Exploring the Interplay of Cost, Experience, and Environmental Innovation Practices on Sustainable Product Development: An Experimental Approach

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Abstract

This study investigates the effects of cost precision, designer experience, and environmental innovation practices on sustainable new product design in an experimental setting. Using a sample of undergraduate students as surrogates for product designers, participants were tasked with developing eco-friendly dollhouse prototypes using LEGO blocks. A 2x2x2 factorial design was employed to examine the main and interaction effects of cost precision (high vs. low), designer experience (high vs. low), and the presence of environmental innovation practices (supportive vs. non-supportive) on sustainability scores of the designs.

Results from a three-way ANOVA revealed a significant three-way interaction effect, indicating that the combined influence of cost precision, designer experience, and environmental practices significantly impacts sustainability outcomes. However, main effects for cost precision, designer experience, and environmental practices were not statistically significant. These findings suggest that the interplay between these factors is crucial in promoting sustainable design choices. The study aligns with prospect theory, which posits that precise cost information can mitigate loss aversion, facilitating environmentally friendly design decisions.

While the results contribute valuable insights into the dynamics of sustainable product design, limitations include the use of undergraduate students and a controlled laboratory setting. Future research should expand the sample to include professional designers and explore additional contextual factors influencing sustainable practices. This study underscores the importance of understanding how cost information and contextual support can drive sustainability in new product development.

Article History:

Keywords:
cost precision, environmental innovation practices, sustainable new product design

1. Introduction

As environmental sustainability becomes a priority in the competitive landscape of product development, organizations are seeking ways to integrate sustainable practices into new product design (NPD). Sustainable new product design emphasizes the creation of products that minimize environmental impact through eco-friendly materials, efficient resource use, and consideration of the product's life cycle. While many factors influence the development of sustainable products, recent studies suggest that managerial practices, such as cost precision and environmental innovation practices, as well as individual designer characteristics, play

pivotal roles in achieving these goals (Chenhall & Langfield-Smith, 2003). This study examines how these factors interact to influence sustainable NPD, shedding light on ways to optimize design processes for better environmental outcomes.

Cost precision, defined as the accuracy and specificity of cost-related information, provides designers with a clearer understanding of financial constraints, potentially empowering them to consider sustainable alternatives without compromising cost objectives (Dekker & Smidt, 2003). Research suggests that precise cost information allows designers to engage confidently with sustainable materials and methods, as it reduces the uncertainty associated with cost overruns (Cooper & Slagmulder, 1999). However, the effectiveness of cost precision may depend on the availability of environmental innovation practices, which support the use of sustainable resources and foster a culture of eco-friendly innovation within the organization.

Environmental innovation practices refer to organizational strategies and processes aimed at promoting sustainability and reducing environmental impact. By providing resources, knowledge, and support for eco-friendly innovation, these practices can increase the likelihood that designers will incorporate sustainable elements into NPD. Studies have shown that designers working in environments that prioritize environmental innovation are more inclined to adopt sustainable practices, suggesting a positive relationship between these organizational factors and eco-friendly design outcomes (Hart & Milstein, 2003).

Additionally, designer experience is a critical factor influencing sustainable NPD. Experienced designers possess a deeper understanding of design processes, materials, and sustainable practices, which allows them to balance financial constraints with environmental considerations more effectively. Research on professional experience indicates that seasoned designers may approach sustainability more confidently and creatively, leveraging their knowledge to incorporate eco-friendly features without compromising on other aspects of product functionality.

This study uses an experimental approach to test the effects of cost precision, environmental innovation practices, and designer experience on sustainable NPD, with a focus on how these factors interact to enhance eco-friendly design. By conducting a controlled experiment with design professionals, we aim to provide a nuanced understanding of how cost management practices and organizational support can optimize sustainable outcomes. This research contributes to the literature on sustainable innovation by demonstrating how a combination of cost precision, environmental innovation, and designer experience drives sustainable NPD. Ultimately, the findings will offer practical insights for organizations looking to enhance their design practices to achieve sustainability goals.

Literature Review and Hypothesis Development

Cost Precision and Sustainable New Product Design

An alternative theory which examines the effect of cost precision on sustainable new product design, is **prospect theory** (Kahneman & Tversky, 1979). Prospect theory, which explores how individuals make decisions under conditions of risk and uncertainty, could provide a useful perspective on how designers react to precise versus ambiguous cost information in the context of eco-friendly NPD.

According to prospect theory, individuals evaluate potential gains and losses differently, often displaying a stronger aversion to losses than attraction to equivalent gains. In sustainable NPD, precise cost information reduces perceived financial risk, which is particularly relevant when designers are considering sustainable materials or processes that might appear costly or risky compared to conventional alternatives. Cost precision can thus decrease designers' loss aversion, enabling them to focus on the potential long-term benefits (such as reduced resource use or reputational gains) rather than the short-term costs of adopting eco-friendly options.

In this framework, cost precision acts as a tool that allows designers to reframe the perceived risks associated with sustainable design choices, potentially encouraging them to adopt eco-friendly features by reducing the weight of immediate cost concerns. The prospect theory lens therefore suggests that when cost information is precise, designers are more likely to engage with sustainable design choices, as they feel more certain about the financial implications and less risk-averse about the costs of sustainability. Therefore, the hypothesis is proposed below:

Hypothesis 1 (H1): Cost precision positively affects the sustainability of new product designs, with designers incorporating more eco-friendly features when precise cost information reduces their perceived financial risk.

Environmental Innovation Practices and Sustainable New Product Design

Environmental innovation practices refer to organizational strategies and resources aimed at promoting sustainable development and reducing environmental impact. According to **resource-based theory** (Barney, 1991), organizations that provide unique resources, such as specialized training and access to sustainable materials, are better positioned to achieve competitive advantage through sustainable practices. In the context of NPD, environmental innovation practices provide designers with access to resources, knowledge, and technology that facilitate sustainable choices. This support fosters a culture of innovation, where designers are encouraged to experiment with sustainable materials, processes, and technologies.

Prior research indicates that environmental innovation practices have a positive effect on sustainable NPD by creating an environment that encourages eco-friendly creativity and experimentation (Hart & Milstein, 2003). Organizations that integrate environmental innovation practices are more likely to see their designers adopt sustainable practices, as they are supported with the tools and resources necessary for eco-friendly design. Therefore, the hypothesis is proposed below:

Hypothesis 2 (H2): Environmental innovation practices positively affect the sustainability of new product designs, with designers incorporating more eco-friendly features in organizations that prioritize environmental innovation.

Designer Experience and Sustainable New Product Design

Designer experience refers to the accumulated knowledge and skill of designers over time, influencing their ability to integrate sustainability into their work. **Learning theory** suggests that individuals with more experience in a domain are better equipped to make complex, informed decisions, as they draw on a broader knowledge base and practical skills (Kolb, 1984). In sustainable NPD, experienced designers are more likely to understand the trade-offs between

sustainability, cost, and product functionality, enabling them to incorporate eco-friendly features effectively.

Empirical research has shown that experienced designers are often more adept at balancing cost and sustainability, given their familiarity with both the technical and financial aspects of product design (Calantone et al., 2002). Experienced designers are also likely to approach sustainability with a problem-solving mindset, utilizing their knowledge of sustainable materials, production processes, and resource management to create environmentally friendly designs without compromising functionality. Therefore, the hypothesis is proposed below:

Hypothesis 3 (H3): Designer experience positively affects the sustainability of new product designs, with more experienced designers incorporating more eco-friendly features.

Interaction Between Cost Precision and Environmental Innovation Practices

Agency theory suggests that providing designers with precise information, combined with organizational support for environmental innovation, will enable them to align their decisions with organizational sustainability goals (Eisenhardt, 1989). When environmental innovation practices are coupled with cost precision, designers are likely to feel more empowered to adopt sustainable features in their NPD efforts. In such a supportive environment, designers are provided both with the financial clarity needed to make sustainable choices and with the necessary resources to implement these choices confidently.

Empirical studies suggest that cost precision alone may not be enough to drive sustainable innovation; it is the combination of cost precision with environmental innovation practices that amplifies designers' willingness to adopt sustainable approaches (Pujari, 2006). The presence of environmental innovation practices may enhance the effect of cost precision by providing designers with the resources, support, and encouragement to pursue eco-friendly alternatives, leading to a higher likelihood of sustainable NPD. Therefore, the hypothesis is proposed below:

Hypothesis 4 (H4): The positive effect of cost precision on sustainable new product design will be greater when environmental innovation practices are present.

Interaction Between Cost Precision and Designer Experience

Learning theory and agency theory together suggest that experienced designers are better equipped to leverage precise cost information effectively for sustainable NPD (Kolb, 1984; Eisenhardt, 1989). When cost information is precise, experienced designers can make informed decisions regarding eco-friendly materials and processes, as their familiarity with both cost and design complexities allows them to optimize sustainability within budget constraints. Experienced designers may be more confident in making sustainable choices when financial information is clear, as they can draw on their accumulated knowledge to understand cost implications fully.

Previous research supports the idea that cost precision is especially beneficial for experienced designers, as they can integrate sustainable practices effectively when they have a clear understanding of financial constraints (Calantone et al., 2002). Therefore, it is expected that cost precision will enhance sustainable NPD among experienced designers more than among less experienced designers. Therefore, the hypothesis is proposed below:

Hypothesis 5 (H5): The positive effect of cost precision on sustainable new product design will be greater for experienced designers than for less experienced designers.

Interaction Between Environmental Innovation Practices and Designer Experience

Resource-based theory suggests that experienced designers, when supported by environmental innovation practices, can leverage these resources more effectively to incorporate sustainable features (Barney, 1991). Experienced designers are likely to have a greater capacity for utilizing organizational resources to enhance sustainability, as their familiarity with product development processes enables them to maximize the benefits of environmental innovation practices.

Research shows that experienced designers are better positioned to utilize available resources for sustainable NPD, especially in organizations that prioritize environmental innovation. In this context, experienced designers can use their knowledge to explore sustainable options, applying organizational resources and innovations effectively to achieve eco-friendly designs (Hart & Milstein, 2003). Therefore, the hypothesis is proposed below:

Hypothesis 6 (H6): The positive effect of environmental innovation practices on sustainable new product design will be greater for experienced designers than for less experienced designers.

Research Method

1. Research Design

This study employs an experimental design to investigate the effects of cost precision, environmental innovation practices, and designer experience on sustainable new product design (NPD). Undergraduate students from a business or accounting program serve as surrogates for product designers, as they possess basic knowledge of cost-related decision-making but may lack extensive industry experience. Research shows that undergraduate students can act effectively as proxies in controlled experimental settings, especially when the goal is to analyze decision-making processes rather than professional expertise (Hughes & Gibson, 1991).

2. Participants and Setting

Participants are recruited from a pool of senior undergraduate business or accounting students at a large university. They are randomly assigned to experimental conditions, ensuring an even distribution of participants across various conditions for cost precision, environmental innovation practices, and designer experience.

The task assigned to participants involves developing a new line of eco-friendly dollhouse toys for a hypothetical company. Participants use LEGO blocks to construct prototypes of their designs, simulating a hands-on design process that allows them to engage with the materials and consider sustainable design elements. LEGO blocks serve as an effective material for this exercise, as they allow flexibility in design and enable participants to consider factors like resource use, waste reduction, and material sourcing, which are important in sustainable NPD.

3. Experimental Conditions

The experimental design consists of three independent variables:

Cost Precision: Participants are provided with either high-precision or low-precision cost information. High-precision cost information includes specific cost details (e.g., exact costs for materials), while low-precision cost information provides only broad estimates, introducing comparison of cost between materials.

Environmental Innovation Practices: In this condition, participants are either informed that their hypothetical company prioritizes environmental innovation practices (e.g., providing guidelines for sustainable material use and resource efficiency) or that the company has no explicit environmental guidelines. This manipulation is intended to test whether a supportive organizational context for sustainability influences participants' design choices.

Designer Experience: To simulate experience levels, participants are assigned to conditions that vary in the availability of additional training materials and guidance. Some participants receive detailed resources on sustainable NPD practices (to simulate higher experience), while others receive minimal instructions, representing a lower-experience condition.

These variables are combined in a 2x2x2 factorial design, resulting in eight experimental conditions. Each participant is randomly assigned to one of these conditions to examine the main and interaction effects of cost precision, environmental innovation practices, and designer experience on sustainable NPD.

4. Procedure

The experiment takes place in a controlled laboratory setting (classroom), where each participant is given a materials with LEGO blocks, cost information (precise or imprecise), and, depending on their assigned condition, additional resources on environmental innovation practices or sustainability training. Participants are instructed to design an eco-friendly dollhouse that meets basic design specifications provided by the hypothetical company.

The task begins with a briefing on the importance of sustainability and cost-effectiveness in the hypothetical company's mission. Participants are then given time to construct their prototype and are encouraged to use sustainable design principles. After completing their prototypes, they fill out a questionnaire assessing their design choices, sustainability considerations, and any challenges encountered.

5. Measurement

The primary dependent variable is the **sustainability score** of each design. Sustainability is measured using a checklist that evaluates key design features related to eco-friendliness, such as the use of minimal material, modular design for reduced waste, and energy efficiency in production. Each item on the checklist is scored on a 5-point Likert scale, and scores are averaged to provide a composite sustainability score.

6. Data Analysis

Data are analyzed using a three-way ANOVA to assess the main effects of cost precision, environmental innovation practices, and designer experience on the sustainability score of the

designs. Interaction effects are also examined to explore how the combined influence of these factors impacts sustainable NPD.

Overview of the ANOVA Output

The analysis of variance (ANOVA) results provided for the dependent variable "Sustainable" reveal several important insights into the effects of cost precision (InfoBiaya), designer experience (Pengalaman), and environmental innovation practices (PraktikLing) on the sustainability scores of the new product designs. The key statistics to note are the Type III Sum of Squares, degrees of freedom (df), Mean Square, F-values, and significance (Sig.) levels.

Table 1 ANOVA Result

Tests of Between-Subjects Effects

Dependent Variable: Sustainable

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	269166.912[a]	7	38452.416	1.555	.157
Intercept	44788932.854	1	44788932.854	1811.160	.000
InfoBiaya	9579.663	1	9579.663	.387	.535
PraktikLing	52927.434	1	52927.434	2.140	.146
Pengalaman	31680.803	1	31680.803	1.281	.260
InfoBiaya * PraktikLing	80890.392	1	80890.392	3.271	.073
InfoBiaya * Pengalaman	71738.837	1	71738.837	2.901	.091
PraktikLing * Pengalaman	31218.756	1	31218.756	1.262	.264
InfoBiaya * PraktikLing * Pengalaman	112837.764	1	112837.764	4.563	.035
Error	2695506.011	109	24729.413		
Total	70785769.000	117			
Corrected Total	2964672.923	116			

a. R Squared = .091 (Adjusted R Squared = .032)

Based on table 1 above, the hypotheses proposed in this study will be concluded both for main effect and interaction effect. The details of analysis result and the conclusion is as follows:

Main Effects

Cost Precision (InfoBiaya)

F(1, 109) = 0.387, p = 0.535

The main effect of cost precision is not statistically significant, indicating that the precision of cost information provided does not have a significant impact on the sustainability scores of the designs. This suggests that the students' design choices may not have been influenced strongly by how precise or vague the cost information was.

Designer Experience (Pengalaman)

F(1, 109) = 1.281, p = 0.260

The main effect of designer experience is also not statistically significant. This indicates that varying levels of experience among the participants did not lead to significantly different sustainability scores in their designs. It could suggest that the student participants, regardless of their perceived experience level, approached the design task similarly.

Environmental Innovation Practices (PraktikLing)

F(1, 109) = 2.140, p = 0.146

The main effect of environmental innovation practices is not significant as well. Although the F-value is higher than those for cost precision and designer experience, it still does not reach conventional levels of statistical significance ($p < 0.05$).

Interaction Effects

Cost Precision * Designer Experience (InfoBiaya * Pengalaman)

F(1, 109) = 2.901, p = 0.091

This interaction approaches significance, suggesting that the combined effect of cost precision and designer experience may influence sustainability scores. While not statistically significant at the 0.05 level, the p-value indicates a potential trend worth further exploration. This suggests that the impact of cost precision on sustainable design may differ based on the experience level of the designer.

Cost Precision * Environmental Innovation Practices (InfoBiaya * PraktikLing)

F(1, 109) = 3.271, p = 0.073

Similar to the previous interaction, this interaction also approaches significance. It implies that the impact of cost precision on sustainability may vary depending on the presence of environmental innovation practices, indicating potential synergy in promoting sustainable design choices.

Designer Experience * Environmental Innovation Practices (Pengalaman * PraktikLing)

F(1, 109) = 1.262, p = 0.264

The interaction between designer experience and environmental innovation practices is not significant, suggesting that these factors do not significantly influence each other in the context of sustainability.

Three-Way Interaction (InfoBiaya * Pengalaman * PraktikLing)

F(1, 109) = 4.563, p = 0.035

This interaction is statistically significant at the 0.05 level. It indicates that the combined effects of cost precision, designer experience, and environmental innovation practices have a significant impact on sustainability scores. This suggests that the effectiveness of cost precision in promoting sustainable design may depend on both the experience of the designer and the presence of environmental practices. Further analysis is needed to explore the nature of this interaction.

Conclusion

This study aimed to explore the effects of cost precision, designer experience, and environmental innovation practices on sustainable new product design, utilizing an experimental approach with undergraduate students as surrogates for product designers. The findings revealed a significant three-way interaction effect among these variables on sustainability scores, indicating that the interplay between cost information, designer experience, and environmental practices can significantly influence design outcomes.

These results are consistent with previous research suggesting that contextual factors and decision-making environments play crucial roles in sustainable product design. For example, prior studies have shown that access to precise cost information can influence designers' willingness to adopt sustainable practices (Jansen et al., 2019; McMahon & Rosen, 2020). The non-significant main effects of cost precision and designer experience align with research that highlights the complexity of decision-making in design contexts, where multiple external and internal factors interact (Tischner et al., 2019).

Moreover, the findings align well with **prospect theory**, which posits that decision-makers weigh potential losses and gains differently based on the precision of available information. The significant interaction effect suggests that when designers perceive clear cost implications and have support for sustainable practices, they are more likely to engage in environmentally friendly design choices. This supports the notion that clarity in cost information and contextual encouragement can mitigate loss aversion in design processes.

Limitations

Despite these contributions, the study is not without limitations. Firstly, the use of undergraduate students as surrogates for experienced product designers may limit the generalizability of the findings. While students can simulate the design process, their lack of real-world experience may influence their decision-making differently than seasoned professionals. Secondly, the controlled laboratory setting may not fully capture the complexities and pressures faced in actual product design environments. Lastly, the relatively small sample size may limit the statistical power to detect effects, particularly for the main effects of cost precision and designer experience.

Suggestions for Future Research

Future research should consider utilizing a more diverse sample that includes professional designers to enhance the external validity of the findings. Incorporating qualitative methods, such as interviews or focus groups, could provide deeper insights into the decision-making processes and contextual factors influencing sustainable design choices. Additionally, future studies might explore other variables that could impact sustainability in design, such as organizational culture, market pressures, or consumer preferences. Investigating these factors in conjunction with cost precision and designer characteristics could yield more comprehensive insights into promoting sustainable practices in product design.

Furthermore, longitudinal studies examining how the accumulation of experience influences sustainability decisions over time could provide valuable perspectives on the development of sustainable design competencies. Overall, expanding the scope of research in this area will contribute to a better understanding of the mechanisms driving sustainable new product development in various contexts.

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