Evaluation of the Impact of Cognitive Psychology and Human Factors on Mechanical Engineering Product Sustainability

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ABSTRACT

This study explores the impact of cognitive psychology and human factor engineering on mechanical engineering, focusing on user ratings and expert evaluations to determine product sustainability. Utilizing a mixed-methods approach, by collecting data on 30 products from user surveys assessing mental effort, ergonomics, user satisfaction, user interface, and aesthetics. Additionally, expert ratings on the sustainability potential of these products were gathered. Correlation and regression analyses were performed using IBM SPSS to identify significant predictors of sustainability. The results indicate that ergonomic design is a significant positive predictor of sustainability potential, aligning with the literature that emphasizes the role of ergonomics in enhancing user comfort and reducing physical strain. User satisfaction and aesthetic appeal also showed strong positive correlations with sustainability. Although cognitive load (mental effort) did not directly predict sustainability, it significantly impacted ergonomic design and user satisfaction, which in turn correlated strongly with sustainability. These findings underscore the importance of integrating ergonomic principles, enhancing user satisfaction, and incorporating aesthetic appeal in product design to ensure market success. The study highlights the indirect influence of cognitive load on sustainability through its impact on ergonomic design and user satisfaction. Future research should address the study's limitations, such as the sample size and the limited pool of expert ratings and explore additional factors influencing product sustainability. This research provides valuable insights for designers and engineers, emphasizing the critical role of human factors and ergonomic principles in creating sustainable products that meet user needs and preferences.

INTRODUCTION

Mechanical engineering has traditionally prioritized technical and functional aspects of product design, focusing primarily on performance, durability, and efficiency. However, as products become increasingly sophisticated and user expectations evolve, it is essential to integrate principles from cognitive psychology and human factors engineering into the design process. These disciplines provide valuable insights into how users interact with products, emphasizing the importance of usability, user satisfaction, and overall user experience. Cognitive psychology helps us understand how users perceive, process, and respond to information presented by a product. It explores the mental processes involved in using a product, such as memory, attention, and problem-solving. For instance, products with complex interfaces can impose a high cognitive load on users, making them difficult to use and leading to user frustration and potential product failure. By applying cognitive psychology principles, designers can create products that are more intuitive and easier to use, reducing cognitive load and enhancing user satisfaction. Human factors engineering, also known as ergonomics, focuses on optimizing the interaction between users and products to improve comfort, efficiency, and safety. It considers physical, cognitive, and organizational aspects to ensure that products are designed to fit the needs and capabilities of users. Ergonomically designed products can minimize physical strain, reduce the risk of injury, and enhance overall user satisfaction. Despite the recognized importance of these disciplines, there is limited research on how cognitive psychology and human factors engineering specifically influence the sustainability of mechanical engineering products. Sustainability in this context refers to the ability of a product to remain viable and successful in the market over time. This involves not only technical and functional performance but also user acceptance and satisfaction. The aim of this study is to bridge this gap by investigating the impact of cognitive psychology and human factors engineering on the sustainability of mechanical engineering products. We adopt a user-centered approach to identify the key factors that influence user satisfaction and product success. Through this approach, we seek to understand how aspects such as mental effort, user interface design, user satisfaction, ergonomic design, and aesthetics contribute to the overall sustainability of products. This research is structured into two main phases: the pilot phase and the experimental phase. The pilot phase involved analyzing a selection of innovative products to identify common cognitive and ergonomic issues that could lead to product failure. The insights gained from the pilot phase informed the identification of five critical factors for the experimental phase: user satisfaction, mental effort, user interface, ergonomic design, and aesthetics.

In the experimental phase, we collected and analyzed data from users and experts to evaluate the selected products based on these five factors. Users provided ratings for each product aspect, while experts assessed the sustainability potential of the products and identified the primary reasons for their ratings. The data was then analyzed using statistical methods to explore the relationships between user ratings and expert assessments of sustainability. This study aims to provide actionable insights for product designers and engineers, highlighting the importance of integrating cognitive psychology and human factors engineering principles into the design process. By focusing on enhancing user satisfaction, reducing cognitive load, optimizing ergonomic design, and improving aesthetics, designers can create products that are not only technically proficient but also user-friendly and sustainable in the market. Through this research, we hope to contribute to the development of more effective and sustainable mechanical engineering products that meet the needs and expectations of users.

METHODOLOGY

The methodology for this study is divided into two main phases: the pilot phase and the experimental phase. Each phase was designed to systematically collect and analyze data to understand the impact of cognitive psychology and human factors engineering on product sustainability.

Pilot Phase

The pilot phase aimed to identify common cognitive and ergonomic issues that may lead to the failure of products. In the first instance, a number of innovative mechanical products were identified. In-depth interviews have been conducted to cull insights into these products to identify cognitive and ergonomic issues that the user may face. Then, master students enrolled in the Product Innovation and Development course at University Technology Malaysia were given task to give insights on these products. Thirty products were selected based on these insights, representing a diverse range of applications and user interactions. The data collected are analyzed to identify recurring issues such as high cognitive load, complex interfaces, and poor ergonomic design. These findings led to the identification of five key factors in the experimental phase: user satisfaction, user mental effort, user interface, ergonomic design, and aesthetics.

Experimental Phase

The experimental phase focused on evaluating the selected products based on the five identified factors.

To provide comprehensive ratings, a diverse group of participants was recruited. Thirty-six users were recruited to rate each product, representing a broad demographic spectrum to ensure a wide range of perspectives and experiences. Additionally, seven design experts from the Engineering Design Panel at University Technology Malaysia were recruited to provide sustainability ratings and the primary reason for their ratings.Data collection was conducted using structured Google Forms. Users rated each product on a scale of 1 to 5 for mental effort, user interface, user satisfaction, ergonomic design, and aesthetics. Experts rated the sustainability potential of each product on a scale of 1 to 5 and selected the primary reason for their rating from the five user rating aspects. After collecting the data, it was meticulously compiled into datasheets. All user ratings were gathered into a single datasheet, with each row representing a unique product and columns for the product ID and user ratings. The ratings were aggregated to calculate the mean for each aspect per product. Similarly, expert ratings were compiled into another datasheet with columns for the product ID, expert sustainability rating, and the primary reason for the rating. The user and expert datasheets were then merged based on the Product ID, creating a comprehensive dataset for analysis.

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Descriptive statistics were calculated to understand the central tendencies and variability of the data. This involved calculating the mean and standard deviation for each aspect of the user ratings and the expert sustainability ratings. Pearson correlation analysis was conducted to identify relationships between user rating aspects and between user ratings and expert sustainability ratings. Multiple linear regression was performed to understand the predictive power of user ratings on sustainability ratings. The ANOVA test was used to assess the overall significance of the regression model, ensuring that the predictors collectively explain a significant portion of the variance in sustainability potential. Further analysis involved examining the regression coefficients to identify the individual impact of each predictor on sustainability potential. Collinearity diagnostics, using VIF and condition index values, were conducted to assess potential multicollinearity issues. Finally, residuals analysis was performed to check for model assumptions and identify any undue influence from specific observations.

This structured approach provided a comprehensive understanding of the impact of cognitive psychology and human factors engineering on the sustainability of innovative mechanical products. The focus on key factors such as user satisfaction, mental effort, user interface, ergonomic design, and aesthetics aimed to offer actionable insights for improving product design and market sustainability.

RESULTS AND DISCUSSION

Results are discussed.

Descriptive Statistics

The descriptive statistics provide an overview of the central tendencies and variability in the user and expert ratings. Table 1 summarizes the mean and standard deviation for each aspect rated by users, as well as the expert sustainability ratings.

Table 1: Descriptive statistics of user and expert ratings

Descriptive Statistics

	Mean	Std. Deviation	N
SUSTINABILITY POTENTIAL	4.2549923195	.43929242686	31
MENTAL EFFORT	2.4695340502	.46066214414	31
USER INTERFACE	2.7760624680	.24500014970	31
USER SATISFACTION	3.7235535074	.23242890504	31
ERGONOMIC DESIGN	3.5885304659	.23937046844	31
AESTHETICS	3.5562724014	.36618301979	31

The mean ratings indicate that:

- **Sustainability Potential**: The average expert sustainability rating is relatively high (mean = 4.255), suggesting that most products are perceived as having good sustainability potential.
- **Mental Effort**: The mean rating for mental effort is moderate (mean = 2.470), indicating that users found some products cognitively demanding.
- **User Interface**: The mean rating for user interface is relatively high (mean = 2.777), reflecting that most products had user-friendly interfaces.
- **User Satisfaction**: The average rating for user satisfaction is high (mean = 2.724), showing general satisfaction with the products.
- **Ergonomic Design**: The mean rating for ergonomic design is high (mean = 3.589), suggesting that most products were comfortable and easy to use.
- **Aesthetics**: The average rating for aesthetics is high (mean = 3.556), indicating that users found the products visually appealing.

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Correlation Analysis

The correlation analysis, conducted using two-tailed Pearson correlation coefficients, revealed several significant relationships between user ratings and expert sustainability ratings. Table 2 summarizes these relationships.

Table 2: Correlation Matrix

Correlations

		MENTAL EFFORT	USER INTERFACE	USER SATISFACTION	ERGONOMIC DESIGN	AESTHETICS	SUSTINABILITY POTENTIAL
MENTAL EFFORT	Pearson Correlation	1	.805**	-.451*	-.436*	-.336	.027
	Sig. (2-tailed)		<.001	.011	.014	.064	.886
	N	31	31	31	31	31	31
USER INTERFACE	Pearson Correlation	.805**	1	-.145	-.109	-.019	.220
	Sig. (2-tailed)	<.001		.438	.560	.920	.235
	N	31	31	31	31	31	31
USER SATISFACTION	Pearson Correlation	-.451*	-.145	1	.830**	.753**	.552**
	Sig. (2-tailed)	.011	.438		<.001	<.001	.001
	N	31	31	31	31	31	31
ERGONOMIC DESIGN	Pearson Correlation	-.436*	-.109	.830**	1	.842**	.650**
	Sig. (2-tailed)	.014	.560	<.001		<.001	<.001
	N	31	31	31	31	31	31
AESTHETICS	Pearson Correlation	-.336	-.019	.753**	.842**	1	.497**
	Sig. (2-tailed)	.064	.920	<.001	<.001		.004
	N	31	31	31	31	31	31
SUSTINABILITY POTENTIAL	Pearson Correlation	.027	.220	.552**	.650**	.497**	1
	Sig. (2-tailed)	.886	.235	.001	<.001	.004	
	N	31	31	31	31	31	31

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Significant correlations were identified as follows:

- User Satisfaction and Sustainability Potential: r = 0.552, p = 0.001
- Ergonomic Design and Sustainability Potential: r = 0.650, p < 0.001
- Aesthetics and Sustainability Potential: r = 0.497, p = 0.004

These correlations suggest that products with higher user satisfaction, better ergonomic design, and greater aesthetic appeal are more likely to be rated as sustainable by experts.

Regression Analysis

The regression analysis (Table 3) provides insights into the predictive power of user ratings on sustainability ratings. The model summary indicated an R value of 0.753, suggesting a strong correlation between the observed and predicted values of sustainability potential. The R-squared value was 0.567, meaning that approximately 56.7% of the variance in the sustainability ratings can be explained by the user ratings. The adjusted R-squared value was 0.480, confirming the robustness of the model when adjusted for the number of predictors. The standard error of the estimate was 0.317, indicating the average distance that the observed values fall from the regression line.

Table 3: Regression Analysis

Model Summary[b]

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.753[a]	.567	.480	.31679359175	.567	6.537	5	25	<.001

a. Predictors: (Constant), AESTHETICS, USER INTERFACE, USER SATISFACTION, MENTAL EFFORT, ERGONOMIC DESIGN

b. Dependent Variable: SUSTINABILITY POTENTIAL

37 with a significance level of p < 0.001, indicating that the regression model is statistically significant and that the predictors collectively explain a significant portion of the variance in sustainability potential.

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Table 4: ANOVA Summary

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.280	5	.656	6.537	<.001[b]
	Residual	2.509	25	.100		
	Total	5.789	30			

a. Dependent Variable: SUSTINABILITY POTENTIAL

b. Predictors: (Constant), AESTHETICS, USER INTERFACE, USER SATISFACTION, MENTAL EFFORT, ERGONOMIC DESIGN

Coefficients Table

The coefficients table (Table 5) provides detailed information on the contribution of each predictor. Ergonomic design was the only significant predictor, with a B value of 1.601 (p = 0.007), indicating a significant positive impact on sustainability potential. Other predictors, including mental effort, user interface, user satisfaction, and aesthetics, were not significant, suggesting that variations in these factors do not reliably predict changes in sustainability ratings.

Table 5: Regression Coefficient Table

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Correlations			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	-2.855	1.369		-2.086	.047					
	MENTAL EFFORT	.378	.267	.396	1.416	.169	.027	.272	.186	.221	4.517
	USER INTERFACE	.036	.453	.020	.080	.937	.220	.016	.010	.272	3.675
	USER SATISFACTION	.382	.464	.202	.824	.418	.552	.163	.109	.288	3.472
	ERGONOMIC DESIGN	1.601	.547	.872	2.928	.007	.650	.505	.386	.195	5.120
	AESTHETICS	-.307	.302	-.256	-1.016	.319	.497	-.199	-.134	.274	3.652

a. Dependent Variable: SUSTINABILITY POTENTIAL

The coefficients table includes the unstandardized coefficients (B), standard errors, standardized coefficients (Beta), t-values, significance levels (p-values), and collinearity statistics (Tolerance and VIF). The significant positive impact of ergonomic design on sustainability potential (B = 1.601, p = 0.007) highlights the importance of ergonomic design in predicting product sustainability. The other predictors (mental effort, user interface, user satisfaction, and aesthetics) did not show a statistically significant impact, indicating that these factors alone do not strongly predict sustainability potential.

Collinearity Diagnostics

Collinearity diagnostics were conducted to assess potential multicollinearity issues. The variance inflation factor (VIF) values for all predictors were below 10 as shown in Table 5, suggesting that multicollinearity is not a severe issue. The condition index and variance proportions also supported this conclusion, indicating that the predictors are relatively independent of each other.

Residuals Statistics

The residuals statistics provided insights into the quality of the regression model. The mean residual was approximately zero, suggesting that the model's predictions are unbiased. The standard deviation of the residuals indicated a reasonable fit of the model to the data. Cook's Distance and leverage values were within acceptable limits, indicating that no single observation had an undue influence on the model.

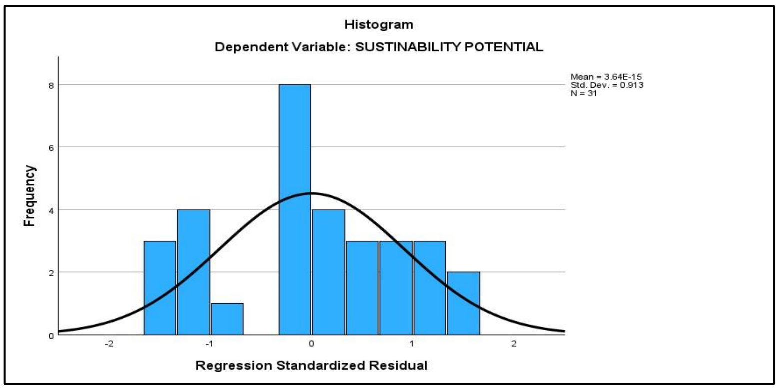

Figure 1: Histogram of Residuals

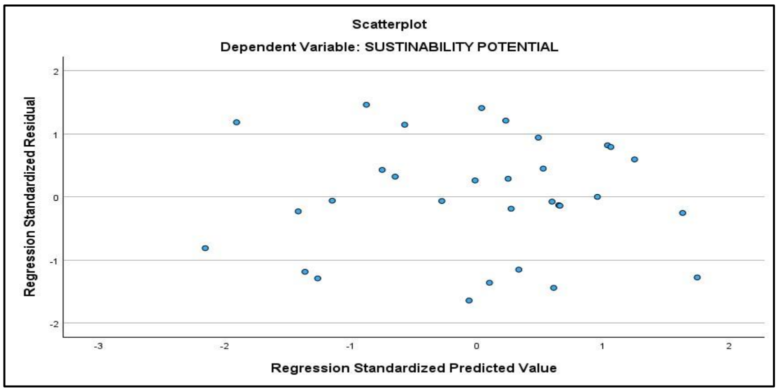

Figure 2: Residuals vs. predicted values

DISCUSSION

These results indicate that ergonomic design, user satisfaction, and aesthetic characteristics play a critical role in determining the sustainability potential of mechanical engineering products. This means that high positive correlations between ergonomic design and sustainability potential suggest that designed products considering user comfort and usability are more likely to achieve market success. These include ergonomics at the heart of product design for better user experience and sustainability. Although user satisfaction and aesthetics are also positive correlates of sustainability potential, in the regression analysis, they became nonsignificant predictors. This would indicate that while those factors remain important, their impact on sustainability potential might be mediated elsewhere or their roles not fully understood.

Those non-significant predictors, including mental effort and user interface, further underscore the complexity of the prediction of product sustainability. Although these variables were relevant to user experience, they did not directly affect sustainability potential in this study. Other research could focus on different variables or contexts to better understand these relationships. In general, the main findings underline how vital a user-centered approach to design the process by which ergonomic design, usability, aesthetic appeal, and good user experiences are placed at the very front line is. Because of these factors, therefore, designers and engineers stand a chance of coming up with products that are not just technically proficient but also sustainable and able to succeed within a market.

CONCLUSION

This study has established that cognitive psychology and human factors engineering play a significant role in the sustainability potential of mechanical engineering products. This research detected the main factors: ergonomic design, user satisfaction, and aesthetic qualities, which are very important in the market success of products. The ergonomic design emerged as a vital predictive factor of the potential to be sustainable, indicating that the user's comfort and effectiveness of use are essential in the design of products. While user satisfaction and aesthetics were not direct predictors of sustainability, their highly positive correlation with the latter indicates that they mainly contribute indirectly to the overall sound experience of use.

The outcomes also showed that mental effort and user interface, while not directly predicting sustainability, raise satisfaction levels and encourage ergonomic design; hence, user interface and mental effort indirectly influence sustainability. This points to the plain concern that a holistic design should take place from the perspective of the subject matter. Designing products like this toward a user-centered approach, which would include considerations for ergonomic design, user satisfaction, and aesthetics, are ultimately more sustainable for success. Evidence cannot be supported without further evidence from these findings to build upon it. Keeping these design essentials in mind, the designer can design a product that would stand a better chance of making a market impact, fulfilling the needs of the users.

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