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Information visualization of metacognitive skills during the software development process based on an adapted engineering design metacognitive questionnaire

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Abstract. In software development, either alone or in a team, there are many aspects that determine the success in developing the software, including each developer's skills. Studies show that the application of metacognition can increase the effectiveness and efficiency of software development. To measure a metacognition skill, there need to be a metacognition measurement tools. One example of this measurement method is adapted engineering design metacognitive questionnaire. However, the respondents feel that existing tools still have not given them any benefits. This research is conducted to develop an information visualization tools for the metacognition measurement from an adapted engineering design metacognitive questionnaire. The research was performed using qualitative method adapted from the user-centered design approach, which is user requirement analysis, design alternatives, prototyping, and evaluation. The finding suggests that with information visualization, the students as the respondents feel the benefits of filling the EDMQ questionnaire. However, from the design standpoint, there are still numerous things that can be improved to make the visualization more informative.

Keywords: Adapted EDMQ, information visualization, metacognition, self-regulated learning, usability testing, user-centered design

1. Introduction

In the age of technology, skills to develop software have become an important part of the computer science students' curriculum. However, not all of the students have the same capabilities in absorbing the knowledge given by the lecturer. Some people absorb knowledge faster than others, while others need to take more time to get what the lecturers are saying. Some people can follow the lecturer's lesson verbally, while others need visual aids in absorbing the lesson. This condition has caused differences in approaches and methods used by someone or a group in solving the problem, such as software engineering and development.

The software development process has several methods that can be used by the developers to develop software, and these methods include Joint Application Design, Prototyping, Scrum, Waterfall, and many others [1]. Each method has its weaknesses and strengths, and so do the approaches used by the group of people developing the software. Not everyone will use the same approach, and a different approach can be used to get the same result. In other words, they can achieve the same goals using different cognition processes. As a result, there are groups that are more efficient and effective than others in achieving their goals, as proven in research which stated that choosing the correct strategy can affect the effectiveness of a software development process [2], and choosing the correct design strategy based on good design planning, minimum context change, and organized problem exploration can make the software development process more effective [3].

One of the proven methods of increasing the efficiency and effectiveness of software development is by applying metacognition in the development life cycle. Research stated that metacognition is used consciously or unconsciously in the software development process [4], and another one stated that metacognition can reduce learning from trial and error [5]. However, then how do we know if metacognition has affected the software development process? One way to know is by using the Engineering Design Metacognitive Questionnaire (EDMQ), a set of questions designed to measure the metacognitive skills of an individual in a group in a software development process [6]. Nonetheless, there is a problem in using EDMQ. The students who filled the questionnaire felt like they did not gain anything from filling the rather long questionnaire, as when they finished, they just got a thank you and that is that. Only the administrator of the questionnaire got the data filled by the students.

This study aims to fix that problem by giving an information visualization of the result of the EDMQ questionnaire that the students had filled before giving the students benefit in assessing their progress. The participants of this research are limited to the students of the Faculty of Computer Science, Universitas Indonesia.

The purpose of this study is to design information visualization of the EDMQ questionnaire that can help students to gain benefit from filling it instead of just being given a thank you, and to assess the usability evaluation of the information visualization tools. Therefore, this study addresses the following research questions.

1. What is a good design idea for information visualization tools for measuring metacognition using the EDMQ questionnaire?
2. How is the usability evaluation of the aforementioned information visualization tools?

2. Relevant Literature Review

2.1. Metacognition

Metacognition is the knowledge of someone's cognition process. It would not be wrong to say that metacognition is thinking about thinking [7]. There is research that studied metacognition's relation to GPA and grades [8]. Metacognition can also increase students' interest in online learning [9].

Metacognition can be measured with appropriate tools. Usually, the tools are made for a certain kind of situation or measurement. Examples are Metacognitive Skills Inventory [10], the confidence-based nameless questionnaire [11], and the Engineering Design Metacognitive Questionnaire.

2.2. Engineering Design Metacognitive Questionnaire

Engineering Design Metacognitive Questionnaire is a set of questions designed to measure the metacognitive skills of an individual in a group in the software development process. It combines the concept of the five-stages prescriptive design model from Dym and Little [12] and Butler and Cartier's self-regulated learning model [13], and the concept of team management.

The five-stages prescriptive design model consists of the problem definition, conceptual design, preliminary design, detailed design, and communication design. Butler and Cartier’s self-regulated learning model consists of task interpretation, planning strategies, cognitive action, monitoring and fix-up strategies, and criteria of success. Each of the aspects is intermixed, creating a matrix of each intermixed aspect. EDMQ is developed in 2014 and can be adapted for several engineering design-based subjects. It has been used in previous research about metacognition in software engineering [4].

2.3. Information Visualization
Information Visualization is an interdisciplinary field of study related to visual representations of complex information to increase the level of understanding for the information given. It is based on computer science, graphic, visual design, psychology, mathematics, and business. The goal of information visualization is to use humans' visual system to capture the deep meaning behind abstract information [14]. It transforms monotone and boring data into a more marketable product and better user experience [15].

One of the methods to transform data into a visual product has four phases [16]. The first phase is raw data. The raw data are processed using the data transformation method, such as data mining. The processed data result in the second phase is data tables. These data tables (or in another term, information) are manipulated and transformed using several visual representation/mappings, and the result in the third phase is visual structure. This visual structure is then transformed again into several different views. Afterwards, these views are what the user/human sees [17].

3. Methodology
This study uses qualitative approaches adapted from the user-centered design, which consists of requirement gathering, analysis and designing alternatives, prototyping, and evaluation.

3.1. Participants
The participants were chosen from the Faculty of Computer Science of Universitas Indonesia, and they fulfilled the requirements, which consist of having taken the Information System Development Project course or Software Project course and having experienced filling the EDMQ questionnaire. The number of participants chosen was 10 based on Nielsen's research about the optimum number of participants for usability evaluation [18]. The ten participants chosen has similar characteristic as all of them came from Faculty of Computer Science of Universitas Indonesia. All of them have experience working in a software development project either alone or in a team. The difference between them is their skills as some are better in one aspect such as coding while others are better in other aspects such as management or design, but overall, everyone know at least a little skill in every stages of a software development project as required by the faculty. Later, the ten participants will be divided into two personas. The two personas represented those who understand the concept and benefits of metacognition, and those who do not.

3.2. Data Collection Procedures
In this study, there were two interviews. In the first interview, participants were interviewed to gather requirements and then after that in the second interview, they tested the prototype for usability evaluation. For the first interview, a set of questions was designed to gather the participants' requirements. It consisted of 20 questions divided into several categories of Exploration, Needs, Pain Points, Gain, and Expectation. Each category has its use. Exploration is to explore the participants' understanding of the topics being interviewed. Needs is to understand what is needed by the participants. Pain Points is to understand what hardships felt by the participants. Gain is to understand what the participants want to gain from the information visualization tools. Expectation is to understand what the participants expect from the tools designed.

3.3. Data Analysis
The result of the first interview was used for analysis and designing the information visualization tools. The analysis consists of creating personas, a user journey map, and an information architecture to help the designing process. Those analyses were then used to design the information visualization. After the design process was complete, then the usability evaluation was conducted with the second interview. The conclusion was then inferred from the usability evaluation result.

4. Findings

4.1. Addressing Research Question 1: Prototype Development of Information Visualization Tools for the EDMQ Questionnaire.

The prototype was developed according to the result of the first interview's analysis. From the analysis, two personas representing the users were created, a user journey map to better explain what the user felt was also created, and an information architecture picturing how the information visualization tools was designed. Each of the stages drew inspiration from the result of the first interview. The two personas represented those who understand the concept and benefits of metacognition (Persona 1) and those who do not (Persona 2). The user journey map explained what the user felt when they filled the existing questionnaire. The information architecture was made as the base for creating the prototype. After the information architecture was designed, the next is the design of the information visualization tools.

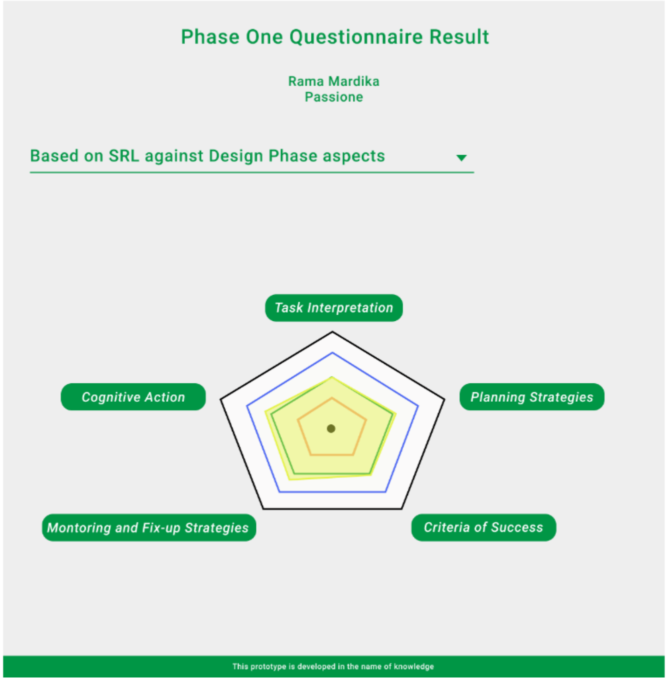

Figure 1. High-fidelity mockup of the result of the questionnaire page based on self-regulated learning aspects against the five-stage prescriptive design model

The design of the information visualization used a spider chart/radar chart to help visualize more than one aspect for a single subject. This is because the EDMQ Questionnaire is created using the combination of the five-stage prescriptive design model's concept and self-regulated learning model, and both concepts and their combination have more than one aspect to explain clearly the level of metacognition of an individual. The result can be seen from four different combinations. The first is based on self-regulated learning aspects against the five-stage prescriptive design model. The second is based on the five-stage prescriptive design model. The third is based on self-regulated learning aspects against team management aspects. The last is based on team management aspects. figure 1 above is an example of the questionnaire result seen based on the five-stage prescriptive design model. The five aspects are represented in the five corners of the spider chart/radar chart. Each green label can be clicked to navigate to the individual aspect's chart.

Each individual aspect chart displays a summary of the information about each aspect and a graph comparing the team members of the questionnaire. The data for the team members were filled out in the personal data section earlier in the questionnaire so the tools can recognize if someone is from the same team. The graph used to compare the result is a bar chart because it presents data in a comparable way. The individual aspect comparison page can be seen in figure 2.

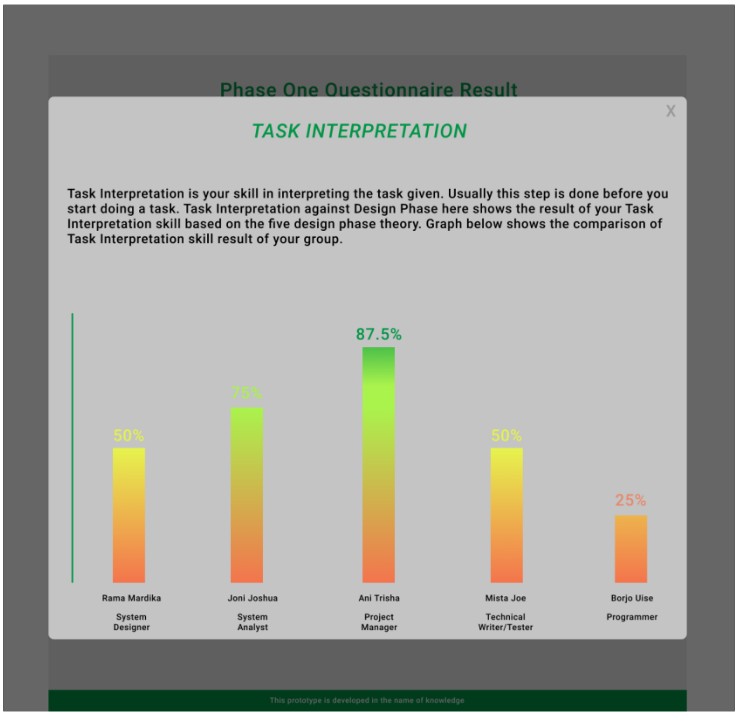

Figure 2. High-fidelity mockup of the individual aspect of the result based on self-regulated learning aspects against the five-stage prescriptive model

4.2. Addressing Research Question 2: Usability Evaluation of the Prototype

When the design process was finished, the participants were asked to use the information visualization tools prototype in the form of a clickable mockup for usability evaluation. Participants were given three tasks and a scenario which consists of filling the questionnaire, seeing the result for an individual score, and seeing the comparison between teammates. A pilot study was conducted to determine the average estimated time, and this estimated time was used to measure the capabilities of the participants. Those who finished the task under the estimated time were categorized as 'easy'. Those who finished the task with slight difficulties or finished the task over the estimated were categorized as having 'slight difficulties'. Those who finished the task over the estimated time and had slight difficulties were categorized as having 'difficulties'. Those who could not finish the task were categorized as 'very difficult’. The participants’ cursor movements and speech were recorded to make the recapitulation process easier. The participants were also mapped to the persona to see if the difference in persona is what caused the difference in the result.

After the usability evaluation was conducted to the 10 participants, the result is as presented in table 1.

Table 1. Result of usability evaluation of the information visualization tools prototype.

No	Respondent	Persona	Task 1	Task 2	Task 3
1	R1	P1	Easy	Easy	Easy
2	R2	P2	Easy	Easy	Slight Difficulty

3	R3	P1	Easy	Slight Difficulty	Easy
4	R4	P2	Easy	Easy	Slight Difficulty
5	R5	P1	Easy	Easy	Slight Difficulty
6	R6	P2	Easy	Easy	Easy
7	R7	P2	Easy	Easy	Easy
8	R8	P2	Easy	Slight Difficulty	Slight Difficulty
9	R9	P1	Easy	Easy	Easy
10	R10	P1	Easy	Slight Difficulty	Easy

All respondents had no difficulties in completing Task 1, as everyone finished the task under the estimated time. Different from Task 1, Task 2 had three people having slight difficulties, while Task 3 had four people having slight difficulties.

After everyone finished the task and scenario, there were questions and answers sessions for each respondent to explain their impression and the difficulties that they faced when they tried the prototype. They did like the ideas of information visualization. Visualizing the result of the questionnaire was more preferred by the students than the current mechanism of filling the questionnaire and getting nothing. However, they had several concerns regarding the prototype. In Task 1, nobody had any comments. For Task 2, the difficulties they faced were that they were not accustomed to gleaning information through a spider chart/radar chart and it took them time to understand the charts presented. Some of the confusion was caused by the lack of information in the page, they said. For Task 3, the difficulties they faced were that they did not realize that the buttons to navigate to the desired page were in fact buttons so they missed them entirely.

The respondents with different mapped personas having the same difficulties mean that the difficulties do not come from the difference in background but come from a mediocre design that does not present compact information and understandable elements.

5. Conclusion

This study shows that the idea for visualizing the information of the EDMQ questionnaire is preferred by the students than the current EDMQ questionnaire where students do not get any information out of the questionnaire. They want to understand their metacognition level and visualizing the EDMQ questionnaire is one way to get students interested in metacognition. However, the prototype developed in this study still requires improvements that can be done such as presenting more compact information and a more usable design.

This study has developed a design for the information visualization tools for the EDMQ questionnaire. This study has also evaluated the usability of the developed design and presented the result. This study only researched the usability of information visualization of the EDMQ questionnaire from the students' perspective. In the future, there needs to be research focusing on the lecturers' perspective as the one who conducts the questionnaire.

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