NORDDESIGN CONFERENCE
REYKJAVIK, ICELAND, 12-14 AUGUST 2024

Do Methods Work?
On the Correlation of Method Application, Effort, and Product Quality

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Abstract: Various approaches to support product development, ranging from German VDI guidelines to agile strategies, share commonalities, e.g., they recommend methods like requirement elicitation or product evaluation strategies. While extensively present in design education, the distinctive effect of development approaches on resulting products often remains unassessed. This paper presents the framework of an empirical study and its results, examining (1) the influence of development method application on product concept quality and (2) the effect of effort spent on both. Participants were supervised in their development process as part of an undergraduate higher education course. Data was assessed via rubrics or self-assessment and investigated using descriptive and inferential statistics. The findings show a significant moderate to strong positive correlation between effort spent and method application quality but no significant effect on product concept quality. However, the introduced framework is a streamlined blueprint for similar studies in educational and entrepreneurial contexts.

Keywords: Design Education, Product Development, Project-Based Learning, Empirical Studies

1 Introduction

Product development methods and supporting approaches are designed to enable the development of products tailored to different needs and requirements (Eppinger and Chitkara, 2007; Tyagi et al., 2015). Most developers rely on best practices based on experience or scientific recommendations (Cross, 2011). Accordingly, design science aims to provide product development approaches for companies and to train young engineers to apply these approaches (Tu et al., 2018). However, industry and academia sometimes fail to impart those skills to young engineers and designers (Lawson, 2005; Meyer and Norman, 2020). Browsing SCOPUS (an extensive citation database of peer-reviewed literature) reveals that since 2020, approximately 1400 publications have been published in engineering alone regarding new methods or best practices (this resulted by searching for TITLE-ABS-KEY (("best practices" OR "meta-analysis" OR "review" OR "approach") AND "product development") AND PUBYEAR > 2020 AND (LIMIT-TO (SUBJAREA, "ENGI"))). This figure excludes all publications in design science, which should further increase the number of new approaches published regarding product development. In contrast, just about 400 publications (again, since 2020 and solely in engineering) evaluated or conducted empirical studies on product development approaches (number found by searching for TITLE-ABS-KEY (("evaluation" OR "empirical study") AND "product development") AND PUBYEAR > 2020 AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (EXCLUDE (EXACTKEYWORD, ("New Approaches" OR “Case-studies”)))). Thus, there is an imbalance between the supply of product development approaches and the level of knowledge regarding their effects.

This is particularly momentous since we, as involved designers or engineers, only partially live up to the demands we make on society and industry. Although we offer sufficient product development approaches, we neglect their large-scale evaluation. Whether our methods work is something we typically validate through case studies; general implications are much harder to find. Therefore, this paper intends to present our approach to method evaluation and its results.

Higher education, i.e., imparting methodological knowledge, plays a vital role in this scenario (Tu et al., 2018). We assess our ability to transfer design knowledge and its impact in academia to eventually transfer its implications to a broader perspective. Thus, this study investigates the relationship between method application and product quality in the context of an undergraduate course in higher education.

A prominent teaching method is Project-based Learning (PBL). Adderley (1975) provides the following definition, still valid and acknowledged today (Helle et al., 2006; Hero, 2019): (1) [projects] involve the solution of a problem; often, though not necessarily, set by the student himself [or herself]; (2) they involve initiative by the student or group of students, and necessitate a variety of educational activities; (3) they commonly result in an end product (e.g., thesis, report, design plans, computer programme and model); (4) work often goes on for a considerable length of time; and (5) teaching staff are involved in an advisory, rather than authoritarian, role at any or all of the stages – initiation, conduct and conclusion.

The essential aspect of project-based learning is the activities-driven, organizational character of a challenging problem, culminating in a final product addressing this problem (Blumenfeld et al., 1991). Thus, this method is often used in modern

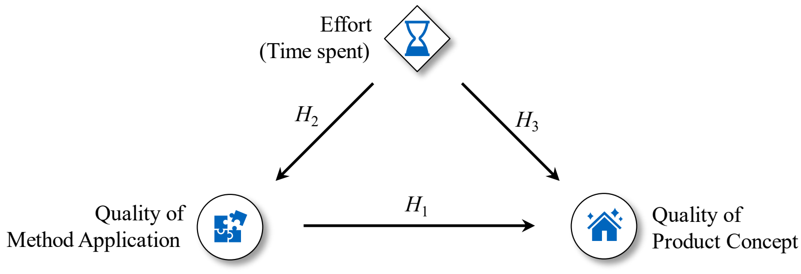

Figure 1. Presumed relations (hypotheses) between considered variables.

higher education (Helle et al., 2006; Hero, 2019). Accordingly, this study examines the influence of methods on product quality in a product development course, which teaches students how to apply methods deploying project-based learning elements.

Research Objective

As depicted, this study aims to evaluate the relationship between method application and product quality in project-based learning. Thus, the overall research question guiding this study is: What is the relationship between the application of product development methods and the quality of the corresponding product? To address that question, three hypotheses were formulated and tested; the presumed relations between the considered variables are shown in Figure 1.

The primary effect considered is the relationship between method application and product quality, as similar studies suggest (Iqbal and Suzianti, 2021). In the context of higher education, we are interested in the quality of method application rather than whether methods were merely applied (Lodge and Bonsanquet, 2014). In addition, the scope of the study does not allow for the development of tangible products, so the quality of the product concepts is examined instead. Thus, the first hypothesis derived from the research question is

H_1: The quality of methods applied in a project-based learning environment correlates with the product concept quality at a moderate to high level ($|\rho| \geq 0.3$).

In addition, potential mediators should also be considered. In higher education, prominent mediators are effort and prior knowledge (Huang and Li, 2012; McKay and Ellis, 2014; Schneider and Preckel, 2017). The study is embedded in a course for undergraduate students, i.e., the methods applied by the students are taught in advance. Thus, the participants' prior knowledge is less impactful and excluded from this study's scope. Therefore, effort is considered the most essential mediator. Accordingly, the question arises as to the relationship between effort and method application quality, so the second hypothesis reads

H_2: The number of hours a team invests in applying product development methods in a project-based learning environment correlates with the method application quality at a moderate to high level ($|\rho| \geq 0.3$).

The correlation between effort and product concept quality is also considered to determine the full effect of the effort spent. Thus, the last hypothesis examined in this study is stated as

H_3: The number of hours a team invests in developing a product concept in a project-based learning environment correlates with the product concept quality at a moderate to high level ($|\rho| \geq 0.3$).

The paper is organized as follows: in section 2, the setting, essential variables, and statistical approach will be shown. In section 3, the study's results will be presented. Section 4 discusses the hypotheses and spotlights the advantages and shortcomings of the study.

2 Method

2.1 Participants

The participants of this study were 78 students enrolled in a product development course during the academic summer term of 2023. Most participants were undergraduate engineering students with little to no experience applying product development methods or developing product concepts. All participants chose project teams of three participants each, resulting in 26 project teams. All participants were offered optional lectures on product development approaches, corresponding methods, and opportunities for supervised exercises. Each method application entailed a mandatory submission of its results during the semester; the developed product concept was due at the end of the academic term.

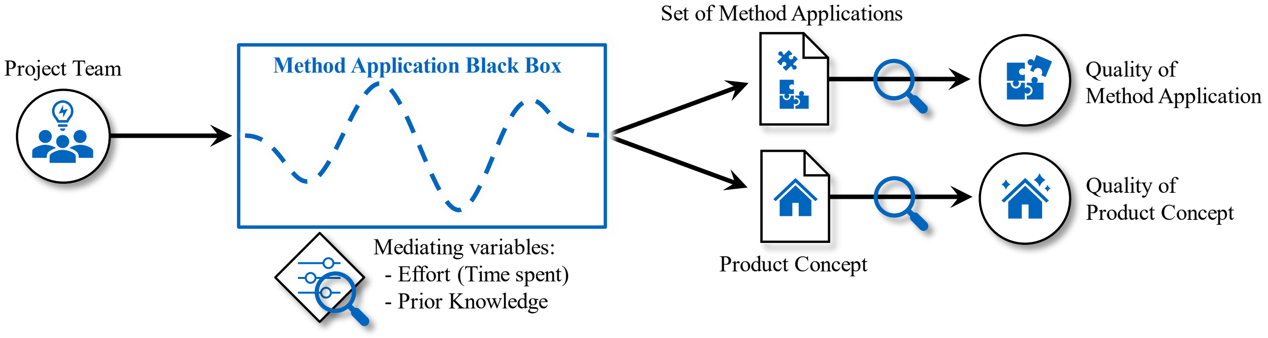

Figure 2. Setting of the study with relevant mediators, input, and output variables. The magnifying glass implies an assessment step.

2.2 Course Setting

The study was planned and carried out as part of a product development course during the academic summer term of 2023. The participating teams were tasked with developing a bottling system according to customer specifications. The course provided the framework for the investigation and offered the participants materials and premises, such as lectures and supervised time to exercise. The Munich Product Concretization Model (MCM) was the course's methodological framework taught during lectures (Lindemann, 2009; Ponn and Lindemann, 2011). The setting of the entire study is visualized in Figure 2.

The MCM primarily classifies product models, i.e., the development process results (Ponn and Lindemann, 2011). It schematically divides the development process into possible product solutions on different layers of abstraction (from an abstract functional layer to the concrete embodiment layer). It provides each layer with a set of requirements as well as a set of corresponding validations. In addition to visualizing the development process, the primary goal is to recommend the next development steps and offer a corresponding portfolio of methods, like Requirement Elicitation, Function Modelling, or FMEA (Ponn and Lindemann, 2011). Thus, the MCM focuses on structuring the development process, neglecting early stages like discovery (Cooper, 2019, 2004). Since the evaluated methods in this setting are shared among other approaches (for comparison, see Table 1), the influence of the MCM as a framework on the study can be neglected.

Guided by the MCM, project teams applied the product development methods shown in Table 1 to the initially stated problem (Ehrlenspiel and Meerkamm, 2017; Lindemann, 2009; Ponn and Lindemann, 2011). Those methods are intended to support the development process for mechanical products; a detailed approach to each method is given by Ponn and Lindemann (2011). The participants were introduced to those methods in a three-stage process: First, the methods and their intended goals were presented in a lecture. Then, the application was demonstrated using trivial examples and expectations for the method application were stated. Additionally, exercises were offered in which the participants could practice, question, and reiterate their method application. Participants were formatively assessed by teaching assistants during their exercises.

Those method applications were submitted biweekly for summative assessment; seven submissions were due. Project teams created and submitted their product concept based on the results of the whole set of method applications.

2.3 Variables and Assessment

This study measured effort spent, method application quality, and product concept quality as crucial variables. Effort spent was an independent variable, whereas product concept quality was the primary dependent variable. The method application quality acted as a secondary dependent and an independent variable.

Table 1. List of Intended Objectives, methods used, and the expected outcomes of corresponding method application.

Intended Objective	Method	Result of Application
Derive technical requirements	Requirement elicitation	Requirement list
Decompose system into sub-systems	Function modeling	Flow-oriented function model
Find innovative, partial solutions	Working principles	Applied working principles
Cluster partial solutions to concepts	Morphological box	Morphological box
Evaluate concepts	Weighted scoring	Justified scoring sheet
Validate concepts	Requirement validation	Design calculations
Analyze weak spots	FMEA	FMEA sheet

Method Application Quality

The specific methods applied by the project teams in this study, the respective objectives, and the assessable results are presented in Table 1. The evaluation was performed by teaching assistants involved in this course for each method application.

All method applications were evaluated using a rubric scheme (Dawson, 2017; Popham, 1997) regarding the five metrics (1) meaningfulness, (2) completeness, (3) innovation, (4) clarity, and (5) formalism of the corresponding method application. The teaching assistants ranked each category using a Likert scale from 1 (lowest value) to 10 (highest value) for each method application. The sum above all method applications for each participant was averaged as the score representing the method application quality for each team.

Product Concept Quality

Each team created a pitch deck for their product concept based on the results of their method application. Those pitch decks included sketches, functions, and unique selling propositions of the designed plant and its modules but no specific method application results. Product Concept Quality was assessed by a jury of four industry and research experts. It is important to note that no jury member was involved in evaluating the method application quality or knew its detailed results beforehand. The product concepts were presented to the jury; each member could assess the team’s product concepts at their own pace.

Analogous to the previous evaluation, a rubric scheme regarding the five metrics (1) meaningfulness, (2) completeness, (3) innovation, (4) clarity, and (5) formalism, was used by the jury; each category was ranked using a Likert scale from 1 (lowest value) to 10 (highest value) for all product concepts. The jury’s scores were averaged as each team's product concept quality.

Effort (Time spent)

Academic effort is typically defined as time and energy expended on academic tasks (Rieger et al., 2022). Since participants’ determination or engagement is not assessed in this study, effort is defined as time spent in hours per method application and for developing the product concept. Teams were asked to self-assess each member’s time spent on each task. The sum of time spent on all method applications above all team members is the team score for effort spent.

2.4 Statistical Analysis

All statistical analyses were performed using R version 4.3.2 (The R Foundation for Statistical Computing, 2023).

The data was tested according to Shapiro-Wilk regarding its normal distribution. Since sample size influences Shapiro-Wilk's assessment of normality, the distribution was also evaluated graphically (Aldor-Noiman et al., 2013). For normally distributed data, the correlation could be checked by Pearson's correlation test; for non-normally distributed data, Spearman's rank correlation was used. In case of doubt, i.e., if normality cannot be assumed unambiguously, both results are available for further consideration. The statistical significance of the results was tested through hypothesis testing. The correlations found were finally classified into small, moderate, or strong effects according to Cohen's d. (Cohen, 2009; Dodge, 2008; Field, 2009)

3 Results

The teams were highly committed to the project, as the average effort (i.e., time spent in hours) of $M = 111$ ($SD = 24$; *range* 60 – 148) indicates. Method Application Quality was evaluated on average as $M = 8.4$ ($SD = 0.64$; *range* 6.6 – 9.2), showing an application quality above the examiner’s expectations. Product quality was evaluated as an average of $M = 5.4$ ($SD = 1.1$; *range* 3.8 – 8.2), indicating a stricter jury evaluation than the assistants’ method application evaluation.

Table 2. Overview of tested hypotheses and corresponding results.

Hypothesis		Variables	Condition	*r*	*p* (H_0)
H_1	null alternative	Method Application Quality, Product Concept Quality	$\lvert\rho\rvert < 0.3$ $\lvert\rho\rvert \geq 0.3$	0.27	0.17
H_2	null alternative	Effort (Time spent), Method Application Quality	$\lvert\rho\rvert < 0.3$ $\lvert\rho\rvert \geq 0.3$	0.55	0.01**
H_3	null alternative	Effort (Time spent), Product Concept Quality	$\lvert\rho\rvert < 0.3$ $\lvert\rho\rvert \geq 0.3$	0.32	0.10

Note that * indicates $p < 0.05$, ** indicates $p < 0.01$.

The Shapiro-Wilk test indicated that neither dataset regarding product concept quality ($W = 0.96$, $p = 0.32$) nor effort ($W = 0.97$, $p = 0.59$) significantly deviated from a normal distribution. At the same time, indicators were found for a deviation from normality ($p < 0.05$) for Method Usage Quality ($W = 0.84$). However, the graphical evaluation does not unequivocally confirm the conclusions regarding non-normality (see Q-Q plots in Figure 3). Thus, Pearson's and Spearman's rank correlation were calculated for further correlation evaluation involving the latter variable.

The results of the correlation analysis and hypotheses tests are listed in Table 2; the scatter plots for each correlation are visualized alongside the results of the Shapiro-Wilk tests in Figure 3.

3.1 Relationship between Method Application Quality and Product Concept Quality

The correlation analysis revealed a statistically significant moderate relationship between Method Usage Quality and Product Concept Quality using Pearson's correlation ($r = 0.41$, $p = 0.04$*). Product Concept Quality showed no significant departure from normality, justifying Pearson's correlation. However, Method Application Quality cannot be assumed to be normally distributed. Thus, Spearman's rank correlation yielded a non-significant result ($\rho = 0.27$, $p = 0.17$). The Spearman test did not detect a statistically significant relationship, but the estimated correlation coefficient suggested a small to moderate positive effect. Since the *p*-value exceeds the threshold for statistical significance of 0.05, the null hypothesis (H_1) cannot be rejected.

3.2 Relationship between Effort (Time spent) and Method Application Quality

The correlation between time spent and method application quality was examined in this study. Both variables were confirmed to be normally distributed. The correlation analysis revealed a high-significant, moderate correlation between effort (time spent) and method application quality ($r = 0.55$, $p = 0.01$**). Therefore, the null hypothesis of H_2 can be rejected, and a moderate effect of effort (time spent) on method application quality is demonstrated.

3.3 Relationship between Effort (Time spent) and Product Concept Quality

The correlation analysis for the relationship between effort (time spent) and product concept quality indicates a non-significant moderate correlation between the two variables ($r = 0.32$, $p = 0.10$). Thus, the null hypothesis (H_3) cannot be rejected, and a statistically significant relationship is not proven.

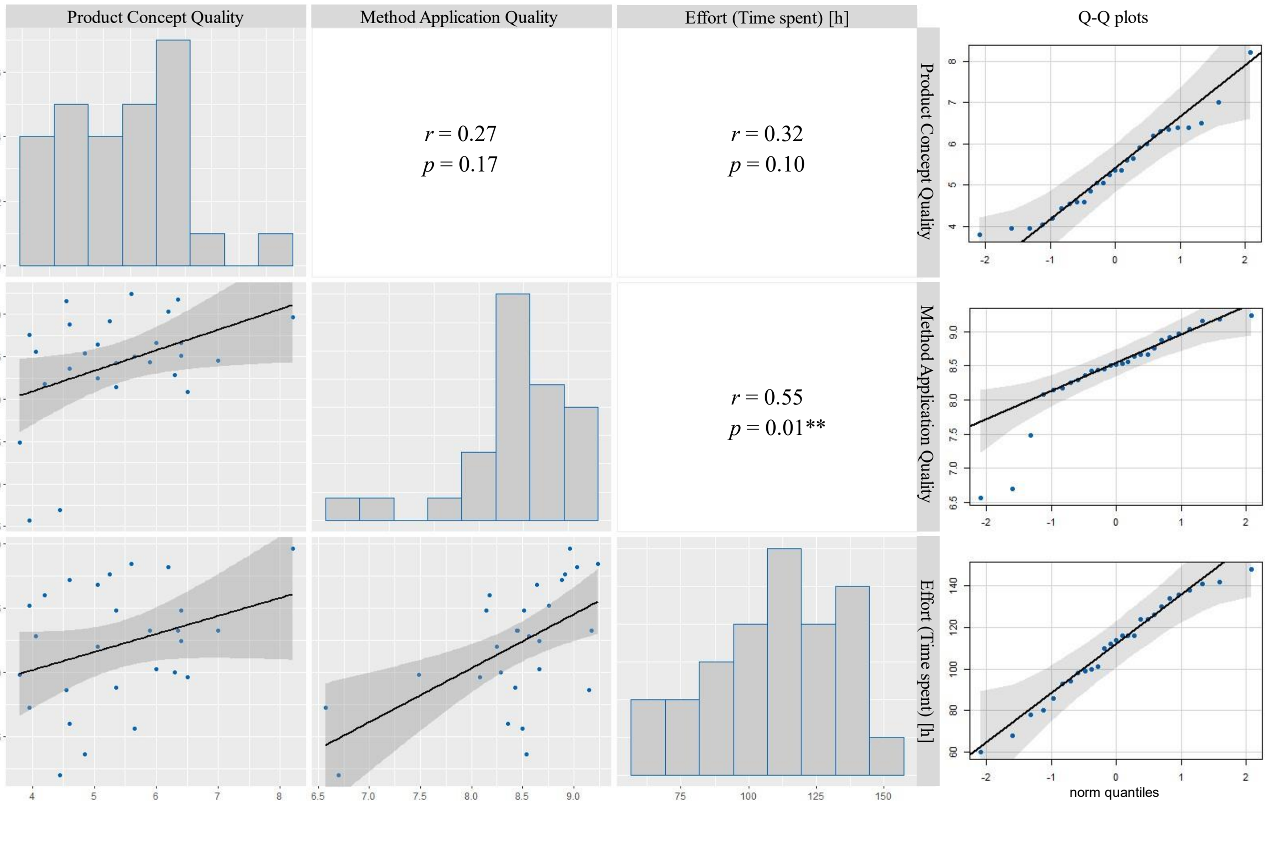

Figure 3. The Shapiro-Wilk normality test visualized as Q-Q plots (right), and the corresponding correlation results (left). All plots show 95 % confidence intervals; scales are dimensionless if otherwise stated.

4 Discussion

4.1 Relationship between Method Application Quality and Product Concept Quality

Spearman’s rank analysis suggests a weak to moderate effect of method application quality on product concept quality ($\rho = 0.27$, $p = 0.17$) but cannot reject the null hypothesis. It is interesting to note that method application quality is not normally distributed: The evaluation of the participants is directly related to assessing method application quality, and normality of the participants' grades is usually expected in education (Taylor, 2021). However, these findings align with recent studies implying that grades may be distributed non-normally (Canale et al., 2016; Kosheleva et al., 2019). The graphical evaluation of the Q-Q plots provides indications of normally distributed data, which could not be confirmed in the Shapiro-Wilk test. Thus, according to Spearman's rank correlation, the null hypothesis cannot be rejected. Nevertheless, indicators of a correlation between the two variables remain since a moderate yet non-significant correlation is shown (Amrhein et al., 2019). This implies the effects of mediators or confounders, which were not considered in this study (Pearl, 2009). Accordingly, this relationship should be re-examined in future studies.

4.2 Relationship between Effort (Time spent) and Method Application Quality

The correlation analysis showed a statistically significant, moderate effect of the effort spent on the method application quality ($r = 0.55$, $p = 0.01$**). This aligns with previous findings regarding the impact of effort on academic achievements (Hagger and Hamilton, 2019; Lee, 2014; Putwain et al., 2019). Thus, it can be stated that the effort involved in methodical product development also correlates with the method application quality in the examined setting. This clear result suggests a transferability to other use cases.

4.3 Relationship between Effort (Time spent) and Product Concept Quality

In contrast to the effort's influence on method application quality, no significant effect on the product concept quality could be demonstrated ($r = 0.32$, $p = 0.10$). However, the moderate correlation can indicate an existing relationship, which could not be proven in this study. This is assumed because of the proven correlation between effort (time spent) and method application, as well as the aforementioned results of similar studies (Hagger and Hamilton, 2019; Lee, 2014; Putwain et al., 2019). The absence of a tangible product might play another role, as studies involving prototyping show effort as a predictor for product success (Batliner et al., 2022; Pacheco et al., 2024). Again, other effects or mediators not considered in this study might have limited the possibility of directly proving this relationship.

4.4 Practical Implications

This study highlights the relevance of PBL for educators and organizations involved in design education. The moderate yet insignificant correlation between method application quality and product concept quality suggests some limitations for a comprehensive understanding of the topics taught. This aligns with Dochy et al. (2003), who show a clear positive effect of PBL on skill acquisition and simultaneously a slightly negative effect on knowledge transfer.

Thus, educators should emphasize imparting skills in PBL, i.e., encouraging students to engage with the material being taught. As shown, providing a PBL environment where students can spend time on their projects significantly improves the quality of their exercise applications. Using formative assessment methods, such as structured supervision, reflection, and cooperative learning during PBL, may improve its educational effectiveness.

Besides, the introduced framework offers a lean opportunity to evaluate the impact of method application on product quality, applicable in both educational and industrial settings. Once applied in further studies, this approach may lead to a better understanding of the mechanics of PBL, allowing for targeted and practical improvement.

4.5 Limitations and Future Research

The study investigated a sample size of 26 teams from a single product development course. This relatively small sample potentially limits the generalizability of the presented results due to sample bias. Thus, caution is advised when extrapolating these findings to other contexts, such as professional working environments or other educational settings. Future studies should incorporate larger and more diverse samples from multiple courses or institutions to enhance generalizability.

Next, jury assessment of product concept quality introduces the potential for individual biases, as industry experts might overestimate their professional background and experiences (Stylidis et al., 2020). This emphasizes the importance of minimizing those biases for future research (Boudier et al., 2023).

Similarly, the evaluation of the effort spent relied on self-assessed data. Since those results may be biased and inaccurate, objective measures such as standardized performance tests should be implemented in future studies (Gustafsson and Borglin, 2013; Shrivastava et al., 2018).

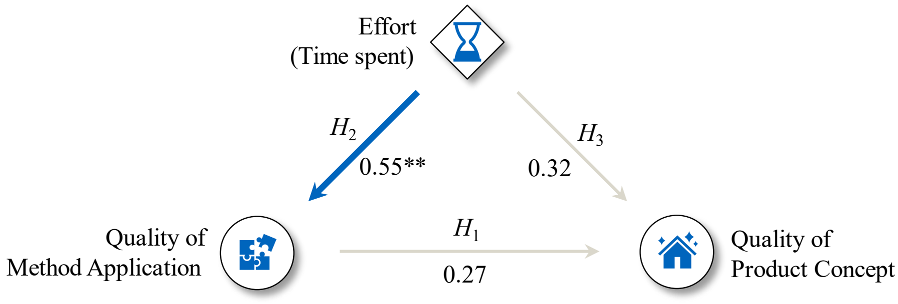

Figure 4. Relations and correlation coefficients of the analyzed variables.

The study focused on the effects of time spent on method application and product concept quality, overlooking potential mediators or confounders (Pearl, 2009). For instance, cultural differences among participating teams were not considered. Given the indicators for the impact of cultural variations in related studies, future research should incorporate these factors (Zhang, 2019). As Schneider and Preckel (2017) suggest, more variables affecting academic achievements exist and should be considered.

The teaching staff was aware of implicit educational biases, especially regarding evaluating the method application quality. However, individual and blind-spot biases cannot be completely ruled out in an educational setting (Boysen and Vogel, 2009; Staats et al., 2017). Thus, the efforts to exclude such biases must be maintained or even exceeded in future studies.

Finally, the study identifies associations between variables but does not establish causation. The presumed linear relationship between effort (time spent), learning effect, and product quality may not fully capture the complexity of these interactions (Pearl, 2009). Future research should explore non-linear relationships and potential moderating or mediating factors to provide a more nuanced understanding of the dynamics involved.

5 Conclusion

This study explored the relationship between method application and product quality within a project-based learning course in higher education. We raised the research question, "What is the relationship between the application of product development methods and the quality of the corresponding product?" and defined the variables effort (time spent), method application quality, and product concept quality. Using methods of empirical statistics, we state a significant, positive, moderate effect of effort spent on method application quality, as seen in Figure 4.

However, the initial research question remains partly unanswered, as no statistically significant correlation was found between the method application quality and product concept quality. Since Spearman's rank correlation states a small to moderate correlation, the existence of an effect is very much possible. Therefore, future research should incorporate other potential moderators and overcome the stated limitations of this study. The same applies to the relationship between effort spent and product concept quality.

While the results of the examined relationships are valid for this study's scope, we acknowledge several limitations. The sample size of 26 teams from a single product development course in higher education raises concerns about generalizability, emphasizing the need for caution when extrapolating findings to other contexts. Additionally, the study recognized potential biases in assessing product concept quality by a jury and suggested further exploration of these biases in future research.

To conclude, this research emphasizes the intricate interplay between method application quality, effort spent, and the resulting product concept quality. We could not show a significant correlation between method application quality and product concept quality; the obvious practical implication is emphasizing a thorough method application for better result quality.

However, this study introduces a lean framework for evaluating methods regarding their effects on product quality. It may be used in an educational or entrepreneurial context to evaluate the effects of product development method application. For example, this framework can be applied in industry as a measure of quality management to find which development approaches potentially have a measurable impact on product quality. This, in turn, enables us to emphasize impactful methods in educating future engineers and designers.

Acknowledgments

We thank all the students who participated and all the teaching assistants who supported and enabled this study.

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