

# Linear Regression Approach to Evaluating Pre-Post Learning Outcomes of Education for Sustainable Development

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## Abstract

There is no standard method for analyzing and displaying pre-post test scores in Education for Sustainable Development (ESD) programs. This article proposes a simple linear regression analysis to display and evaluate pre-post intervention changes in competency scores in ESD. Using three previously published datasets as examples, the results indicated that the mean pre-post change scores adjusted by the mean pre-intervention scores were better indicators of the development of ESD competencies. The linear regression analysis may be a statistically and visually useful method for comparing pre-post intervention changes in ESD competencies among different studies.

## Keywords

Regression Analysis, ESD, Competency, Pre-Post Intervention Change

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## 1. Introduction

Over the past two decades, the field of Education for Sustainable Development (ESD) has developed frameworks of key sustainability competencies. Early studies have focused on conceptualizing key competencies for sustainable development (de Haan, 2006; Wiek et al., 2011; Rieckmann, 2012). Wiek et al. (2011) proposed five key competencies: systems-thinking, anticipatory, normative, strategic, and interpersonal competence. Later, UNESCO (2017) expanded Wiek et al.'s (2011) key competencies by adding socio-emotional, critical, and action-oriented dimensions and then proposed eight key competencies: systems thinking, anticipatory, normative, strategic, collaboration, critical thinking, self-awareness, and integrated problem-solving competencies. Recently, Bianchi et al. (2022) developed the GreenComp framework, identifying a set of sustainability competences that

should be cultivated across all levels of education in response to global ecological crises.

Assessing changes in key competences over time (e.g., pre- and post-testing) is a major challenge (Rieckmann, 2018). However, there is no standard method for presenting the changes in key competences. One possible method is to use radar charts for longitudinal data, such as pre- and post-outcomes. For example, Green (2021) used a radar chart (Fig. 3.9 in the thesis) to illustrate pre-post changes in Ocean Literacy dimension scores. However, this method is highly sensitive to axis ordering, as the resulting polygon's shape and area are not uniquely determined by the underlying data. Consequently, radar charts can distort visual comparisons and provoke subjective misinterpretations of the results. Therefore, this technical note aims to propose a simple linear regression approach to display and compare pre-post changes in key competencies in ESD.

## 2. Materials and Methods

This article used mean scores of competencies extracted from three previously published studies: Tab. 4 of Takahashi and Utagawa (2021), Fig. 4 of Mizukami and Iguchi (2023), and Fig. 3 of Zorn and Malz (2023). Mizukami and Iguchi (2023) and Zorn and Malz (2023) adopted five-point Likert scale, while Takahashi and Utagawa (2021) adopted four-point Likert scale. When numeric values were not explicitly reported in the articles, they were extracted from figures using the digitizing software GSYS2.4.9 available at <https://www.jcprg.org/gsys/>.

Mizukami & Iguchi (2023) distinguished between collaborative 1 and collaborative 2. However, the mean scores for both categories were nearly identical. Moreover, Takahashi & Utagawa (2021) and Zorn & Malz (2023) used a single collaboration-related competency: collaborative competency in Takahashi & Utagawa (2021) and interpersonal competency in Zorn & Malz (2023). Consequently, the present study treated collaborative 1 and collaborative 2 in Mizukami & Iguchi (2023) as a single, unified collaborative competency, using the average of both scores to compare the three studies.

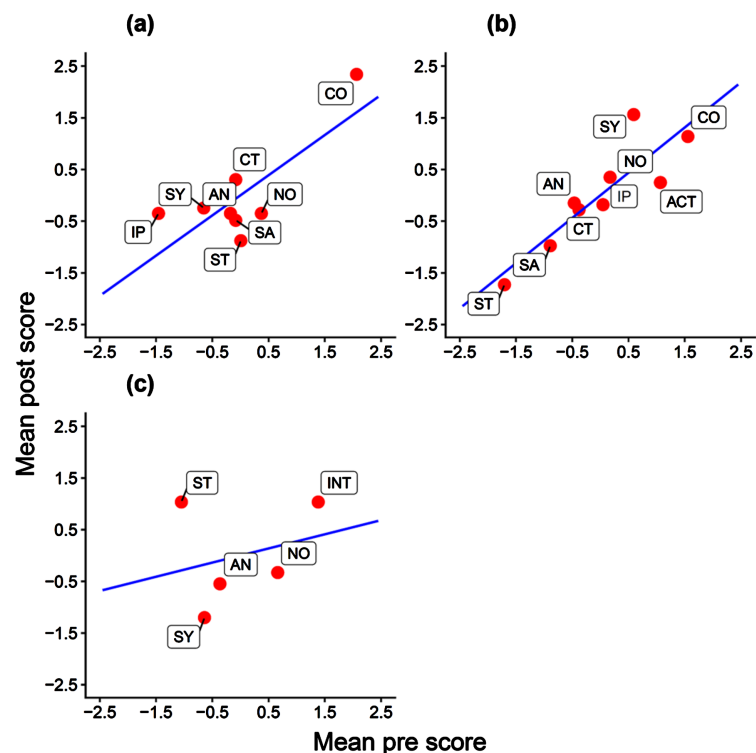
The median is often preferred for representing the central tendency of Likert-scale data. However, as suggested by Valderrama-Hernández et al. (2020), mean values are particularly useful for ranking the relative effects of various items for comparative purposes across competencies and studies. Consequently, the present study treated the mean score of each competency as the unit of analysis and then adopted a simple linear regression model for visualization and regression modeling of pre-post competency changes, and performed an analysis conceptually similar to ANCOVA in which the dependent variable was either the mean post-intervention score or the mean change score for each competency, adjusting for the corresponding mean pre-intervention score. The mean change score was computed as post minus pre. All the variables were standardized to a mean of 0 and a standard deviation of 1 before the regression analysis. The number of mean scores used as data points was 8 in Takahashi & Utagawa (2021), 9 in Mizukami & Iguchi

(2023), and 5 in Zorn & Malz (2023). The performance of the regression analysis was evaluated through the statistical indices R<sup>2</sup> (the coefficient of determination), RMSE (root mean squared error) and Sigma (residual standard deviation) using the performance package (Lüdecke et al., 2021) in R.

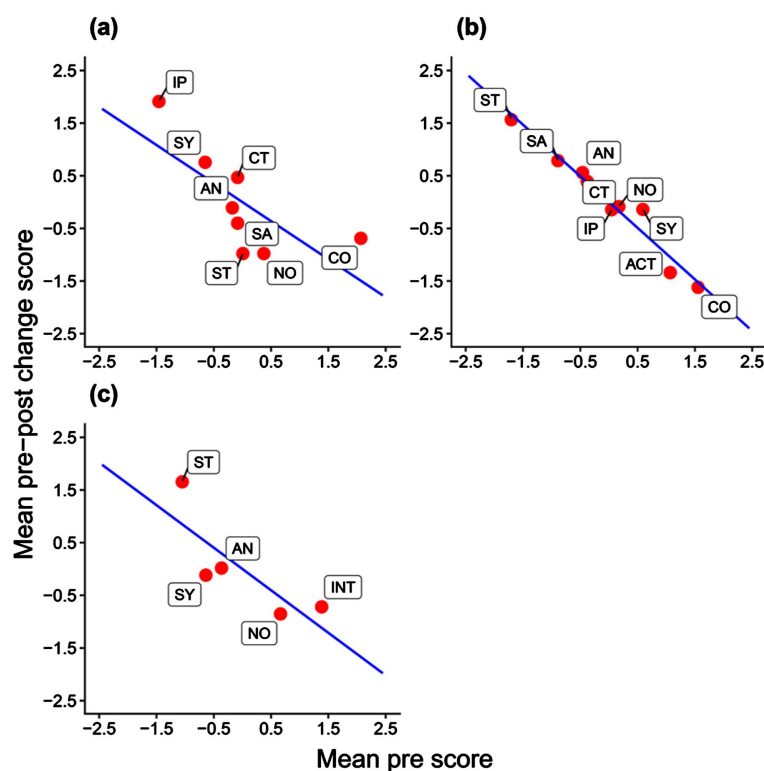
### 3. Results and Discussion

Figure 1 and Figure 2 are scatter plots showing the mean post-intervention score and the mean change score adjusting for the mean pre-intervention score. Unlike radar charts, the scatter plots placed competency scores within a Cartesian coordinate system, so that their positions reflected objective magnitudes rather than subjective axis ordering.

Table 1 shows the performance of the regression analysis for each dataset. In all studies, the regression analysis presented better performance in the relationship between the mean pre-intervention and pre-post change scores than between the mean pre- and post-intervention scores. In particular, the regression analysis of the pre-post intervention scores in Zorn & Malz (2023) presented very poor performance. Based on R<sup>2</sup>, RMSE, and Sigma, the present study concluded that pre-post change scores adjusted by the mean pre-intervention scores may be a better indicator of the development of ESD competencies.



**Figure 1.** Relationship between the mean pre-score and mean post-score. Data from (a) Takahashi & Utogawa (2021), (b) Mizukami & Iguchi (2023), and (c) Zorn & Malz (2023). The variables were standardized. Abbreviations: SY, Systems Thinking; ST, Strategic; SA, Self-Awareness; IP, Integrated Problem Solving; CT, Critical Thinking; AN, Anticipatory; NO, Normative; CO, Collaborative; ACT, Action-oriented; INT, Interpersonal.



**Figure 2.** Relationship between the mean pre-score and mean pre-post change score. Data from (a) Takahashi & Utagawa (2021), (b) Mizukami & Iguchi (2023), and (c) Zorn & Malz (2023). The variables were standardized. Abbreviations: SY, Systems Thinking; ST, Strategic; SA, Self-Awareness; IP, Integrated Problem Solving; CT, Critical Thinking; AN, Anticipatory; NO, Normative; CO, Collaborative; ACT, Action-oriented; INT, Interpersonal.

**Table 1.** Performance of regression analysis.

Regression analysis	Study	R <sup>2</sup>	RMSE	Sigma
Pre-post	Takahashi & Utagawa (2021)	0.605	0.588	0.679
	Mizukami & Iguchi (2023)	0.766	0.456	0.517
	Zorn & Malz (2023)	0.075	0.860	1.111
Pre-change	Takahashi & Utagawa (2021)	0.522	0.647	0.747
	Mizukami & Iguchi (2023)	0.958	0.193	0.219
	Zorn & Malz (2023)	0.653	0.527	0.680

In the relationship between the mean pre-intervention and pre-post change scores (**Figure 2**), collaborative (represented by CO) or interpersonal (represented by INT) competencies presented the highest mean pre-intervention scores, but resulted in almost the lowest pre-post change scores. Consequently, the three studies showed common characteristics in terms of the development of collaboration-related competencies.

In that relationship (**Figure 2**), strategic competency (represented by ST) presented the lowest mean pre-intervention scores, but resulted in the highest pre-

post change scores in Mizukami & Iguchi (2023), and Zorn & Malz (2023) (Figure 2(b) and Figure 2(c)). However, in Takahashi & Utagawa (2021) (Figure 2(a)), it presented the medium mean pre-intervention scores and resulted in almost the lowest pre-post change scores. These findings indicated that the development of strategic competency was different between Takahashi & Utagawa (2021) and the other two studies.

All these findings together suggest that linear regression analysis may provide a statistically and visually useful method for comparing pre-post intervention changes in ESD competencies among different studies.

There are two major limitations of this study. First, the three studies compared in the present study used different competency frameworks and different response scales. Second, it was not clear why a simple linear regression model better fitted mean pre-post change scores adjusted by the mean pre-scores. Therefore, further studies using the same competency frameworks are required to validate a simple linear regression model for evaluating pre-post learning outcomes of ESD.

#### 4. Conclusion

This study performed simple linear regression analysis of three previously published datasets in terms of pre- and post-intervention competency scores in ESD. The method was a descriptive comparison based on aggregated published means rather than participant-level longitudinal data. The results indicated that the mean pre-post change scores adjusted by the mean pre-intervention scores were better indicators of the development of ESD competencies. This study proposes simple linear regression analysis as a statistically and visually useful method for comparing pre-post intervention changes in ESD competencies among different studies.

#### Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this article.

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