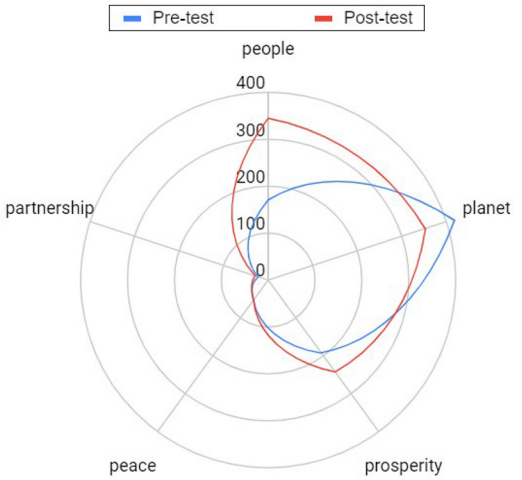

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Figure 3.
Pre- and post-test distribution of the 5Ps of sustainability knowledge

The three groups mentioned the planet dimension less frequently in the post-test, representing the ebb-and-flow effect of the limited time available to draw mind maps. Before being taught the sustainability objectives of this study, the students had a limited understanding of sustainability issues, mostly equating them with environmental issues. The use of multiple teaching strategies allowed all groups to demonstrate their understanding of the multiple dimensions of sustainability.

Although the number of references to people and prosperity increased in all three groups after teaching (Figure 4), the design-thinking model of Group I proved most effective in guiding students to focus on multiple dimensions of sustainability during the same teaching period. There was little difference in the performance of each group in the pre-test, but Group I outperformed Group II and the Control Group in terms of the richness of the multiple dimensions mentioned in the post-test (Figure 5).

Such results are closely related to the design-thinking approach, which emphasizes the learning model of contextual insight and problem identification. The findings suggest that through this process, students can think deeply about issues related to the achievement of sustainability goals from multiple perspectives, thereby broadening their knowledge.

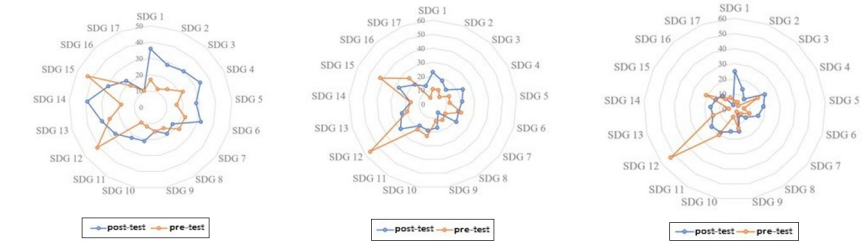

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Figure 4.
Distribution of the times of 5P mentioned in the pre- and post- tests in the three groups

4.4 Qualitative feedback

This study gathered qualitative feedback data from the open-ended post-class feedback forms for Experimental Groups I and II in order of their group codes. Code A was used for Group I, and B was used for Group II:

(1) Innovative teaching strategies encourage deeper thinking about SDGs

In both the design-thinking and thematic-teaching groups, students discussed the problems to solve and the importance of taking action. However, the feedback from students in the design-thinking group was more profound, encompassing feelings, self-exploration and urgency, thus demonstrating more strongly the power of sustainable practice from the ground up (Group A). The reasons for this aptly reflect the kernel of design thinking, which is "penetrating and touching." Learners can find touching solutions from in-depth insights and are given the opportunity to reflect on and explore themselves in highly engaging and macroscopic issues:

> A-13: I was most impressed by the mid-term SDGs discussion because it was the first time I had identified an issue that I wanted to explore on my own in-depth, and the issues we explored were relevant to our everyday lives.
>
> A-22: The most impressive part for me was the five weeks I spent making the poster. The process was very taxing, but I found it very interesting. Throughout the course, I learned a lot and became more proactive in understanding the social and current affairs of sustainable development.
>
> A-37: I was most impressed by the 17 goals of the SDGs because I spent the whole semester working on the big stuff and learning about its importance. Tough planetary issues should be solved as soon as possible.
>
> A-40: The knowledge and information I acquired during this time were immense and powerful, and I was impressed to learn about the urgency and importance of sustainable development and to be exposed to more issues that I had not previously been concerned about.
>
> A-35: It has helped me to understand more about myself and to care more about sustainable development in society and internationally. I think the course has had a great influence on me in, for example, exploring myself in a deeper way.
>
> A-23: I think it's about looking at yourself and observing what's happening around the world, not letting yourself become a person with a limited outlook.

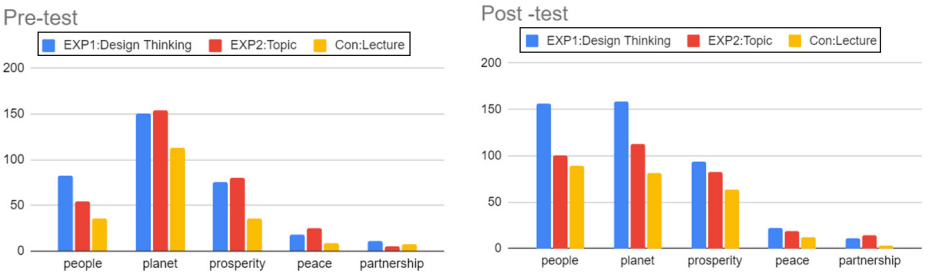


Figure 5.
Pre- and post-test results of the 5P dimensions of sustainability knowledge mind map

Source: Author's own work

B-23: I think SD is not just about words; it's also about action.

B-24: I think that although sustainability may sound distant, it is something that you can start to act on by doing things around you.

B-26: I believe that the environment and people co-exist and are inseparable, so we need to treat the environment well and achieve sustainability.

B-30: Water, consumption, hunger, and poverty all need to be addressed in order for sustainable development to be successful.

(2) Sustainability course combined with design thinking enhances subjective and independent thinking skills

More than one of the students interviewed for design thinking mentioned the effect of the course in stimulating students' thinking when asked about the features of the course compared to the thematic approach (A01: "*constantly being trained to think independently*," A02: "*realized that thinking is very important*," A11: "*It requires more independent thinking*"). This indicates that a design-thinking approach to teaching sustainability goals, with an emphasis on higher level thinking and practical problem solving, can guide students' knowledge and attitudes toward higher-order and independent thinking in the "touching" process; these are essential in helping students implement sustainability goals in a sustainable and practical way.

5. Discussion

5.1 Mind mapping aids in the development of higher-order thinking

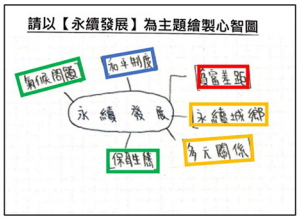
Higher-order thinking skills like problem-solving, critical thinking and reflective thinking are key for SD education. Students under different teaching methods can construct a mind map of SD themes. It was noted that students in design-thinking and thematic-teaching groups systematically listed relevant concepts, highlighting interconnections within the 17 SDGs and deriving more specific keywords. Mind mapping thus facilitates understanding of direct event interactions, making it a potent tool for enhancing higher-order thinking skills (Polat and Aydın, 2020).

When evaluating mind maps, students initially used vague terms like "environment," "economy" and "society." Post-course, students detailed more clear, defined SD goals. Experimental group students pondered each goal's meaning and solutions, suggesting the teaching strategies and mind mapping enhanced independent thought, impacted SD thinking and encouraged deeper issue exploration.

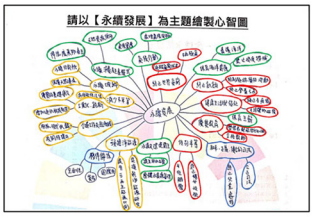
This study used the Mind Mapping Knowledge Assessment Scale to assess the depth of association between the keywords of mind mapping drawn by learners before and after taking the courses and the five dimensions. The study found that "SDG12 Ensuring Sustainable Consumption and Production Patterns" and "SDG15 Safeguarding Terrestrial Ecology" were the goals mentioned more frequently by all three groups of students in the test before drawing mind maps. Compared to SDGs 2, 10 and 17, Goals 12, 15 and 17 most closely related to learners' daily behaviors and can be changed the most through individual behaviors. This finding illustrates that the knowledge acquired from the course allowed learners to reflect on their daily lives through mind-mapping activities. Thus, while no goal was favored in the course content, the findings reflect the ARCS motivational mode – the relevance perspective: when learning about a goal that is more closely related to them,

subjects have a stronger motivation to learn, which affects their learning performance (Lin and Li, 2017).

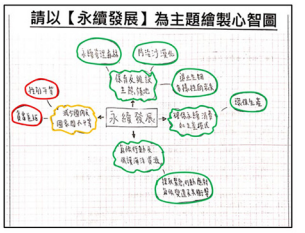
In terms of the differences between the pre- and post-tests of the Mind Mapping Knowledge Assessment, it was found that the students in the three groups could briefly identify the keywords for SD before the pedagogies (left side in Figure 6). In the post-test Mind Mapping for SD, students were able to clearly identify the full name of the development goals, give a full and diverse presentation and extend the connotations of the



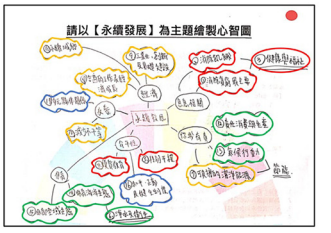
Pre-class mind map of Student C-A01-27 in Experimental Group I



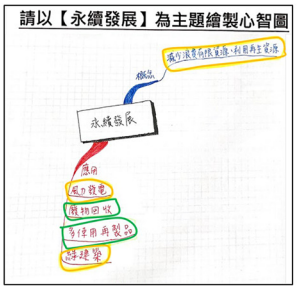
Post-class mind map of Student C-A01-27 in Experimental Group I



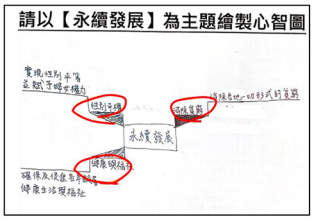
Pre-class mind map of Student C-B01-2 in Experimental Group II



Post-class mind map of Student C-B01-2 in Experimental Group II



Pre-class mind map of Student C-C01-3 in Control Group



Post-class mind map of Student C-C01-3 in Control Group

Source: Author's own work

Figure 6.
Comparison of three groups of mind maps before and after the pedagogies

goals (right side in Figure 6). Moreover, although goals in the earth/environmental dimensions (SDG6, 12–15) were mentioned more often than goals in the other four dimensions, this study also unexpectedly found that "SDG1 no poverty" and "SDG4 quality education" replaced "SDG12 sustainable consumption and production patterns" as the more frequently mentioned goals in the post-test mental mapping by students in Group I and Control Group. This also reflects post-learning diversity; in the limited time available for mind mapping, students spent more time mapping their newly learned concepts than they did in the pre-test. Unlike in the pre-tests, where almost all mind maps were limited to the environmental dimension, they were evenly distributed among the humanity, prosperity and peace dimensions. In short, mind mapping can help students improve their memory and understanding of SD concepts, and further contribute to developing higher-order thinking skills that enhance their knowledge on SD.

5.2 Design-thinking pedagogy enhances understanding and engagement in education for sustainable development goals

The findings of this study revealed that the effectiveness of different teaching methods differed in terms of SD knowledge (to know), emotional engagement (to feel) and the enactment of sustainable behaviors (to do). First, both the design-thinking and thematic approaches were more effective than traditional teaching approaches at promoting students' understanding of SD (to know). This finding is consistent with previous studies that adopted similar teaching methods (Massari *et al.*, 2021; Petillion *et al.*, 2019).

The results of the post-course mind mapping indicate that all three groups of students expanded their understanding of SD from focusing on Earth's environment to a humanity, social, peace and partnership perspective, implying that students developed a more diverse understanding of SD than they had before the course.

Notably, students in the design-thinking group (Group I) had the most significant learning outcomes in terms of SD knowledge (to know), attitudes (to feel) and behaviors (to do). This finding is closely related to the emphasis of design-thinking pedagogy on domain-based insights and problem discovery. The four design-thinking steps of this research course are "Seeing the Convergence: Seeing the SDGs we are all concerned about," "Deeper Inquiry: Diving into SDGs issues through multiple perspectives," "Strategic Thinking: Developing a strategy for the problem being investigated" and "Feasibility Assessment: Assessing the feasibility of a solution." These steps consisted of hands-on activities, including social observation for each week of the course, SD mind mapping for each course group and devising an empathy map, strategy development and feasibility assessment posters. The process of "deep thinking, investigation, and practice" has effectively enhanced college students' attitudes and behaviors toward SD.

Thematic teaching (Group II) included multi-media materials such as SD videos, SD board games and picture book activities. While not as effective as design-thinking for SD behaviors, it raise awareness and attitudes toward SD.

Compared to the first two innovative teaching strategies, the traditional teacher-centered approach of lectures is one-way, less conducive to learning about sustainability. It lacks opportunities for active thinking and connecting life experiences with practices (Maher, 2017). Therefore, while it enhances sustainability knowledge, improving attitudes and behaviors is challenging.

In terms of Bloom's perspective on cognitive goals, the above findings suggest that, while traditional methods of giving lectures facilitate the cognitive memory of SD, thematic instruction can enhance learners' cognitive understanding. Moreover, design thinking can stimulate students to achieve higher-order cognitive goals, namely, application, analysis and

creativity, as well as various higher-order thinking strategies, including problem-solving and critical thinking skills, to attain deeper cognitive learning. Thus, thematic teaching and design thinking can lead to effective learning.

From the perspective of affective goals (Krathwohl *et al.*, 1973), thematic teaching, guided by learning sheets and interactive activities, aims to evoke emotional responses and personal connections with sustainability (Krathwohl *et al.*, 1973). It emphasizes the human aspect, fostering empathy and understanding through real-world examples and diverse perspectives. Group discussions further encourage emotional sharing, reinforcing the importance of sustainability and responsibility. However, unlike design thinking, it may not lead to character development and slightly lower performance in sustainable attitudes and behaviors.

Characterization in Krathwohl's Affective Domain Taxonomy is the consistent application of values in decision-making and actions, reflecting internalized values. In the design-thinking teaching strategy, this connects with "engaging in sustainable actions" through hands-on activities (Norman and Combs-Richardson, 2001). These activities, such as social observation and creating empathy maps, require applying sustainable principles to real-world contexts and putting values into practice. Strategy development and feasibility assessments reinforce the connection between values and actions, fostering problem-solving and critical thinking skills based on sustainability beliefs.

In summary, design thinking guides students through a series of activities that steer them toward investigating and implementing development goals in depth (to know), fostering an emotional connection with the subject matter (to feel) and enacting sustainable behaviors (to do), thereby allowing them to develop higher-order cognitive and attitudinal goals, leading to outstanding performance in terms of SD knowledge, attitudes and behaviors.

6. Conclusion

Based on our findings, we propose a practical ESD instructional model for higher education (Figure 7), showcasing the differential effectiveness of diverse strategies on cognitive and affective goals. Lectures improve basic cognitive skills like remembering and understanding, and help students grasp the importance of receiving SDGs through "attention." ESD's objective extends beyond imparting knowledge to equipping the "future masters of mankind" with the ability and courage to address SD issues (Grindsted and Nielsen, 2021). Affective strategies such

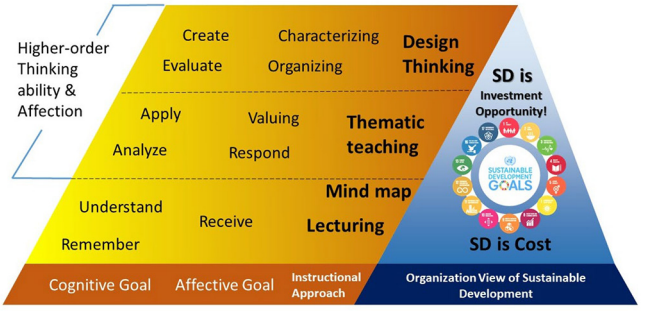


Figure 7.
ESD instructional model in higher education

Source: Author's own work

as thematic teaching or design thinking foster higher-order thinking and affection by moving beyond unidirectional knowledge transfer.

Combining mind-mapping with thematic teaching improved learners' cognition, attitude and analytical abilities regarding SD. Students in the design-thinking group, through discussions and problem-solving exercises, showed high performance in cognitive, attitudinal and behavioral aspects. They internalized SD values, foreseeing its importance and displaying higher-order cognition in their work.

Many organizations, focusing on SDG or ESG information delivery, overemphasize "remembering" and "presenting" SDGs, treating them as costs for image-building or compliance. But, thematic and design-thinking teaching illustrate that addressing SDG issues can be innovative business practices catering to human and social needs and potentially creating market niches. In this context, SD can align with economic growth, becoming an investment opportunity and motivating substantive engagement. Thus, SD practices advance significantly among academia, NPOs, environmental organizations and businesses.

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Dr Tien-Chi Huang, currently a Professor at the Department of Information Management, National Taichung University of Science and Technology, brings his expertise in Educational Technology and Sustainability Education to the forefront of his work. As a PhD graduate from National Cheng Kung University's Department of Engineering Science, he has spearheaded numerous research projects in sustainable development education. His work spans the innovative use of technology in learning, nurturing corporate responsibility through ESG initiatives and applying academic findings for societal improvement. His efforts amplify the integral role of education in fostering sustainable development.

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