Investigation of the Importance of Quality Criteria in Software Requirements Specifications and the Effect of Specification Revisions on Requirements Quality

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Abstract. Well-crafted requirement specifications contribute to enabling software developers to implement technical solutions quickly and with high quality. The aim is to contribute to the implementation of *good* requirements engineering. As the quality of requirements is particularly dependent on compliance with requirement quality criteria, the importance of these criteria is analyzed in relation to predictive success. An experiment and a survey were conducted for this purpose. Participants in the experiment (n=30) and the survey (n=34) were dual bachelor's students of computer science or business informatics, with the option to skip individual questions. The most important quality criteria identified were *correctness, unambiguity, completeness*, and *comprehensibility.* Moreover, it is possible to improve the quality of requirement specifications in specific quality dimensions through targeted revision. In the course of the RCP/AE experiment, a significant improvement was observed in consistency, correctness, and completeness. Ambiguity was also significantly reduced. Only the improvement in testability was not statistically significant.

Keywords: Requirements Engineering, Requirement Quality Criteria, Requirements Specification Revisions

1 Introduction

For software development to be successful, requirement specifications must be of high quality. In [Kuh25a, p. 5152], it was found that a proper understanding of software requirements is both a challenge and a key competency for developers. Accurate comprehension of requirements is inextricably linked to the quality of the requirements specification. Improving the quality of requirements specifications can reduce the likelihood that the software will not meet customer expectations, which in turn affects the cost-effectiveness of software development [KSP24]. Contradictory, ambiguous, or incorrect requirements specifications can lead to additional effort and financial losses. During the requirements analysis, the Business Analyst must describe the functional requirements with an appropriate level of quality. These quality standards have been specified by IEEE Std. 830-1993 [IEE93] and ISO/IEC/IEEE Std. 29148:2011(E) [ISO11].
This study aims to answer the following research questions:

- **RQ1:** How should the quality criteria for requirement descriptions be prioritized?
- **RQ2:** Does the revision of requirement specifications successfully improve their quality?

Section 2 provides an overview of selected related work. This is followed by an analysis in Section 3, which serves to prepare the answering of the aforementioned research questions. Section 4 presents the methodology through which the results described in 5 were obtained. Section 6 outlines the validity scope of the results. The discussion concludes with a summary and an outlook.

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2 Related Work

To ensure that the effects of a change request are identified and considered, Williams and Carver propose a model for the systematic analysis of requirements [WC07]. This model categorizes changes using a decision tree framework: (1) the motivation is identified, (2) the change is categorized, (3) the effect is classified, (4) relevant attributes are determined, and (5) both functional and non-functional aspects, along with logic and runtime behavior, are documented [WC07]. After this general analysis, a more specialized evaluation of the impact on specific subsets of system elements and their behavior is recommended [WC07]. The systematic collection of detailed change information can improve the quality of impact analysis. The technical report [WC07] focuses on presenting this model, which functions as a reference framework and merits further testing.
Pasham discusses the challenges arising from requirement volatility due to weak specifications [Pas24]. Such specifications often fail to meet IEEE standards, leading to missed quality, time, and cost targets [Pas24]. As a solution, Pasham recommends greater attention to requirements engineering and strict adherence to quality standards [Pas24]. Given that requirement changes are inevitable, developing high-quality specifications helps manage volatility. Pasham recommends that specifications (1) define the software's goal, (2) describe the system context, and (3) include both functional and (4) non-functional requirements [Pas24]. Requirements documents should (I) meet IEEE standards, (II) be designed as living documents, (III) be quality assured, (IV) contain concise and clear definitions, (V) avoid redundancy, and (VI) be described as formally as possible [Pas24]. Considering the developer's perspective when writing requirements can help assess their implementability [Pas24].
Prasetya et al. conduct a literature review of factors influencing *Software Change Requests (SCR)* and approaches to managing them [PPP24]. Their goal is to help software vendors achieve business objectives through better management of SCRs [PPP24]. Reviewing 18 studies, they identify project size, complexity, stakeholder involvement, and the quality of requirements documentation as key influencing factors [PPP24]. They emphasize the importance of a well-structured change management process, especially through the use of change impact analysis to assess the effects of change requests on software components [PPP24, p. 2213].
Prasetya et al. also highlight the challenge of prioritizing change requests [PPP24, p. 2204]. A machine learning-based approach for prioritization is presented by dos Santos et al. [dSdSLP24]. They trained a machine learning model on historical data from 1,441 prioritized change requests [dSdSLP24]. To process the textual data, they standardized capitalization, removed articles and pronouns, and applied regression analysis to identify high-weight keywords for critical requirements [dSdSLP24].

3 Analysis

The standards IEEE Std. 830-1993 [IEE93] and ISO/IEC/IEEE Std. 29148:2011(E) [ISO11] define quality criteria that requirement specifications should meet. Figure 1 summarizes and compares the quality demands of these standards. Hruschka limits his analysis to the ten IEEE criteria, which state that requirements should be *understandable, complete, agreed upon, correct, testable, prioritized, traceable*, and *modifiable* [Hru14, p. 123–125]. Accordingly, the scope is limited to the quality criteria of IEEE Std. 830-1993. In Figure 1, the quality criteria are categorized based on whether they represent domain-specific requirements (blue text) or requirements for the management of requirements (light gray

SRS shoud be...	IEEE Std. 830-1993	ISO/IEC/IEEE 29148:2011(E)
...correct	✓	(✓) (see p. 29)
...unambiguous	✓	✓
...complete	✓	✓
...consistent	✓	✓
...ranked for importance [...]	✓	(✓) (see p. 11)
...verifiable	✓	✓
...modifiable	✓	(✓) (see p. 37 ff.)
...traceable	✓	✓
...comprehensible	(✓) (see p. 10 - 14)	(✓) (see p. 8, 25)
...necessary		✓
...implementation free	(✓) (see p. 5)	✓
...singular		✓
...feasible/affordable		✓
...bounded		✓
...validate	(✓) (see p. 7)	(✓) (see p. 8, 29)

Fig. 1. Overview of quality criteria as requirements for specification documents, differentiated according to the standards IEEE Std. 830-1993 and ISO/IEC/IEEE 29148:2011(E). Content-related requirements are shown in blue, while those serving requirements management are shown in light gray. Own illustration, created with Microsoft© PowerPoint© [Cor19b]

text). The focus is further restricted to those quality criteria that define domain-specific requirements.

4 Method

In the present study, the methods RCP/GP and RCP/AE were applied. These are described in detail below. RCP/GP refers to a survey, while RCP/AE represents an experiment.

4.1 RCP/GP: Evaluation of Requirement Quality Criteria

To address RQ1, the RCP/GP method is applied. Dual bachelor students in computer science and business informatics are asked to prioritize the IEEE quality criteria *unambiguity, consistency, understandability, completeness, agreement, correctness, testability, prioritization, traceability*, and *modifiability*, as limited in Section 3. Each participant assigns a unique numerical value from 1 to 10 to each criterion, where a lower number indicates a higher priority. The Ranking function from [Men] is used for this purpose. The resulting priority is treated as an ordinally scaled variable.
For the evaluation of RCP/GP, the following method is applied:

- **RCP/GP/M1**: Comparison of the priorities of the quality criteria

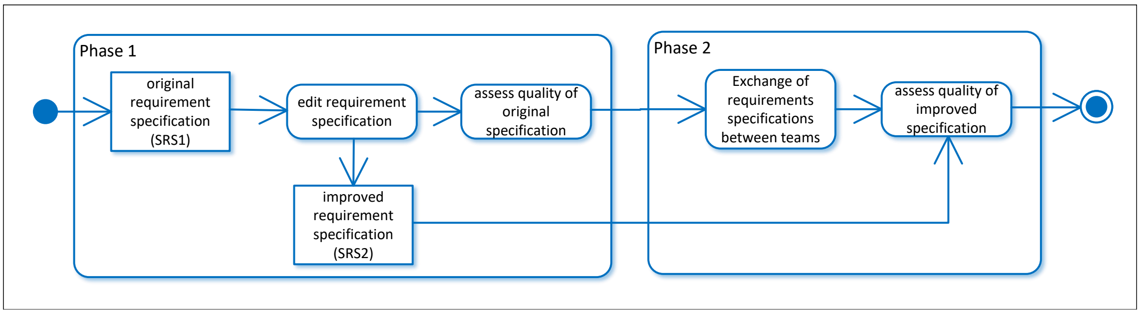

Fig. 2. Overview of the procedure of the RCP/AE experiment. Own illustration, created with Microsoft© Visio© 2021 [Cor21]

A total of 34 individuals participated in the RCP/GP survey. The participants were dual bachelor students in computer science and business informatics. They were asked to prioritize selected quality criteria. Participation was voluntary, so not all criteria were rated by every participant. Participants could skip quality criteria, which led to some criteria being evaluated by fewer individuals. Seven of the ten criteria were rated by 33 participants, while the remaining three were rated by 34. In method RCP/GP/M1, the location measures (minimum, 0.25-quantile ($q_{0.25}$), median, 0.75-quantile ($q_{0.75}$), and upper bound of normal values) are calculated for each criterion and displayed in a box plot. The upper bound of normal values is calculated as $q_{0.75} + \frac{3}{2}(q_{0.75} - q_{0.25})$.

4.2 RCP/AE: Experiment on requirements quality improvement

The research methodology RCP/AE was previously described in [Kuh26]. It is the same experiment referred to as RCP/AE in the aforementioned paper. In the context of this research, specific alternative aspects are examined within the experiment. The following description has therefore been adapted accordingly. Indeed, as described in [Kuh26], the experiment was conducted in three phases. However, since only two phases are relevant in the context of this research, only these will be described below. The RCP/AE experiment was conducted to examine the importance of quality criteria and options for predicting requirement changes. To address research question RQ2, the experiment is described here with a focus on the impact of quality criteria. The procedure is illustrated in Figure 2. Steps not relevant to the research questions discussed here are omitted. Additional results from the same experiment, focusing on the prediction of change requests, are covered in [Kuh26], where further details can be found.

The experiment was conducted in several phases, but only phases 1 and 2 are relevant for answering RQ2. Participants worked in teams. As shown in Figure 2, teams first received an initial requirements specification, which served as the starting point. The contents of this specification (SRS1) are available in [Kuh26], see Figure 5 from [Kuh26]. These specifications lack detail and contain quality deficiencies. Teams were tasked with analyzing and improving the quality of SRS1 and then evaluating SRS1 based on quality criteria. Participants revise the specifications into improved technical specifications (SRS2). At the end of Phase 1, participants evaluate the quality of the original specifications (SRS1). In phase 2, the revised specifications were exchanged between teams and re-evaluated. Based on the initial requirements, Groups I and IV, and Groups II and III exchange their specifications. Each group evaluate the received technical specifications using the quality criteria, see Figure 1. This re-evaluation was performed by other teams using the revised specification (SRS2) as the basis.

A total of 30 individuals participated in the RCP/AE experiment. As in RCP/GP, participants could skip individual questions, so response counts vary by phase and question. Table 1 summarizes the questions and number of responses.

Table 1. Participant Information of the Requirements Experiment

Phase	Assessment	n
Phase 1	unambiguous	28
	consistent	26
	correct	28
	verifiable	28
	complete	28
Phase 2	unambiguous	26
	consistent	26
	correct	26
	verifiable	26
	complete	26

To address the research questions, data from RCP/AE is analyzed using the following methods:

- **RCP/AE/M1**: Analysis of the quality of the requirements shown in Figure 5 and how it develops from Phase 1 to Phase 2
- **RCP/AE/M2**: Analysis of the effectiveness of the requirement revisions
- **RCP/AE/M3**: Analysis of the impact of initial requirement quality on the resulting technical specification
- **RCP/AE/M4**: Analysis of how the manifestation of requirement quality criteria affects prediction success

As part of the RCP/AE/M1 investigation, the arithmetic means of the evaluated quality criteria for the requirements in the requirements and functional specifications are calculated and compared. Calculating the arithmetic mean makes the ratings of different quality criteria comparable. It could be debated whether using the median is preferable to the arithmetic mean. This work uses the arithmetic mean. Whether and to what extent the ratings are manifestations of a ratio-scaled characteristic can be viewed in different ways. A parallel can be drawn to grades, where the same discussion occurs, but the arithmetic mean is typically used to calculate an average grade. The ratings provided here (rankings) are closely comparable to grades. Further correlation analyses are also based on the arithmetic mean.

The effectiveness of the requirement revisions is examined using the RCP/AE/M2 methodology after the data has been prepared. In the data preparation phase for RCP/AE/M2, the ratings of participants who did not assess all quality criteria are excluded. Consequently, RCP/AE/M2 is based on n=26 data sets. The effectiveness of the requirement revisions is then evaluated independently of individual requirements by comparing the mean values and standard deviations for each quality criterion between Phase 1 and Phase 2. As a result, RCP/AE/M2 considers the overall outcome across all requirements. For each quality criterion, average ratings are calculated across all requirements for each phase. In addition, standard deviations for each criterion and phase are computed. Based on a two-tailed hypothesis test, the significance of the changes in quality criteria from Phase 1 to Phase 2 in the overall result is assessed. The evaluation is performed using a significance level of 5%.

The RCP/AE/M3 investigation examines whether the quality of a requirement in the requirements specification influences the quality of the corresponding requirement in the functional specification. To investigate this potential contribution of the initial quality of a requirement to the achievement of result quality, a regression analysis is conducted within RCP/AE/M3. This is based on a comparison of the average evaluations of the quality criteria between the requirements and functional specifications. It should be noted that the quality criteria for the requirements specifications are not assessed by the same participants who evaluate the corresponding functional specifications. Therefore, a direct comparison based on participant-level data is not possible. The aggregation of data based on the average ratings per quality criterion and phase was performed via a database query. Only those data sets with available ratings were automatically included in the calculation of average values per quality criterion and phase.

To examine the influence of requirement quality on forecasting success, a regression analysis is conducted in RCP/AE/M4. The requirement ratings at the end of Phase 2 are compared with the forecasting success of the participants' own team. The requirement ratings in the respective quality criteria are treated as independent variables to explain the development of forecasting success in RCP/AE/P3/2. To analyze the relationship between requirement quality and forecasting success, an ANOVA analysis is conducted using Microsoft© Excel© [Cor19a].

5 Results

This section presents results obtained using the RCP/GP/M1 and RCP/AE/M1-4 methods (see Section 4 for details).

5.1 Analysis of RCP/GP: Priority of Quality Criteria

As outlined in Section 4.1, the analysis of the priorities assigned to the quality criteria of requirements is carried out in RCP/GP/M1 through a comparison of priorities. The depiction in Figure 3 illustrates the location and dispersion measures of the prioritized quality criteria of requirements in the form of a boxplot diagram. With a median of 3, *Correctness* and with a median of 3.5, *Clarity* are prioritized most highly. The median priority for the criteria *Completeness* and *Comprehensibility* is 4. The criteria *Consistency* and *Modifiability* have a median of 5. *Testability* is prioritized with a median of 6. The criteria *Alignment* and *Traceability* have a median of 7. The importance of the criterion *Prioritization* is rated the lowest, with a median of 8.

5.2 Analysis of RCP/AE: Insights from the Experiment on Requirements Quality

The procedure of the RCP/AE requirements experiment and the methods applied for investigation are described in Section 4.2. In RCP/AE/M1, the development of the quality of the requirement specifications is examined. Figure 4 illustrates the different evaluations of the specification requirement (P1) compared to the functional specification requirement (P2), differentiated by quality criteria and by requirement, as defined in Table 5. The 3D diagram clearly shows that, overall (rows labeled with total), the quality of the functional specification (P2) was rated higher than the requirement specification (P1). However, when examining individual requirements, it becomes evident that the quality of the functional specification requirement is not always rated higher. For example, the completeness or clarity of functional specification requirements in the domain Sales Planning were rated lower than their corresponding requirement specification. Within the scope of RCP/AE/M2, a further investigation of the effectiveness of the requirement revisions is necessary.

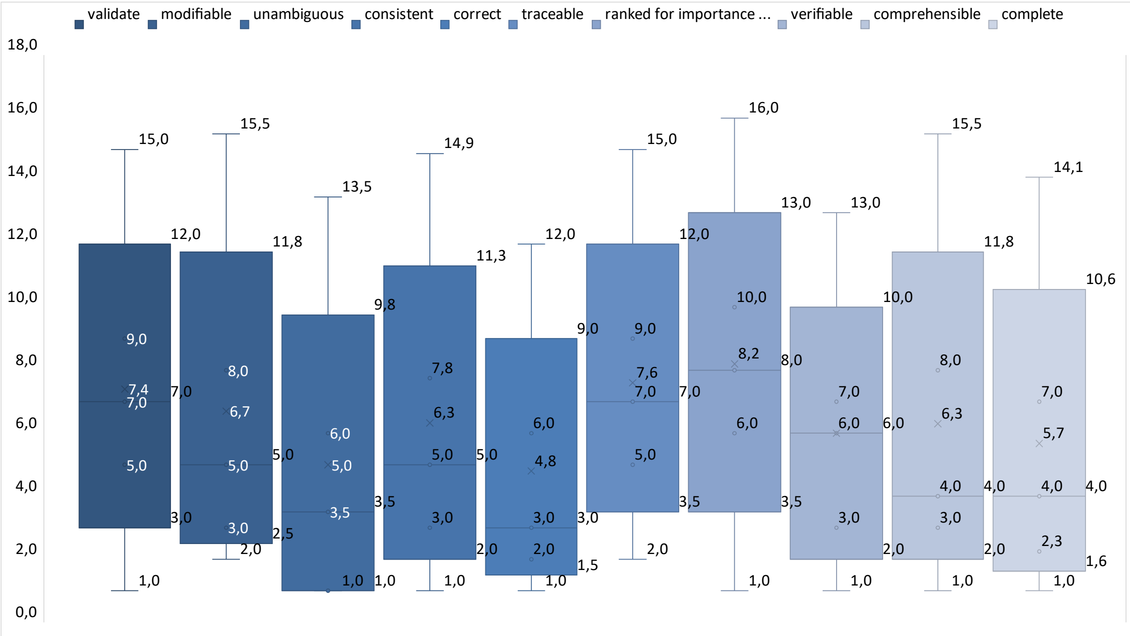

Fig. 3. Measures of dispersion and central tendency of the prioritizations of requirement quality criteria. Own illustration, created with Microsoft© Excel© [Cor19a] and Microsoft© PowerPoint© [Cor19b]

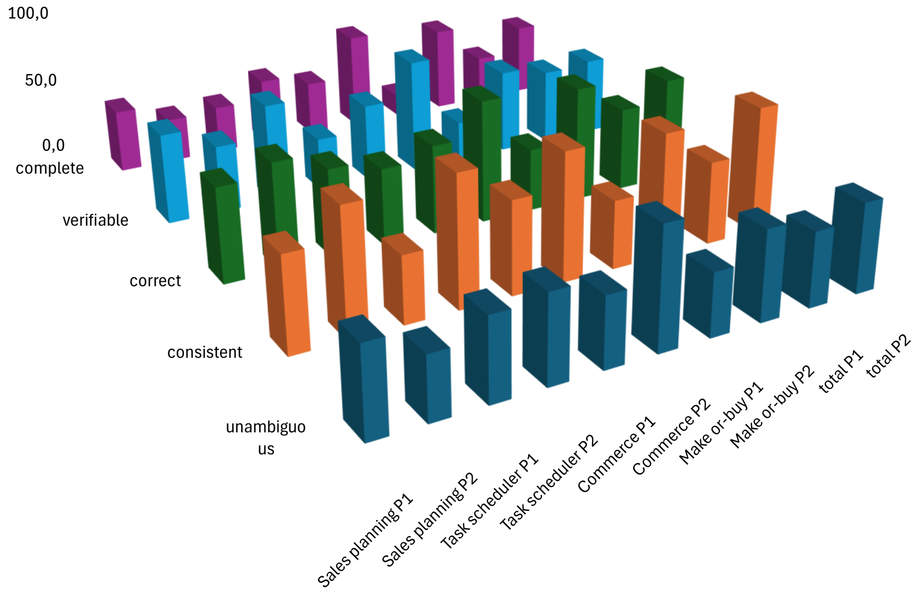

Fig. 4. Comparison of the requirement quality between specifications and functional requirements, differentiated by criteria and individual requirements. Own illustration, created with Microsoft© Excel© [Cor19a] and Microsoft© PowerPoint© [Cor19b]

Figure 6 presents, across all requirements, the overall results of revising the requirement specifications to create functional specifications. The Before revision data reflect the av-

Domain	Requirement
I) Commerce	Development of a price calculator (gross price based on the net purchase price, value-added tax rate, and a desired profit margin).
II) Task scheduler	Development of a program that enables scheduling for a task list under sequential processing.
III) Sales planning	Development of a program that calculates the break-even quantity based on variable unit costs and total fixed costs, indicating the sales volume at which production becomes cost-effective.
IV) Make-or-buy	Development of a program that supports make-or-buy decisions.

Fig. 5. Overview of the initial requirement specifications, serving as the starting point of the experiment. Already published in [Kuh26]. Illustration, created with Microsoft© PowerPoint©[Cor19b]

erage quality assessments of the requirement specification, while the After revision data represent the average assessments of the functional specification. It is evident that the functional specification is consistently rated as higher in quality. The greatest improvements were found in the criteria *Consistency* (+29.4%), *Completeness* (+17.3%), and *Correctness* (+14.7%). The smallest improvement was observed in *Testability* (+3.7%).

In line with Section 4.2 regarding RCP/AE/M2, a significance analysis was conducted to evaluate the effectiveness of requirement revisions. Figure 7 presents the results of this analysis, as well as the location and dispersion measures per quality criterion and phase. As anticipated from Figure 6, a statistically significant improvement in the quality of the functional specification over the requirement specification was found for nearly all criteria ($\alpha = 5\%$). Only the improvement in *Testability* was not statistically significant.

In RCP/AE/M3, the influence of the initial quality of requirements on the result of a revision was examined. Separate regression analyses were performed to assess whether the initial quality scores for each criterion in the requirement specification could explain the corresponding quality in the functional specification. The results, summarized in Table 2, indicate that no statistically significant correlations were identified at a 5% significance level.

An additional regression analysis was conducted in RCP/AE/M4 to determine whether quality characteristics such as *Clarity, Consistency, Correctness, Testability*, and *Completeness* influence the accuracy of change requirement predictions. As described in Section 4.2, a 5% significance level was applied. The analysis found no statistically significant influence of any individual quality criterion on prediction success. The resulting t-statistics for the multivariate regression were: -0.96 for *Clarity*, -0.14 for *Consistency*, -1.12 for *Correctness*, -0.23 for *Testability*, and 0.51 for *Completeness*.

6 Threats to Validity

The findings presented here are limited in their significance due to the small number of participants. The number of individuals who took part in the experiment or survey does not allow for conclusions that can be regarded as universally valid. Consequently, these findings

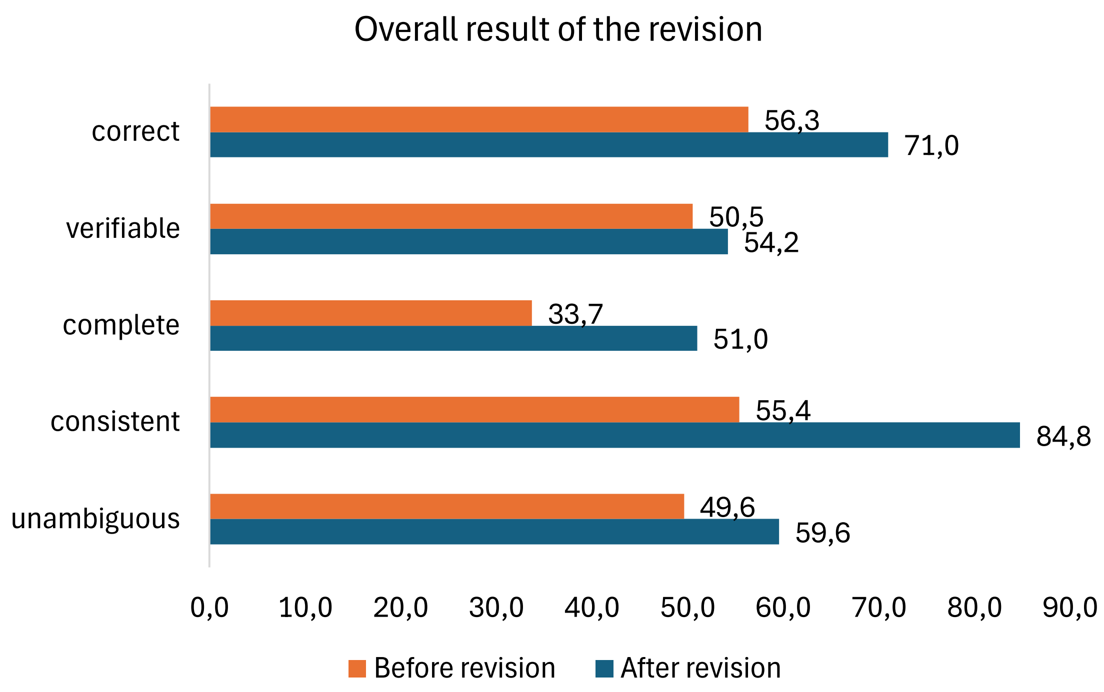

Fig. 6. Overall result of the success of the requirements revision. Own illustration, created with Microsoft© Excel© [Cor19a] and Microsoft© PowerPoint© [Cor19b]

Criterion	Phase 1	Phase 2	Assessment
unambiguous	$\bar{x}$ =49,62; s = 19,51	$\bar{x}$ = 59,58; s = 30,14	significant improvement
consistent	$\bar{x}$ = 55,42 ; s = 28,35	$\bar{x}$ = 84,77; s = 20,10	significant improvement
complete	$\bar{x}$ = 33,73; s = 24,95	$\bar{x}$ = 51,00; s = 32,68	significant improvement
verifiable	$\bar{x}$ = 50,54; s = 29,27	$\bar{x}$ = 54,19; s = 35,06	no significant improvement
correct	$\bar{x}$ = 56,35; s = 25,18	$\bar{x}$ = 70,96; s = 29,41	significant improvement

Fig. 7. Significance analysis of the changes in requirement quality criteria from the specification document compared to the functional specification. Own illustration, created with Microsoft© Excel© [Cor19a] and Microsoft© PowerPoint© [Cor19b]

Table 2. Investigation of the Contribution of Initial Requirement Quality to the Achievement of Outcome Quality. Calculated with Microsoft© Excel© [Cor19a]

Criterion	t-Statistik	adj. R^2
unambiguous	-0.87058	-0.70658
consistent	-0.05646	-1.99047
complete	-0.57978	-1.24527
verifiable	-0.47377	-1.45006
correct	-0.28605	-1.77309

should be considered only as initial indications. It should also be noted that, in any case, the results must be verified before practical application. For example, it is necessary to determine whether there are specific circumstances in the respective area of consideration (such as within a particular company or domain) that need to be taken into account.
The evaluation of the IEEE quality criteria conducted as part of RCP/GP (cf. [IEE93] [ISO11] & [Hru14, p. 123–125]) was carried out in general terms in the present work. In this regard, it should be noted that an assessment of the same quality criteria, as undertaken during RCP/AE, is normally conducted in the context of a functional requirement. The evaluation of quality criteria independent of requirements is possible; however, a general statement may need to be revalidated when applied to specific matters in the context of the respective requirement. For instance, it can generally be assumed that the assessment derived from RCP/GP, according to which the *Correctness* of requirement specifications holds the highest priority, must be accurate. However, the assessment of the importance that requirement specifications must be modifiable may be prioritized differently depending on the context. It can be assumed, for example, that the necessity to modify requirement specifications is not equally weighted in all projects, which also affects the priority of this quality criterion.

7 Conclusion

This study has examined the importance of quality criteria that must be fulfilled by requirements specifications (RQ1).
Regarding RQ1, the priorities of quality criteria for requirements specifications were identified in a survey conducted as part of RCP/GP. The assessments were provided by dual-study bachelor students with programming experience. The criteria identified as most important for requirements specifications were *correctness*, *unambiguity*, *completeness*, and *comprehensibility*.
Within the framework of the RCP/AE experiment, relationships concerning the quality of requirements specifications were also examined. The application of RCP/AE/M2 demonstrated that the targeted revision of a requirement can improve the quality of its specification in terms of *unambiguity*, *consistency*, *completeness*, and *correctness*. In the course of the regression analysis RCP/AE/M3, it was investigated whether the quality of the initial requirements (requirements specification) influences the quality of the derived requirements (functional specification). The results showed no evidence that the initial quality has a significant impact on the quality of the revised requirement specification. Consequently, even poor requirements specifications can be improved.
Using the RCP/AE study data (following RQ1), it was evaluated whether the quality of a requirements specification influences the success of predicting change requests. Although the regression analysis RCP/AE/M4 could not demonstrate that the quality of a requirements specification has a significant influence on the success of predicting potential change requests, this does not mean that the typical positive effects of high-quality specifications do not occur.
The insights gained from this study cannot be considered universally valid due to the small scope of the investigation. For subsequent research building on this work, it would be advisable to expand the survey and experiment to include more participants. By repeating the methodologies with a larger number of participants, it could be determined whether the findings presented here are generally applicable. Furthermore, it would be beneficial to examine the contribution of specific requirements engineering approaches with regard to their effect on the quality of requirements specifications. For example, the study in [Kuh25b, p.

4964 – 4967] showed that goal process analyses are conducted for goal definition. It would be worthwhile to investigate, for instance, whether the quality of requirements specifications is positively influenced by conducting goal process analyses. Furthermore, it should also be examined how the quality criteria are applied in the context of the documentation of the 3D model [KS23b] as part of the presented reference model. It would also be worth investigating whether the use of platforms that support communication and collaboration in requirements engineering within software engineering [Kuh24] influences the importance of quality criteria. Further insights could be gained by examining the effect of quality attributes as quality-related factors (QRFs) [KS23a] in the context of a simulation.

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