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Exploring Two Worked Example Designs for Learning Introductory Programming from Students' Perspectives

Nainan, Mariam[1*], Balakrishnan, Balamuralithara & Mohamad Ali, Ahmad Zamzuri

[1]Faculty of Art, Computing & Creative Industry, Sultan Idris Education University, 35900 Tanjong Malim, Perak, MALAYSIA

*Corresponding author email: marnai2004@yahoo.com

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Abstract: Worked examples are effective for learning problem-solving, but only if students engage with the content. An approach to promote engagement is through signalling. This study compared worked example designs for learning introductory programming using two approaches for signalling: labelled and visualized. It explored students' preferences and perceptions of the designs through a crossover design where students were exposed to both worked example designs. Data was collected through a questionnaire. Quantitative analysis showed that more students favoured visualized design. Qualitative analysis showed that students found both designs helped to understand the solution. Additionally, visualized work examples helped students understand the problem, the relationship between the problem and solution, and the programming process. Other differences were also identified.

Keywords: Worked examples, signalling, programming education

1. Introduction

Research has shown that students who study worked examples have benefited more in learning how to solve problems than students who attempted to solve the problems independently (Renkl, 2014). A worked example demonstrates domain concepts, principles, or procedures and a specific problem to which these are applied. In the context of the programming domain, the demonstration would contain a complete program that solves the given problem (Skudder & Luxton-Reilly, 2014). The program would show the application of different programming concepts and their implementation in a programming language so that students can demonstrate how the concepts are applied and implemented in the language.

Since the worked example already has the solution, students do not need to make an effort to solve the problem themselves, unlike the case of learning through problem-solving. However, students need to invest cognitive resources to process the information in the working example to properly understand how the solution has solved the problem. They need to recognize the concepts demonstrated in the solution. They must explain to themselves how these concepts have been applied so that they remember and learn how and for what type of problems they are applicable. This process of self-explanation is the foundational premise for the effectiveness of learning from worked examples or example-based learning (Renkl, 2014). In other words, students should read more than just the worked example content. They must be cognitively engaged with the content.

Worked examples must be designed in such a way as to encourage students to self-explain. Subgoal labelled worked example design (Atkinson et al., 2003; Catrambone 1998) is helpful to encourage students to explain to themselves how the solution solves the problem. In a labelled worked example, groups of related statements are demarcated, and labels are inserted to explain the purpose of that group (Morrison et al., 2015). The purpose would be stated as a subgoal. Hence, the label is called a subgoal label. A subgoal represents a mini-problem or subproblem. In other words, it is a small aspect of the overall problem. The group of statements represents a sub-solution that achieves the subgoal. The intention of inserting subgoal labels is to assist students in understanding that the solution is made up of sub-solutions and that the various sub-solutions achieve different subgoals, which collectively contribute to

*Corresponding author: marnai2004@yahoo.com

achieving the overall goal.

Subgoal labels may be regarded as signals (Margulieux & Catrambone, 2016) for drawing students' attention to the group of program statements. Signals, or signalling, is an instructional technique for alerting students to important information in instructional text and making the structural organization of the information more obvious to students (Schneider et al., 2018; Lorch et al., 2011). The subgoal labels in the solution program should draw the student's attention to the group of statements and assist them in understanding those statements as well as how they relate to the rest of the program.

The current study proposed a visualized worked example design as another approach that uses signals to draw students' attention to relevant information in worked example content to encourage students to cognitively process the information. A visualized worked example would contain a problem section and solution section, containing a complete program, just as in a labelled worked example. However, no labels would be inserted in the program. Instead, there will be an additional problem analysis section, where the subgoals or subproblems will be listed to demonstrate to students how to break a problem down into subproblems. Removing the labels from the program into a separate problem analysis section is to demonstrate and emphasize problem analysis. The intention is to address the need for more need for more problem-analysis skills among students learning programming. Students who spend less time analyzing a problem may expend unproductive time attempting to find a solution because they need to fully understand it (Loksa & Ko, 2016). Students need to understand the requirements of the problem before attempting the solution (Hanks & Brandt, 2009). The lack of problem-analysis skills is also found in other domains where problem-solving is an integral component of teaching and learning. For example, in chemistry education, Yuriev et al. (2017) reasoned that students may have incorrect solutions because they must pay more attention to certain aspects of the problem due to inadequate problem analysis.

In a visualized worked example design, signalling in the form of text highlighting links the subproblem to the statements in the program that address that subproblem. This highlighting is interactive. These features are achieved through the use of web technology. The relevant program statements are highlighted when the student selects a subproblem in the analysis section. More specifically, whenever the student moves the mouse over a subproblem, the program statements linked to that subproblem are highlighted. So, signalling is interactive because signals are activated in response to the student's actions.

On the other hand, in labelled worked examples, the signals are fixed or static as labels. In visualized work examples, the signals are activated, deactivated, or reactivated in accordance with the student's needs. The interactive signals were expected to encourage students to engage with the learning content.

The current study sought to compare labelled and visualized worked example designs by exploring students' perspectives of the two designs. Understanding students' perceptions of the worked example design to support learning may help to identify characteristics they perceive as useful (Peart et al., 2017; Liaw, 2008). It may shed light on the aspects of the worked example study that students felt helped their learning through a comparison of the two worked example designs. Specifically, the current study sought to explore 1) which worked example design (labelled or visualized) that more students selected for different aspects of learning; and 2) the reasons for their selections. The reasons given by students may give deeper insight into the learning experiences of the students. The empirical study employed a crossover design so participants could experience both worked example designs and select between them. Students' sections and reasons were collected through questionnaires. The context of the study was teaching and learning introductory programming, which is the first programming course taken by students in undergraduate programmes leading to careers in computing-related fields. Introductory programming courses are also commonly mandatory for engineering and science undergraduate programmes. Hence, understanding how worked examples should be designed to support successful introductory programming learning is essential.

2. Literature Review

2.1 Need to Emphasize Problem Analysis in Programming Process

The programming process is a problem-solving process. Students in introductory programming courses must know the programming process, which involves problem analysis and solution generation. Medeiros et al. (2019) identified problem-solving as an important skill. They identified that learning to analyze a problem and generate a solution may be challenging for students in an introductory programming course.

In their study of the self-regulation behaviour of students during the programming process, Loksa and Ko (2016) identified that very few students performed the initial step of interpreting and clarifying the problem. In other words, those students needed to properly analyze the problem to understand the requirements. Loksa and Ko (2016) also mentioned that this caused delays later when creating the solution because the students realized they did not fully understand the problem. They suggested that further research is needed to consider whether teaching this step of analyzing the problem leads to better problem-solving. Furthermore, Denny et al. (2019) called for research to teach students how to break problems into subproblems and why students struggle.

Similarly, Selby (2015) mentioned that problem decomposition is perceived as challenging, possibly because of inexperience or inadequate understanding. Hence, research is necessary to demonstrate to students how a problem may

be broken down into subproblems (or problem analysis). The current study on visualized worked example design sought to address this issue.

2.2 Signalling

Signals are instructional devices used in learning content to assist students as they read and process the content by emphasizing what is important and making the organizational structure of the content more explicit (Schneider et al., 2018; Lorch et al., 2011; Lemarié et al., 2008). Signalling helps students distinguish between relevant and irrelevant information, comprehend unfamiliar or new information, and create a mental representation of the information (Lemarié et al., 2008). Signals may emphasize, label, or identify text sections or show their relationships. However, student factors, such as background knowledge, learning goals, and motivation, may impact the effectiveness of signals in learning content (Lemarié et al., 2008).

Signals may appear in text, pictures, or video (Schneider et al., 2018). Text-based and picture-based signals, mostly used in printed and multimedia, are typically static. Signals in video-based learning content are usually dynamic since they appear at different points in the video presentation, as and when needed. But, although the presentation is dynamic, the appearance of a video-based signal is fixed in its sequence. In other words, whenever the video is replayed, the signal will appear in the same place and simultaneously, with all its defined changes, as when played the first time. Visualized work examples are designed to employ interactive signals. The signals are designed to appear interactively, that is, in response to students' actions.

The effectiveness of signalling for learning has been studied through experimental studies (Schneider et al., 2018). Eye-tracking studies have also explained how signals help draw attention and reduce effort in searching for relevant information (Ozcelik et al., 2010). The current study sought empirical evidence from students' perspectives.

2.3 Sub-goal Labelled Worked Examples for Teaching and Learning Programming

The use of sub-goal labelled worked examples has recently been researched in the context of teaching and learning programming. Margulieux et al. (2016) studied using subgoal labels in worked examples for teaching a block-based programming language. In their experiment, the experimental group (using the labelled version) outperformed the control group (using the non-labelled version). Morrison and colleagues conducted studies of work examples using text-based programming languages. Morrison et al. (2015) explained that segmenting the solution program and inserting labels for each segment helped students process the worked example content for more effective learning. The labels acted as signals to facilitate processing (Margulieux et al., 2016). According to Morrison et al. (2015), the researchers divided students into three groups: those who studied worked examples with no labels, those with labels given, and those students who generated labels. The worked examples were interleaved with practice problems. The three groups were split into two subgroups: isomorphic or transfer practice problems. Their study showed that among the best-performing groups were students who were given labels and transfer practice problems. In a similar study, Morrison, Margulieux et al. (2016) found that the students given labels and either type of practice problem performed the best. Both studies were conducted among students in an introductory programming course. The current study also focused on work examples using a text-based programming language in an introductory programming course. Still, it sought to identify students' perceptions of labelled and visualized worked example designs.

3. Methodology

An empirical study was conducted to explore two worked example designs (labelled or visualized) for learning introductory programming from students' perspectives. In order for students to compare the two designs and state their selections and reasons for their selections, the study employed a crossover design similar to the design used for other education research studies. For example, Mathieson (2012) conducted a study where participants were given two types of feedback on assignments. The participants were divided into two groups. For the first section of the study, the first group was given one type of feedback and the second group was given the other. During the second section of the study, the type of feedback given to the two groups was switched. In this way, both groups received both types of feedback. At the end of the study, participants were given a questionnaire to indicate their preferred type of feedback. They were also asked to give reasons for their selections.

Similarly, in a study conducted by Smith et al. (2011), the researchers investigated two different instructional delivery forms. Two participants were given one delivery form and then switched to the second form. Participants were then given a questionnaire where they evaluated both types of instructional delivery forms. Prunuske et al. (2016) also studied two instructional delivery methods in a crossover design. Participants were assigned to four different groups. Each group was given both delivery methods over four sessions but in different combinations. For the fifth (5) session, participants were given both methods and allowed to select either one. At the study's end, participants were given questionnaires to determine their preferences and comments.

Similarly, in the current study, a crossover design was used. Participants were divided into two groups, named Group A and Group B. Both groups were given three work examples to study. The work examples were presented using two different designs: labelled and visualized. For Group A, the first worked example was presented using a

visualized design, whereas for Group B, it was presented using a labelled design. For the second work example, the design was switched. In other words, Group A studied a labelled worked example, and Group B studied a visualized worked example. The purpose of switching was to control for the order of presentation of the different designs (Johnson & Christensen, 2014). Participants were exposed to both designs for the worked examples in this manner. For the third worked example, similar to the study by Prunuske et al. (2016), participants could select to view the worked example in either visualized or labelled design. It is noted that for all three worked examples, the problems and solutions were exactly the same. The only difference was in the design. This crossover design is illustrated in Fig. 1. Similar to the abovementioned studies, data was collected through a questionnaire.

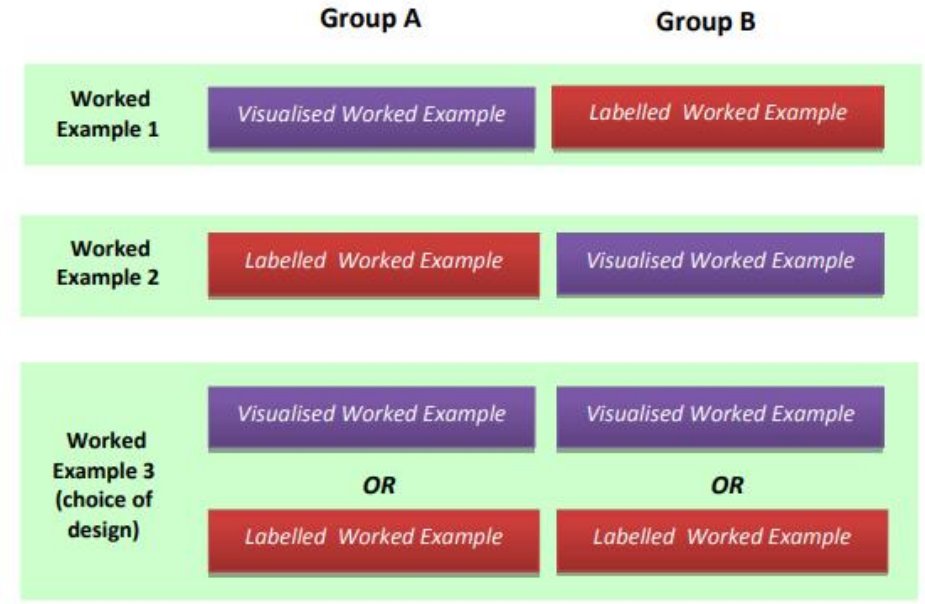

Fig. 1: Types of design used for worked examples presented to the two groups

Participants were recruited from a university in Malaysia in the first semester of 2018 among undergraduate students enrolled in an introductory programming course. The course assumed that none of the students had any prior programming knowledge. In their weekly course schedule, students attended lectures and computer laboratory classes for hands-on programming sessions. In these sessions, students were given a review of the lecture topics covered in the previous week, after which they were expected to solve problems given in worksheets. The course covered fundamental programming topics, such as selection and repetition control structures, and used a text-based programming language. The course was mandatory for all students and a prerequisite for other mandatory courses in their undergraduate programmes. The participants were from two intact classes in the course. One was designated as Group A and the other as Group B. The same lecturer taught both of the classes. All participants gave informed consent for the study, and the university's ethics review committee gave the study ethical clearance.

The empirical study was conducted during one of the programming sessions. Each participant was presented with three work examples based on three common patterns related to the "loop" concept. For the participants, the labelled and visualized designs were denoted as three (3) sections with presentation style and four (4) sections with highlighting presentation style, respectively. A labelled worked example contained a problem, solution, and sample run sections, as shown in Fig. 2.

The problem section contained the problem specification. The solution section contained the program. Labels were inserted as comments in the program to describe the purpose of one or more program statements that appeared below them. The sample run section contained a sample of the program's execution in terms of input and output (Input was indicated by underlining).

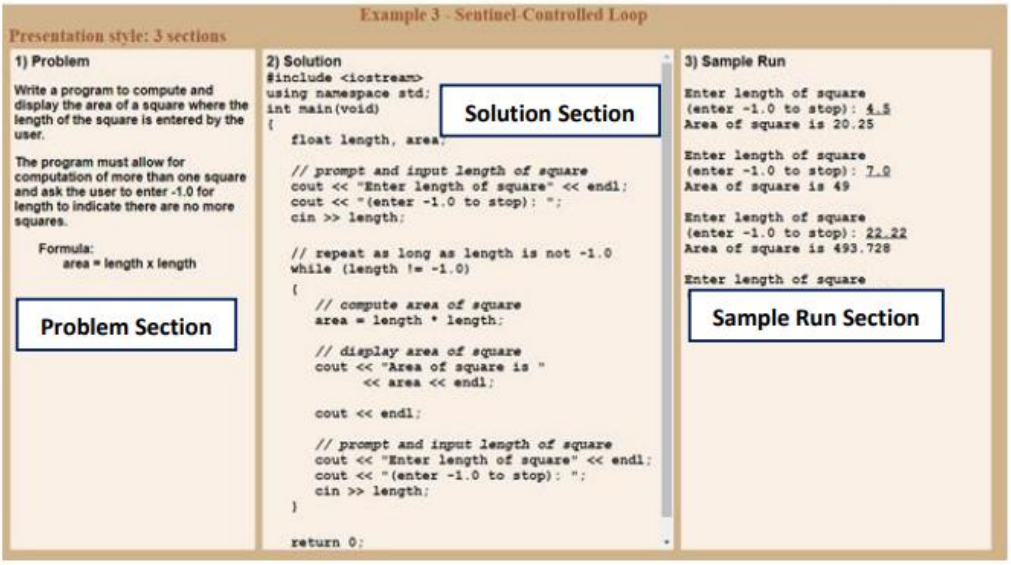

Fig. 2: Sample labelled worked example (or 3 sections style)

Similarly, a visualized worked example contained problem, solution, and sample run sections. The problem and sample run sections contained the same information as the labelled design version. However, the program in the solution section did not have labels. Instead, the visualized version had an additional analysis section. This section contained a list of subproblems that corresponded to the labels in the labelled design. A sample is shown in Fig. 3. The analysis section aimed to demonstrate how problem analysis might be done. The subproblems were listed at two levels in a question-and-answer format. The question represented a subproblem category. The answer was the detail that was specific to that particular problem. By doing so, common subproblem categories that are shared by problems of similar types could be illustrated.

Furthermore, visualized work examples employed text highlights to link the subproblems to relevant elements in the other sections, as shown in Fig. 3. The highlights were activated when the student moved the mouse over a subproblem. Text highlighting was implemented for the subproblem question and answer, the statements in the program associated with that subproblem, and the elements in the problem specification relevant to the subproblem. In addition, the boundary of the loop control structure was highlighted. The purpose of boundary highlighting was to show students the statements' position in relation to the control structure. These highlights activated through interactivity are regarded as interactive signals.

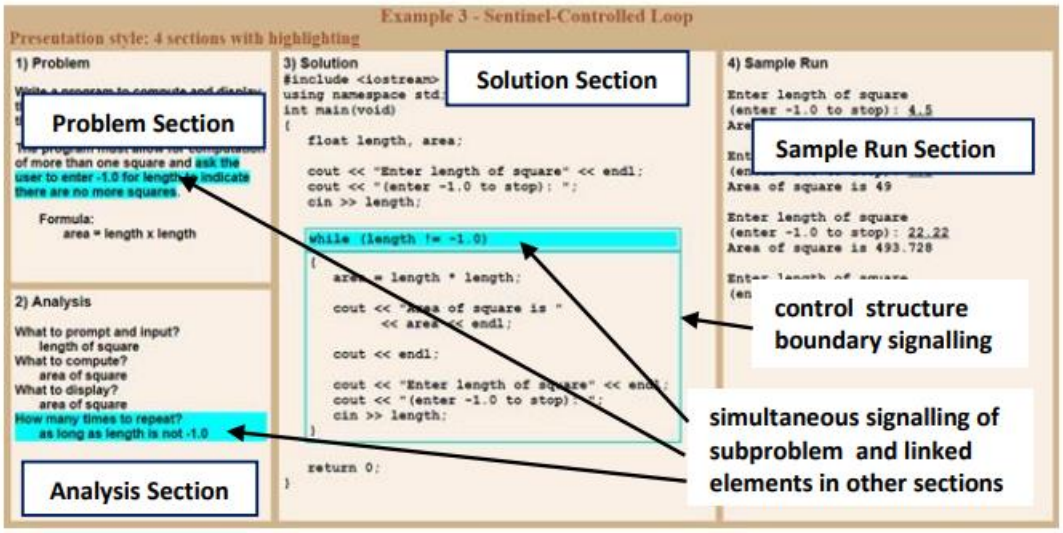

Fig. 3: Sample visualized worked example (or 4 sections with highlighting style)

Both labelled and visualized worked examples were implemented as web pages using HTML5 and CSS3. In addition, highlighting and interactivity in visualized worked examples were implemented using JavaScript. Highlights were implemented by turning the background colour of the relevant text to blue. It also entailed setting the outline of

the control structure to a blue colour. Highlights were activated when students hovered the mouse over a subproblem in the analysis section. Students could select different subproblems to activate the relevant highlights for each.

A questionnaire collected participants' perspectives on the worked example designs. The questionnaire contained four questions. The first question asked participants which worked example design they preferred. The purpose was to obtain their overall impression. The second and third questions were related to perceived learning effectiveness and satisfaction, respectively. These aspects of learning from the participants' perspectives have been investigated in studies of technology-supported learning (Nugroho et al., 2019; Liaw, 2008). The fourth question asked for their preference for possible future work example study. All questions, except for the first, were adapted from the questionnaire used in (Mathieson, 2012). Participants were also asked to give reasons for their selections for the first three questions. Hence, the questionnaire collected both quantitative and qualitative data. The participants' selections for the questions represented the quantitative data. The reasons given by participants formed the qualitative data. Three experts reviewed all questions for face and content validity.

The study was conducted during a session after the instructor had reviewed the "loop" concept. First, participants were introduced to the study, invited to participate, and completed demographic information forms. Next, they were asked to study the three worked examples. After the learning activity, participants completed a post-test and a questionnaire. Overall, the study lasted for 30 minutes. The post-test scores did not contribute to the grade for the course. This paper focuses only on the questionnaire responses, so the post-test and its results should be discussed further.

Data collected from the questionnaires were analyzed both quantitatively and qualitatively. The quantitative analysis involved the computation of frequency distributions of participants' selections by groups and in total. Qualitative data were analyzed using qualitative content analysis (Schreier, 2012). After a first and second reading of the reasons given by participants for the first three questions, the first coder created a coding frame inductively from the data. A second coder then evaluated the coding frame. The second coder independently coded the whole data set and identified issues with the coding frame. These issues were discussed, and the coding frame was revised where necessary. The first coder then recoded the complete data set with the revised coding frame. Next, a third coder coded the complete data set. The coding results of the first and third coders were compared, and wherever there were differences, they were discussed until a consensus was reached.

4. Results and Discussion

Questionnaires were collected from 38 participants from the two groups, aged between 19 and 25 years, with 10 females and 28 males. Of these participants, 14 were from Group A and 24 from Group B.

The four questions asked participants to select between the two worked example designs about overall preference, perceived effectiveness for learning, satisfaction, and preference for future worked example study. Frequency counts and percentages of the selections made for each question for each worked example design, in total and by groups, are shown in Table 1. The results showed that a large majority (64% and above) preferred visualized worked example design in both Group A and Group B. The totals showed that visualized work examples were preferred by at least 73% of the participants. And, a greater number of participants felt that visualized worked examples were more effective for learning, were more satisfied with them, and would select them for future worked example study.

The most common theme that emerged among the reasons given by participants for their selections was related to understanding. Participants mentioned that the content was easy or easier to understand. Participants who selected both labelled and visualized designs mentioned this reason. Some needed to provide further details on what aspect was easier to understand. However, many of the participants elaborated further.

Those who selected visualized design reported that they could understand "what the purpose was for each section of the code" (S23). Some participants explicitly mentioned that the program was easier to understand because the visualized design related the subproblem in the analysis section to the program statements: "helped me understand the [program] lines which [relate] respectively to the analysis steps" (S21). This meant the participant could understand which program statements were linked to a particular subproblem. This was made possible because of the highlighting feature, which resulted in the subproblem and the program statements associated with it being highlighted simultaneously. The purpose of the simultaneous highlighting was to help participants realize that those program statements were addressing that subproblem. Since the subproblem specified what was required to be done, it explained the purpose of highlighted program statements. By looking at the program statements linked to the subproblem, the participant may have been assisted in understanding what those statements were achieving.

One participant elaborated that the program was easier to understand because the highlighting was "done part by part" (S30). The highlighting feature helped participants focus their attention on the relevant parts of the program and do so one part at a time. This helped reduce the cognitive processing they needed because their concentration was directed to one small part at a time. For participants who selected labelled design, the reason given for being able to understand the program was "it is easier to understand as the explanation is [written] above the code" (S26). So, for both designs, participants felt supported in understanding the program because the different parts of the program were labelled (for labelled design) or highlighted (for visualized design) so they could understand each part. This resonates with findings from experimental studies of labelled worked example design (Margulieux & Catrambone, 2016;

Morrison et al., 2015). This is also consistent with the explanation of how signaling helps to draw attention to relevant information and to recognize the organizational structure of the information presented in learning materials (Lorch et al., 2011; Lemarié et al., 2008). Table 1 shows the frequency distribution of students' selections for each question by groups.

Table 1: Frequency distribution of students' selections for each question by groups and in total

No	Selection criteria	Group	Worked example design			
			Labelled	Visualized	Labelled	Visualized
			N (%)	N (%)	Total (%)	Total (%)
1	Preferred overall	A	5 (35.7)	9 (64.3	10 (26.3)	28 (73.7)
		B	5 (20.8)	19 (79.2)		
2	More effective for learning	A	2 (14.3)	12 (86.7)	5 (13.2)	33 (86.8)
		B	3 (12.5)	21 (87.5)		
3	More satisfied with	A	4 (28.6)	10 (71.4)	8 (21.1)	30 (78.9)
		B	4 (16.7)	20 (83.3)		
4	Preferred for future worked example study	A	2 (14.3)	12 (85.7)	7 (18.4)	31 (81.6)
		B	5 (20.8)	19 (79.2)		

Whereas participants who selected labelled design restricted their comments about support for understanding the program only, the participants who selected visualized worked examples went on further to point out other things that they found were easier to understand. One participant mentioned that it helped "understand what is the question asking" (S15). Visualized work examples may have drawn the participant's attention to look at the problem in addition to the solution program. This indicates that a visualized worked example may help participants carefully examine the problem the program was solving. It is pointed out that the participants who selected the labelled version should have mentioned the problem. This implied that their focus was mainly on the program.

A few participants who selected the visualized design elaborated that it helped them understand the links between the problem, the analysis, and the solution program: "With the help of the analysis part, I can see clearly on the program which relates to the question's needs" (S17). Since the elements in the problem specification were highlighted simultaneously with the subproblem in the analysis section and the program statements, the links between these three sections were made visible to the student. It helped participants cognitively process these connections and relate them together. It helped them understand the purpose of problem analysis and how it involved identifying the problem requirements. They may have been assisted in understanding how the program statements fulfilled those requirements. This finding is similar to studies on signalling, where signals are used to show connections between related elements in learning content to help students integrate the information (Lemarié et al., 2008). A few participants who selected visualized design reported that they had an understanding of the programming process (or coding) because of the analysis section: "Because it consists of the part of the analysis which gives me a clear information [about] what should I do in coding" (S29). The visualized worked example design had a separate analysis section to emphasize problem analysis. These participants' comments about the analysis section showed that they did note the analysis section, which may have made them aware of its purpose and importance. Students who do not analyze a problem may jump too quickly to design a solution. They may then realize that they lack sufficient information about the problem, as was observed in a study by Loksa and Ko (2016). Introducing a problem analysis section in a visualized work example design may assist students in becoming more aware of problem analysis and its role and importance in the programming process.

A small number of participants reported that visualized work examples made it easier for them to find the relevant information: "easy to find the info from the problem […] easy to find the relevant code" (S4). Furthermore, a few participants reported that it helped them process the information faster. This meant that visualized design makes searching for relevant information easier and faster, which is one of the benefits of signalling (Lemarié et al., 2008).

Some participants who selected the visualized design mentioned that they found it user-friendly and suitable for beginners. These two design aspects should have been mentioned as reasons for labelled design. On the other hand, three participants who selected labelled design mentioned that it was a presentation style that they were familiar with. Furthermore, one participant who selected the labelled design mentioned that it was more appropriate to his learning method because he wanted "to read the question and solution and then analyze it myself" (S8). In other words, the participant felt that the highlighting was not necessary.

Similarly, another participant felt that the highlighting feature was unnecessary because he wanted to process the information himself. These comments implied that the participants were knowledgeable and confident about their ability to process the worked example content without the additional information provided by the visualized design. This suggested that students' self-efficacy or confidence in processing the learning content impacted the design they found suitable for them. This is aligned with Moreno's (2006) suggestion that individual student differences, such as prior knowledge, may impact the effect of example-based learning.

Another reason a participant selected a labelled design was that the visualized design required shifting attention to

different sections to relate the information. However, since the comments were embedded in the program, it was easier to see the related information for the labelled design. Another two participants who selected the labelled design did not like the visualized design because it required moving the mouse to activate highlighting. As one of them mentioned, it was "troublesome to hover to the analysis [section] to show me the parts" (S37). The other mentioned that he wanted to take down notes, so having to move the mouse did not help. These reasons given by participants showed that the personal learning style impacted the design students preferred. This, again, suggested that consideration of the impact of student differences on worked example design is an important area of research (Moreno, 2006). The findings of the current study are summarized in Table 2. The negative comments were not included.

Table 2: Summary of students' positive perceptions of both worked example designs

Labelled worked example design	Visualized worked example design
Understand the solution	Understand the solution, the problem, the relation between problem and solution, and the programming process through analysis
Analyze the information themselves	See or perceive the analysis, the relation between problem and solution, and the programming process
Familiar presentation style	Find needed information Suitable for beginners User friendly

Limitations of the current study are that it was conducted during a single class session and covered only one programming topic. Future research should consider other programming topics and the use of worked examples throughout the course. Another limitation is the small number of participants in the study. However, the preliminary findings of the current study could be used in the future as input for a more comprehensive questionnaire survey of students' perceptions of the worked example design. A threat to the validity of the findings could be the students' bias toward visualized worked example design because of its novelty in terms of interactivity. However, the negative comments of the participants about whether highlighting was necessary showed that participants could express their comments freely. Furthermore, since a number of participants selected labelled worked example design as well showed that participants were at liberty to select either design.

5. Conclusion

The current study compared labelled and visualized worked example designs in the context of teaching and learning introductory programming from the students' perspectives. The findings showed that more students favoured visualized work example design. Although both designs led to cognitive engagement in understanding the solution in the worked examples, the visualized design was also found to help understand the problem, the relationship between the problem and the solution, and the programming process. This may have been facilitated by explicitly listing subproblems in the analysis section and using text highlighting in response to students' actions (interactive signalling). However, student differences, such as prior knowledge, may impact which design students prefer, as shown by the negative comments about the highlighting in visualized design. Furthermore, emotional factors, such as familiarity with a certain design and level of self-efficacy, should be considered in the design. The findings of this study provide preliminary results on students' perceptions, which may be used for future, more comprehensive investigations into the different aspects of engagement with content for better-worked example design.

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