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Preliminary Study to Empirically Investigate the Comprehensibility of Requirements Specifications

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Abstract. This paper presents a pilot study to test plans for an empirical study, which will compare the comprehensibility of two specifications: a formal specification and an informal specification. The two documents used in the pilot study implemented the same logic, namely a portion of the Irish Electoral system. The "informal specification" was taken directly from the legal definition of the count rules for Irish elections. A formal requirements specification language was not employed for the pilot study. In place of a formal requirements specification language, the java programming language was used. Our main motivation for using the java programming language is based on an empirical study carried out in [19].

1. Introduction

There is a common perception in the requirements engineering community that formal specifications are more difficult to comprehend than informal specifications. This is often cited as one of the reasons why formal methods are not used more often. It appears however, that little or no empirical evidence exists to substantiate this claim.

Informal specifications, i.e. specifications written in natural language, are the most common and widely accepted approach to specifying requirements [23]. Many people have concluded that requirements specifications written using informal notations result in a common model, comprehensible by a general audience, which helps to enhance communication among all parties involved. In essence, informal specifications are seen as being easier to comprehend than formal specifications [23].

Formal methods provide developers with the facility to work at a level of abstraction independent of the implementation of the system [14, 6, 7]. They claim to help engineers focus on what a system should accomplish instead of how it should accomplish it [12]. In [8] a formal method is defined as:

“A set of tools and notations (with a formal semantics) used to specify unambiguously the requirements of a computer system that supports the proof of properties of that specification and proofs of correctness of an eventual implementation with respect to that specification”

"Formal semantics" implies that such a method has a sound mathematical base [14]. Thus, Formal methods help avoid the ambiguity inherent in natural language [9, 13]. They allow for systems to be specified, developed and verified in a systematic manner [14, 13, 7]. Formal methods allow increased precision in a specification, allowing consistency and correctness to be obtained [14, 12], which results in the reduction of the possibility of errors that creep in during software development [8, 6, 17].

Most advocates of formal methods would agree that formal methods should be applied to systems where the issue of correctness is a concern. While safety and security critical systems fall into this category, there are a number of other systems that are not classified in these terms and could equally benefit from the application of formal methods [8]. One of these is the single transferable voting system, as it is required by society to have the highest level of integrity [11]. The electorate must have absolute confidence in the use of a computerized voting system, in a similar manner to that of a safety critical application [11]. An example of where formal methods have been applied to the STV system can be found in [11] where a number of ambiguities were uncovered in the informal specification.

Despite the many advantages that formal methods can offer to certain projects and systems, they have not been "universally embraced" [6]. In [24] it is observed, "While formal methods are being applied to hardware in industry, the results of formal methods research for software has only rarely reached beyond the research lab and used in industrial practice for day-to-day software development".

One of the key factors associated with this widespread lack of adoption is that formal notations are perceived as being difficult to comprehend and that highly trained mathematicians are required to read them. However, this common perception is disputed by practitioners Snook and Harrison [19].

It is true that non-computer specialists may find formal methods difficult to understand and a certain amount of training is required. However, there is no general consensus on the amount of training involved. For example in [9] and [24] it is merely suggested that a long time is required to learn them. On the other hand in [3] they make the claim that "After a weeks training in formal specifications, engineers can use it in their work".

1.1 Related Work

Sobel and Clarkson [20] carried out an empirical study to investigate the integration of formal methods into an undergraduate software engineering curriculum under

which the evaluation was given over a three-year educational program. Two groups of mostly two-person teams were asked to develop running programs to meet the requirements of a given problem. One group developed formal specifications and the other did not. It resulted that the group that had received training in formal methods and developed the formal specifications developed better software than those who had not taken the training in formal methods. Many criticisms of the experiment were expressed by Berry [2], due to lack of control, and poor measurement. They suggest that the experiment suffered weaknesses in that students were given the choice of whether to sign up to the formal methods course or not. This hints that the students that signed up to the formal methods course were more motivated to begin with than those who did not.

Other experiments have been conducted investigating the comprehensibility of formal specifications due to their structure such as in [5]. One of the hypotheses tested was that "comprehensibility is not improved as a result of the modularization of a Z specification". This hypothesis was rejected suggesting that structural presentation of a formal specification has an effect on its comprehensibility.

Despite the existence of these experiments, little or no empirical evidence exists to suggest that informal methods are easier to comprehend than formal methods, although it is a common perception in industry. It is fair to argue that empirical evidence to support a common view should not be taken for granted, no matter how popular [5]. For example, in 1989 Scanlan carried out a study where the popular myth that pseudocode was superior to flowcharts as a means of documenting algorithms was debunked. The study showed that people performed better with flowcharts than with pseudocode [18].

The objective of this empirical study was to carry out a pilot study for testing plans for further, more comprehensive, evaluations, which aim to answer the following question:

Which is easier to comprehend, formal methods or informal methods?

The purpose of a pilot study is to assess the viability of an experimental plan before embarking on the real study [16]. Pilot studies help to identify potential problems in advance so that they can be corrected [16]. The experimental procedure, the materials to be employed and the specified timing were just a few things we assessed.

2. Experimental Design

The experiment was a one-way independent between-participants design and was conducted in the University of Limerick, Ireland.

2.1 Materials

Part of the legal document [10] that specifies the transfer of surplus rules for the Irish Electoral system which is founded upon the STV system [22] was employed as the informal specification. The authors realize that legal language is not representative of all informal specifications. Legal language was developed to prevent misinterpretation of law, and thus tries to avoid ambiguities that can exist in normal everyday wording [6]. Thus, the legal document can be regarded as a thoroughly reviewed comprehensive document written using unambiguous structured natural language. The size of the legal specification, and its context as a real-life electoral system, provided a realistic subject for the experiment.

Moreover, our decision to employ this legal specification transpired from the rejection, in April 2004, of an electronic voting system developed for the Irish Electoral system. Its rejection was based on reservations expressed by the Software Engineering and other communities on the accuracy and integrity of the software [15]. Underlying such concerns is the fact that no formal methods were used in the development of the system. One of the reforms proposed by opposing politicians to ensure the reliability of the voting system was the "use of Formal Methods to ensure that the software used in both the election machines and in the vote counting is totally reliable"[15].

Due to the pilot nature of this experiment and due to time constraints, we did not use a formal requirements specification. Also, it wasn't possible to find an adequate number of participants who were familiar with one common formal specification language. In place of a formal specification language, we used the java programming language. Our main motivation for using the java programming language is based on an empirical study carried out in [19]. In this experiment, they set out to test the hypothesis that "formal specifications are no more difficult to understand than code". They carried this experiment out on the basis that because practitioners have a reasonably good intuitive feel for the comprehension of code, a quantified comparison will therefore transfer this feeling to formal specifications. They compared the comprehension of a Z specification with that of its implementation in java code. Their results indicated that there is little difference in the comprehensibility between the two.

A glossary of expressions provided definitions of some of the terms used in both the legal and java documents. This was necessary, as some of the expressions used in the legal document and the java document may have been unfamiliar to the participants. The glossary was identical for both groups.

A questionnaire was used to test comprehensibility. It consisted of seven realistic scenarios, and ten multiple-choice questions that were devised based on the legal and java documents.

The materials are available for viewing at [25].

2.2 Participants

Eight participants took part in the experiment on a voluntary basis. The participants were all software engineering Masters or PhD students. All participants had received honors undergraduate degrees in either computers systems or information technology. They were all aged between twenty and twenty-five, and had roughly the same experience with requirements specifications and java programming.

2.3 Experimental Procedure

Each participant was randomly assigned to one of two groups, which will be referred to as the legal group and the java group hereafter. Both groups consisted if 4 participants each. Each participant was given a package consisting of an experimental procedure booklet, a warm-up questionnaire, and the questionnaire under review.

Firstly, the participants were instructed to perform a warm-up task in order to familiarize them with the type of material and the type of questions they would be asked in the main task. They were then given a distracter task to carry out over a five-minute period.

For the main task, each participant was instructed to read a document (a java document or a legal document) on a computer screen over a ten-minute period. After that ten-minute period they were instructed to answer the questionnaire, but were allowed to look at the document on the computer screen at the same time. They were given fifty minutes to answer the questionnaire.

In addition to this, two participants, one from the legal group and one from the java group were randomly selected, and asked to perform talk-aloud while answering the questionnaires. Dictaphones were used to record the talk aloud data. The aim of this talk-aloud data was to find qualitative information to support their responses to the questions.

2.4 Controls

The experiment took place in a controlled environment in an attempt to limit any confounding factors. Participants were not permitted to leave the room or talk to each other for the duration of the experiment. The two participants selected to perform talkaloud were put into two different rooms in order to limit noise effects.

3. Threats to Validity

The main threat to the validity of the experiment has its roots in the participants' familiarity with the Irish electoral system. A series of questions were included to try to

gauge this familiarity. The questions covered the participants voting practices and how familiar they perceived themselves to be with the Irish Electoral system.

The size of the two different documents given to the groups is another factor that may have affected the results of the experiment. The legal document was considerably shorter than the java document. Also, as mentioned above, the java document actually consisted of six different documents, which meant that the java group would have had the drawback of having to switch between documents on screen.

Due to time constraints, the one supervisor was not used for all participants. One person supervised the six participants who were not selected to perform talkaloud. Two supervisors were allocated to those doing talkaloud. Each supervisor received the same instructions prior to the experiment. An improvement on this would be to conduct a supervisor-training course and to provide supervisors with a supervisor procedure booklet containing guidelines on the experimental protocol.

4. Quantitative Data Analysis

The supervisors noted the time it took for each participant to read the specifications and answer the questionnaires. Because the questionnaires consisted of multiple-choice questions only, the marking criteria were very straightforward. For every correct answer a mark of one was given, otherwise no mark was given. The marks were then added up and each participant's score was noted.

The talk-aloud data was transcribed and then analyzed by looking for common trends running throughout the data. Comments associated with particular emotions were documented, in order to give an insight into the participants' reaction to particular questions. The time taken to answer each question was also documented in order to observe the participants commitment to the questions. The results of this were used to support the quantitative data obtained from the questionnaires.

4.1 Concretization of Hypothesis

With regard to the research question presented in section 1.1, it is difficult to quantify the meaning of "easier". In this experiment, "easy" is a measure of the number of correct answers each participant received denoted by a score. Following the classical null hypothesis statistical testing process, the reformulated hypothesis states:

H_{01} : The scores obtained by the Java group are identical to the scores obtained by the Legal group.

The alternative hypothesis states:

H_{a1} : There is a significant difference in the scores obtained by the Legal group and the Java group.

The experimental hypothesis here is two-tailed, that is, we have not predicted the direction of the difference.

In addition to this, we also looked at the rate achieved by each participant where rate is the time it took each participant to answer each question divided by their score.
The null hypothesis states:

H_{02} : The rates obtained by the Java group are identical to the rates obtained by the Legal group.

The alternative hypothesis states:

H_{a2} : There is a significant difference in the rates obtained by the Legal group and the Java group.

4.2 Variables

The independent variable is the notation (Java code or legal language) used for the description. Two dependent variables were analyzed. Firstly the score which is the sum of correct answers obtained by each participant. Secondly the rate of scoring was found by dividing the time taken by the score. This was used as an alternative measure of comprehension.

4.3 Method of Analysis

In deciding which statistical analysis test to carry out on the data, we first needed to check if the data was normal. A good indication of telling whether data is normally distributed can be found by observing histograms of the data displaying the normal curve [4]. In SPSS (Statistical Package for the Social Sciences) [21] we generated histograms with normal curves for the dependant variables. The result for the scores is illustrated in Fig. 1. The result for the rates is illustrated in Fig. 2. From these we can see that the data is not normally distributed.

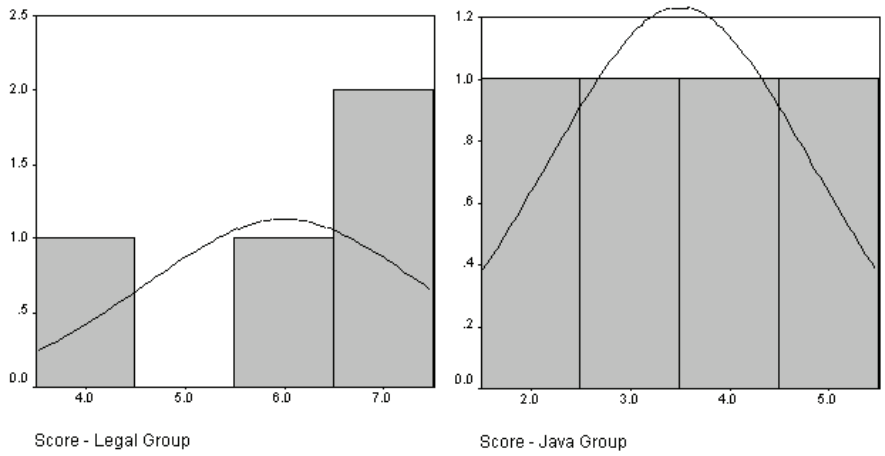

Fig. 1.

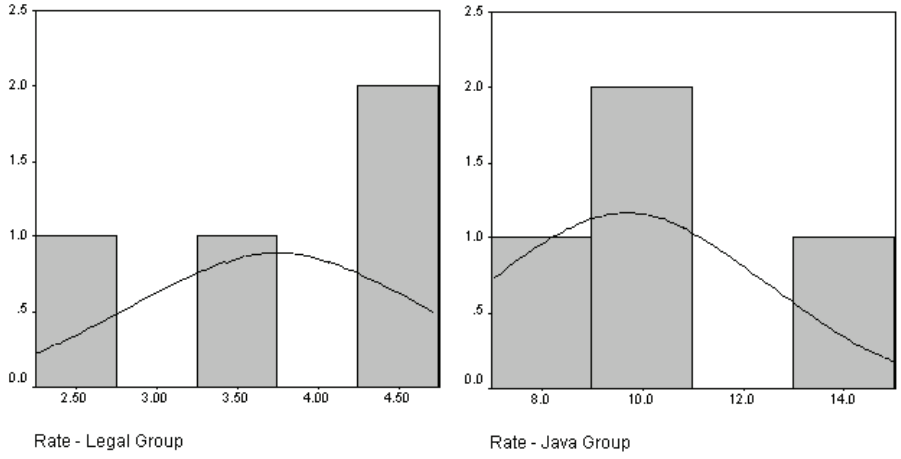

Fig. 2.

4.4 Testing the Hypothesis

In order to test the hypotheses, the Mann-Whitney-Wilcoxon test was considered to be the most suitable. The objective of the Mann-Whitney-Wilcoxon test is to determine whether there is a difference between two populations [1]. The samples of the populations that are used are independent of each other. There is no assumption made that both populations are normally distributed [1]. It is based on ranking the combined

data from two samples from low to high. The test is ideal for this experiment for two reasons:

- The data was not normally distributed
- The test accommodates for small sample sizes (i.e. less than 10) from both populations. The sample sizes from this experiment were 4 from both populations

4.4.1 Testing the Scores

Firstly, the median from each group was examined. The median for the Legal group was 6.5 and the median for the Java group was 3.5. Thus the Legal group got higher scores than the Java group.

The value of the test statistic, in this case the Mann Whitney (generated using SPSS) is 1.5, with an associated probability of 0.58. Because the significance value is greater than 0.05, the null hypothesis H_{01} cannot be rejected, and we cannot draw any statistical significance from this result.

4.4.2 Testing the Rates

Firstly, the median from each group was examined. The median for the Legal group was 4 and the median for the Java group was 9.13. Thus the Java group got higher rates than the Legal group. Because "rate" is a measure of time divided by score, the lower the rate the better. Therefore the Legal group got better rates than the Java group.

The value of the test statistic, in this case the Mann Whitney (generated using SPSS) is 0.0, with an associated probability of 0.021. Because the significance value is less than 0.05, the null hypothesis H_{02} was rejected. Therefore, the rates obtained by the Legal group were significantly better than the rates obtained by the Java group.

5. Qualitative Data Analysis

Talkaloud data collected from two participants (one from the java group and one from the legal group) were analyzed to provide qualitative data to support the quantitative data obtained in section 4. The data was transcribed and then inspected for words and behaviours relating to certain emotions that were recorded in a lexicon. The lexicon included words that were apparent to a particular emotion, sighing and heavy breathing, and long pauses.

5.1 Legal Group Participant

The general emotions expressed by this participant were ones of confusion and frustration throughout answering the questionnaire. The participant completed the questionnaire in just ten minutes achieving an overall score of four, even though fifty minutes were allocated to this task. This suggests that the participant was extremely frustrated with the legal document. It also suggests that the participant was not very motivated in finding the correct answers. The reactions of the participant and the time it took to answer each question are illustrated in Table 1.

Table 1.

Question	Reaction	Time (minutes. seconds)	Correct
1	Strong certainty	0.15	Yes
2	Strong confusion	0.57	No
3	Confusion	1.07	No
4	Strong confusion Frustration	0.43	No
5	Strong frustration Strong confusion Difficulty	2.10	No
6	Frustration	0.05	No
7	Frustration Uncertainty	0.50	No
8	Confusion	0.53	Yes
9	Confusion	0.26	Yes
10	Strong certainty	0.37	Yes

Note: The general reaction has been preceded with the word strong in places where the reactions are powerfully conveyed.

From this we can see which questions the participant had the most difficulties and we can use this to infer the parts of the legal document the participant had most difficulty in comprehending. Certain comments the participant made such as "anyway I can't read lawyer English", suggest that the participant had difficulty in comprehending the legal document.

5.2 Java Group Participant

Again, the general emotions expressed here were ones confusion and frustration. This participant was much more expressive than the participant from the legal group, and was clearly more motivated. After answering the questionnaire, the participant rechecked it. It took the participant thirty-seven minutes to complete the questionnaire, achieving a score of four. The reactions of the participant and the time it took to answer each question are illustrated in the table below.

Table 2.

Question	Reaction	Time (minute. seconds)	Correct
1	Certainty	1.40	Yes
2	Strong confusion	4.08	No
3	Strong confusion Strong frustration Certainty	11.27	Yes
4	Strong confusion Certainty	3.23	Yes
5	Certainty	0.06	No
6	Certainty	0.50	Yes
7	Frustration Confusion Certainty	2.18	No
8	Strong confusion Strong frustration Strong difficulty Strong uncertainty	7.28	No
9	Frustration Confusion	1.55	No
10	Frustration Confusion	2.52	No

Note: The general reaction has been preceded with the word strong in places where the reactions are powerfully conveyed.

From Table 2 we can see that the participant was generally very confused when answering the questionnaire. There were places where a positive reactions were observed, particularly when deciding on a final answer. In some places, this was partially due to the length of time the participant spent on finding the answer. For every correct answer, the participant expressed a level of certainty. This reveals that certain parts of the java document, although time consuming and sometimes confusing, could be clear enough to find to correct answer.

If we compare Table 1 and Table 2, we see that there is just one correct question, which both participants had in common. This is interesting as it gives us a faint indication of the strong areas of each document. For example, if we look at question ten in both tables, we can see that the participant from the legal group expressed strong certainty, and got the answer correct. However, the participant from the java group expressed frustration and confusion and did not get the answer correct. Likewise, for question four, the participant from the java group expressed strong confusion fol-

lowed by certainty and got the answer correct. The participant from the legal group expressed strong confusion and frustration and did not get the answer correct.

The participant from the java group expressed overall, much more confusion, frustration and difficulty. This finding gives us an indication of why the H_a was accepted above, the rates obtained when using the legal document are better than the rates obtained when using the java document.

6. Conclusion and future work

We are careful not to draw any firm conclusions from the analysis results, due to the pilot nature of this experiment. Given a larger number of participants, we anticipate that much stronger conclusions could be reached, but inevitable variations and interpretation of both questions and answers resulting from such small sample sizes diminish our confidence in the results.

This is not to say however that the analysis results are worthless. The results give us several indications and inclinations in favour of the Legal document. The time it took participants to complete the questionnaires is of particular interest, whereby the legal group completed the questionnaires in less time than the java group. Many influencing attributes could be at blame for the differences in the times, structure being the most dominant which comprehensibility might have been affected by. The java document could have been structured in many ways. In an attempt to avoid the introduction of un-quantifiable influences we structured it as in line as possible with its legal counterpart. However, due to time constraints, it wasn't possible to conduct a thorough review of the java document. In future experiments all documents will be thoroughly reviewed.

For the next experiment, which will not be a pilot study, we plan to specify the legal rules for the voting system using formal methods. Thus the words used should conform more so than the java to the words used in the legal document.

The results of testing the rate in section 4.4.2 indicate that we should accept the abstract hypothesis that "The legal document is easier to comprehend than the java document". Again, we do not claim that these results are conclusive. Further, more comprehensive, experiments must be conducted before we can make any claims about our results.

The talkaloud data proved very beneficial in observing the participants reactions to particular questions. We cannot make any claims that this data provides us with an explanation as to why the null hypothesis was rejected in section 4.4.2 because the participants concerned seemed to have different levels of motivation, but it does suggest that the participant from the java group was much more confused than the participant from the legal group. Again a larger number of participants will be employed for this section of the study in future experiments to provide us with more definitive

results and conclusions. Also, because the talk-aloud data was captured while the participants answered the questionnaire, we could not be sure if signs of confusion or frustration were due to miscomprehension of the documents, or miscomprehension of the questions being asked. To avoid uncertainty, talk aloud data will be captured from when the participants start reading the document, right through till the questionnaire is completed. Also, participants will be asked to notify the supervisor if they have difficulty understanding anything in the questionnaire.

The most important aspect of this pilot experiment was that it helped us identify a number of holes in the experiment, which would not have been identified otherwise. In particular, we found that the experiment procedure booklet presented to all participants should have been more explicit about the materials that could be accessed at each stage of the experiment. For example, during the experiment, many participants asked whether they were allowed to look at the documents whilst answering the questionnaire.

We also intend to conduct a training course for supervisors in future experiments to ensure that they know their exact roles. In addition to this, they will be provided with a supervisor procedure booklet that they should consult while supervising the experiment. This should improve consistency between supervisors lessening any threats to the validity of the experiment.

Because all participants completed the questionnaire with significant time still available, the timing will need to be adjusted when conducting future experiments. In the time designated for the experiment, we should therefore be able to include more questions in the questionnaire, and conduct a pre-examination of the participants' familiarity with the Irish electoral system.

Another interesting research question, which could be integrated into future experiments, is the question of ambiguity in requirements documents. After each question the participants will be asked to indicate how certain they are that the preceding answer in correct, on a scale of 1 to 5. In cases where high confidence is expressed and the answer is wrong, ambiguity is suggested, especially where more than 50% of the group select the same answer.

In future experiments, we will need an indication of whether participants' answers are based on reading the specification or not, as prior knowledge was a possibility in this experiment. After each question the participants will be asked
Is your answer based on:

A. A hunch
B. Previous knowledge
C. Common sense
D. Reading the specification
E. Reading the glossary

By selecting the answers based on reading the specification, we will be confident that we are evaluating the specification itself and not any external factor.

In addition to this, a “Don’t know” option will be included after each question. We can then use the number of “don’t knows” each participant selected as a contributing measure of comprehensibility.

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