Digital Teaching Aid Development to Answer Challenges in Learning Quadratic Equation in Indonesia

Dion Krisnadi, Universitas Pelita Harapan, Indonesia
Samuel Lukas, Universitas Pelita Harapan, Indonesia
Pujianto Yugopuspito, Universitas Pelita Harapan, Indonesia
Dina Stefani, SPK SMAK 8 PENABUR, Indonesia

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Abstract
Quadratic equation is considered as the most challenging mathematics topic for secondary high school students in various countries, including Indonesia. Studies have been done to identify challenges in the teaching and learning of this topic. The three most common challenges discovered include dull teaching method that does not encourage active learning, difficulty in obtaining conceptual understanding on quadratic equations and its associated information, and difficulty in interrelating different solution methods, including the factor form, vertex form and graphical representation. Teaching aid in the form of digital technologies is commonly proposed to address these challenges. However, existing media may not fully address all the discovered challenges. Moreover, digital media adds additional challenges in the form of various distractions that can hinder students' focus in learning the material. Therefore, this paper discusses the development of a digital teaching aid that is specifically designed to help learn quadratic equations by mapping challenges to features of the digital media. As a result, an offline computer software has been developed with the following five features: it supports both English and Bahasa Indonesia, it has well-defined input mechanisms for ease of use, it is able to generate graph automatically from a given quadratic equation and highlight it with associated information of the equation, it has an "Exercise" menu with a simple game to maintain students' interest, and it has three "Form" menu to interrelate various forms of a quadratic equation complete with sliders to experiment with coefficients of a quadratic equation.

Keywords: Educational Software, Teaching Aid Development, Digital Media, Quadratic Equation

Introduction

As a subject that is used in various disciplines (Kim How et al., 2022), particularly in science, technology, and engineering (Reid O'Connor & Norton, 2022), mathematics is commonly considered as a compulsory subject for secondary school in various countries. In Indonesia, mathematics is not only a compulsory subject, but also the subject with the most study hours (Anggraini & Kartini, 2020). However, even with this much emphasis on mathematics, many students still find it to be a difficult and terrifying subject (Anggraini & Kartini, 2020; Fatoni et al., 2017; Tanu Wijaya et al., 2020). One topic that proves to be a challenge for secondary school students is algebra, which may be caused by its abstract nature (How et al., 2022). Students struggle to understand the concept of variables and how to solve equations with variables. Evidence can be seen from various research that showed algebraic mistakes made by students in solving related problems (Kim How et al., 2022; López et al., 2016; Reid O'Connor & Norton, 2022; Vaiyavutjamai & Ken Clements, 2006; Zakiyah et al., 2021). This problem needs to be addressed since algebra is one of the main components in mathematics and is considered as a key requirement to enter higher education (How et al., 2022). This becomes a concern since the difficulty in learning basic mathematics in junior secondary years may in turn reduce the number of students learning advanced mathematics subjects in later years (Reid O'Connor & Norton, 2022). Not having the necessary human resources will eventually hinder the development of science, technology, and engineering.

Among all algebraic topics taught in secondary school, quadratic equation is considered as the most challenging (Kim How et al., 2022). Various research has been conducted on the topic of quadratic equation in various countries, such as Australia (Reid O'Connor & Norton, 2022), Thailand (Vaiyavutjamai & Ken Clements, 2006), Puerto Rico (López et al., 2016), Malaysia (How et al., 2022; Kim How et al., 2022), America (Faghihi et al., 2017), and Indonesia (Anggraini & Kartini, 2020; Fatoni et al., 2017; Hidayah, 2020; Zakiyah et al., 2021). The recurring topic among the research is the difficulty faced by students and teachers in teaching and learning quadratic equations. Some difficulties that were repeatedly found are students' understanding of the concept of quadratic equation, the concept of a solution to a quadratic equation, and the various forms of quadratic equation. It is noteworthy that these difficulties persist over time, as evidenced by the same finding from research in 2006 (Vaiyavutjamai & Ken Clements, 2006) and in 2022 (Reid O'Connor & Norton, 2022). This is of high concern because quadratic equation is widely used in real-life situations and other disciplines, is helpful in establishing a connection among mathematical topics (How et al., 2022; Kim How et al., 2022), and is fundamental in understanding advance topics in mathematics (López et al., 2016; Reid O'Connor & Norton, 2022). Failing to understand basic mathematics concepts, such as quadratic equation, has long-term effects that can lead to misconceptions in other topics since topics in mathematics are interrelated (How et al., 2022).

One potential solution believed to help students learn quadratic equation is the utilization of technology (Vaiyavutjamai & Ken Clements, 2006). In fact, the use of various forms of digital technologies in mathematics education has been proven to be beneficial (Alabdulaziz, 2021). Some of the benefits include facilitating experimentation and increasing motivation in learning mathematics. The need of a teaching aid in quadratic equation has also been proposed in various recent research (Fatoni et al., 2017; How et al., 2022; Kim How et al., 2022; Vaiyavutjamai & Ken Clements, 2006). To answer this need, this paper discusses the development of a digital teaching aid in the form of computer software to help teaching and learning of quadratic equations. The resulting digital media provides a way for students to face common difficulties in understanding quadratic equations and grasping the meaning behind each coefficient in various forms of quadratic equations through graphical representation. Thus, students can observe and experience the effect of each coefficient in a quadratic equation.

The remainder of this paper is organized as follows. Chapter II discusses previous research on the teaching and learning of quadratic equations in various countries. Challenges found in previous research are then listed and mapped to the requirements of the software in Chapter III. The resulting software is discussed and shown in Chapter IV. Chapter V contains concluding remarks.

Literature Review

Study on the teaching and learning of quadratic equations has long been conducted. In 2006, a study with 231 Grade 9 students in two government secondary schools in the Chiang Mai Province in Thailand was conducted (Vaiyavutjamai & Ken Clements, 2006). The teaching method used was the traditional teaching approach where teachers act as the primary source of information while students listen and follow given instructions. This approach was commonly used in many countries at that time. After analyzing the test results of 231 students along with the transcripts of interviews with 18 selected students, it was found that most students have problems in conceptual understanding of quadratic equations, especially on the notion of variables and solutions of a quadratic equation. The writers suggested the use of modern technology to help students in learning the material, particularly one that can generate graph of a function and pinpoint the important information of that function.

Various other studies have also been performed in more recent years in various countries. In Australia, a study was carried out with 25 Year 11 students from a coeducational high school in Queensland (Reid O'Connor & Norton, 2022). Written tests and diagnostic interviews were used to discover students' lack of conceptual understanding and problem-solving abilities. The challenges found were summarized into four main topics, which are the null factor law, nature of quadratics, algebraic conventions, and solving techniques. It is important to note that the same mistakes were made by students in this research and the previous one. Similar problems were found in another study conducted in Puerto Rico with eight beginning college students and 121 science and engineering student who took multivariable calculus course (López et al., 2016). Students in the study failed to understand the meaning of solutions of quadratic equations and the relationship between different solution methods for quadratic equations.

In line with the previous studies, some studies in Indonesia observed similar problems (Anggraini & Kartini, 2020; Hidayah, 2020; Zakiyah et al., 2021). The three studies conducted in three different cities in Indonesia found common difficulty faced by students in learning quadratic equations, that is interrelating different forms of quadratic equations to find solutions, both in factor and vertex forms. Moreover, two of the studies confirmed (Hidayah, 2020; Zakiyah et al., 2021) that students in their study had a hard time understanding conceptually the meaning of quadratic equations and their solutions. It is noteworthy that traditional teacher-centered approach is still widely used in Indonesia (Fatoni et al., 2017; Lan et al., 2021), which might also be the reason for the lack of conceptual understanding due to overemphasis on procedural knowledge in symbol manipulation, as suggested in (Reid O'Connor & Norton, 2022; Vaiyavutjamai & Ken Clements, 2006). The problem of teacher-centered approach was also observed in a study with 38 Grade 8 students in Jember, East Java (Fatoni et al., 2017). The authors commented on teacher-centred approach that does not encourage students to be actively engaged in learning as the reason why students perceived mathematics subject as difficult. They proposed to use simple and exciting teaching and learning media to increase students' motivation in learning mathematics. This reasoning was also supported by another study with 10 Grade 9 students in Bangkinang, Riau (Anggraini & Kartini, 2020). In one study on gamification of statistical material, the use of interesting teaching and learning media increased students' engagement and motivations, which in turn resulted in better comprehension of the material (Rembulan & Putra, 2018).

Previous research already hinted on the use of digital technologies to help the teaching and learning of quadratic equations. In general, the utilization of digital tools to improve mathematics and science learning have been discussed and proven (Hillmayr et al., 2020). The study concluded that secondary school students who were taught using digital tools in science or mathematics classes had significantly more positive attitudes toward the subjects than their counterparts. Another study had also investigated the benefits of using various forms of digital technologies in mathematics education (Alabdulaziz, 2021). The author interviewed 120 mathematics teachers and found some benefits. Some notable ones are its potential to motivate and excite students by making mathematics more interesting and meaningful, improve learning, facilitate active learning through experimentation that enable students to better relate functions to graphs, encourage students to learn more, and provide in-depth learning strategy.

In the teaching and learning of quadratic equations, few research have been done to investigate the benefits of using digital media. Hawgent dynamic mathematic software was used to teach quadratic equations in (Tanu Wijaya et al., 2020). According to the research, students who were taught using the software were able to visualize and generalize the graphical form of a quadratic equation more effectively than those who were taught using traditional methods. However, the majority of the Hawgent dynamic mathematics software materials were still written in Chinese, which makes it less suitable to be used globally, particularly in Indonesia.

Another form of digital media was developed in the form of a game in (Faghihi et al., 2017). The study pointed out lower anxiety levels for adult participants who played the game compared to others who just waited before they were asked to solve a quadratic equation problem. However, the game itself did not have elements that could help students relate different solving methods, especially between a function and its associated graph. Moreover, an observation by (How et al., 2022) indicated that secondary school students are easily distracted with irrelevant elements on a digital media, which commonly exist in a game to build an exciting gaming environment.

Another approach was used in (Fatoni et al., 2017) that integrated GeoGebra to an online learning platform in Indonesia called KelasKita. GeoGebra is an online computer algebra system (CAS) that can help learn mathematics for all levels of education, while KelasKita is an online learning platform where teachers can interact with students through various features, such as forum, quiz, chat, etc. The study showed that the resulting online digital media was deemed interesting and motivating by the students. The author also verified the effectiveness of the media by showing that 89.5% of the students successfully passed the minimum required score for a test in quadratic equations. However, GeoGebra is an online CAS that is not specifically intended for learning quadratic equations. There are a lot more features for other topics that can be accessed and experimented with on GeoGebra, which may become a distraction for students. This is in line with another observation by (How et al., 2022) that indicated secondary school students are easily side-tracked when they browse through online learning media, particularly YouTube. Another consideration is the availability of internet connection in developing countries, as observed in (How et al., 2022). Moreover, there is no readily available feature that can interrelate various forms of quadratic equations, particularly the factor and vertex forms.

Although digital media has been generally accepted as a teaching aid that can help students in learning mathematics, only a few research has attempted to develop one that can specifically address previously studied challenges in learning quadratic equations. In addition, the use of digital media to help teach mathematics is not a common practice in developing countries (Tanu Wijaya et al., 2020), including Indonesia. Therefore, this paper discusses the development of digital media with features that specifically mapped the challenges that have been identified from previous research. The research question that will be covered in this paper is how to develop a digital teaching aid that could help students face common challenges in comprehending quadratic equations.

Teaching Aid Design

Based on previous studies, the three most common problems in the teaching and learning of quadratic equations are the lack of conceptual understanding (Hidayah, 2020; How et al., 2022; Kim How et al., 2022; López et al., 2016; Reid O'Connor & Norton, 2022; Vaiyavutjamai & Ken Clements, 2006), the lack of ability to build connections among different solution methods (Anggraini & Kartini, 2020; Hidayah, 2020; López et al., 2016; Reid O'Connor & Norton, 2022; Zakiyah et al., 2021), and the use of dull teaching methods (Anggraini & Kartini, 2020; Kim How et al., 2022; Vaiyavutjamai & Ken Clements, 2006). Moreover, two additional problems from using digital media in developing countries need to be considered, which are students' limitation in accessing internet and resources in their language, and also and their tendency to get easily distracted and side-tracked with irrelevant contents (How et al., 2022). These problems are summarized and mapped to requirements in Table 1.

Conceptual understanding is defined as knowing both what to do and why as opposed to procedural understanding that is loosely defined as rules without reason (Vaiyavutjamai & Ken Clements, 2006). In terms of quadratic equations, misconceptions can occur on the concept of variables, solutions, and roots. Many students find difficulties in explaining the meaning of each component in the quadratic equation (Reid O'Connor & Norton, 2022; Vaiyavutjamai & Ken Clements, 2006). They may be able to solve the equation without understanding the meaning of their solution. In addition, these students may not be able to associate the equation with the graph as suggested in (López et al., 2016). Solving a quadratic equation and representing it in a graph are two sides of the same coin. Therefore, it is crucial to provide both equations and their graph simultaneously. Moreover, important information, which is intercepts and the extreme point, needs to be highlighted to help students in realizing the meaning of those.

Quadratic equations can be represented in various forms, such as standard form, factor form, vertex form, and graphical representation.

$$\begin{aligned} \text{standard form} &: \quad y = ax^2 + bx + c, \\ \text{factor form} &: \quad y = a(x - x_1)(x - x_2), \\ \text{vertex form} &: \quad y = a(x - x_v)^2 + y_v. \end{aligned}$$

Each form emphasize different important information, and thus it is important for students to become familiar with each form and to identify which form is best for their needs. However, as evidenced in (López et al., 2016), students often find it difficult to express quadratic equations in factor or vertex form. Consequently, students tend to use inefficient procedures to obtain the required information that should be easily seen when students use the appropriate form. In addition, notice that each form has a different set of coefficients, which may cause confusion in relating the forms. To address these problems, the teaching aid should provide a way to represent a quadratic equation in those four forms as well as to display the relationships between coefficients in other forms. This requirement is consistent with the findings in (How et al., 2022; López et al., 2016) that suggested students should be able to explore alternative answers to improve their understanding of quadratic equations.

Teaching methods have a significant influence on students' comprehension, as supported by earlier findings. The use of teaching approaches that focus on procedural knowledge leads to students overlooking conceptual understanding (Reid O'Connor & Norton, 2022; Vaiyavutjamai & Ken Clements, 2006), which has been discussed in the previous paragraph. Another finding from (Anggraini & Kartini, 2020; Fatoni et al., 2017; Kim How et al., 2022) stated that dull teaching method that heavily stressed on teacher's explanation caused students to become passive and unmotivated. This needs to be addressed since (Alabdulaziz, 2021; Rembulan & Putra, 2018) have shown positive relationship between students' motivation and their comprehension. Hence, it is imperative that the teaching aid must be interesting and interactive to encourage students to actively experiment and explore the material.

Although the use of digital media in teaching mathematics has been proven to be beneficial, a study by (How et al., 2022) observed some drawbacks in the form of accessibility and distractions. The study mentioned students' difficulty in accessing the internet at home for self-study, which is also a common problem in Indonesia. Even after having Internet access, students faced difficulties in finding the right resources that match their linguistic ability. Another problem discovered is students' tendency to get easily distracted and side-tracked with irrelevant content, either other online content or elements in the digital media itself. To overcome these problems, an offline digital media needs to provide both English and Bahasa Indonesia. Moreover, to minimize distraction, the interface should be simple and intuitive. Ease of use has been suggested to increase students' motivation to learn (Fatoni et al., 2017).

Challenges	Requirements	Additional References
Inability to obtain conceptual understanding.	A mechanism to visualize a quadratic equation into graph complete with its associated information.	(Hidayah, 2020; How et al., 2022; Kim How et al., 2022; López et al., 2016; Reid O'Connor & Norton, 2022; Vaiyavutjamai & Ken Clements, 2006)
Difficulty in interrelating different solution methods.	A mechanism to represent a quadratic equation in various forms and to display the effect of changing a coefficient in one form to other forms.	(Anggraini & Kartini, 2020; Hidayah, 2020; López et al., 2016; Reid O'Connor & Norton, 2022; Zakiyah et al., 2021)

Challenges	Requirements	Additional References
Dull teaching method.	Interesting and interactive teaching aid.	(Alabdulaziz, 2021; Anggraini & Kartini, 2020; Fatoni et al., 2017; Kim How et al., 2022; Rembulan & Putra, 2018)
Difficulty in accessing the internet and finding resources in their languages.	An offline teaching aid that uses both English and Bahasa Indonesia.	(How et al., 2022)
Tendency to get easily distracted and side-tracked with irrelevant contents.	Simple and intuitive interface.	(Fatoni et al., 2017; How et al., 2022)

Table 1: Mapping from Students' Challenges to Requirement

Implementation

To ensure that the digital teaching aid can address all studied challenges, each requirement in Table I is then derived into features. First, note that from the fourth requirement, an offline teaching aid may be desirable since it has less distractions. Hence, the teaching aid is developed in the form of an offline computer application. Moreover, as stated in the requirements, users will be able to choose their preferrable language, either in Bahasa Indonesia or English. When the application is first launched user will be prompted to choose the language as shown in Figure 1. In this paper, however, the application will be shown only in English.

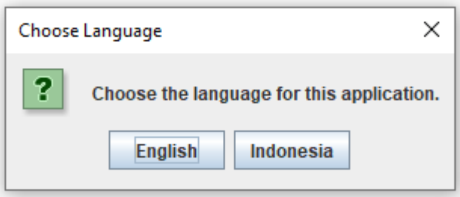

Figure 1: A dialog to choose between English and Bahasa Indonesia

The offline computer application is made to be simple and intuitive as required in the fifth requirement. In total, there are five menus in the application, which will be explained in the next few paragraphs. To ensure simplistic interface, each menu has a consistent design that consists of two panels. The panel on the left is used to input and control the quadratic equations, while the one on the right will display the graph of the given equations. To provide an intuitive interface, the application provides textboxes as the main input mechanism where users can enter the coefficients. Furthermore, clear error messages will be shown for every incorrect input. Figure 2 shows an example of an error message when users' input is not a number.

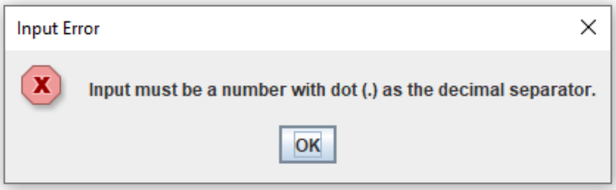

Figure 2: An error message when users' input is not a number

The next feature is developed to fulfill the first requirement, that is to show the equations and their graph simultaneously. A menu is specifically designed where users can specify at most six quadratic equations to be compared. The associated graphs will be displayed after users click the "Draw Graph" button. Each displayed graph can then be clicked to show the important information regarding the equation, which includes the intercepts, extreme points, and any intersections among the graphs. The actual coordinate of each point will appear when users click the point. This "Types" menu and its features can be seen in Figure 3.

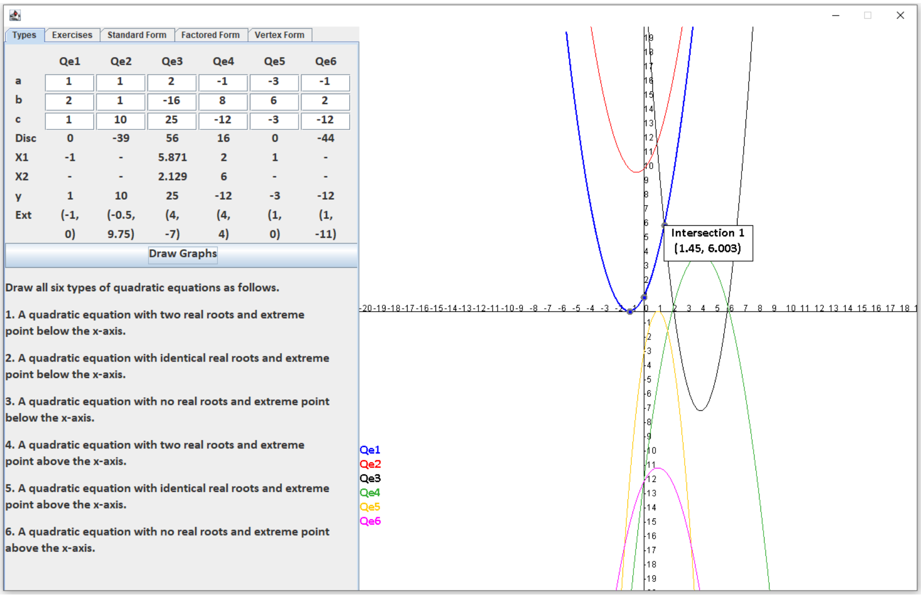

Figure 3: The interface for the "Types" menu

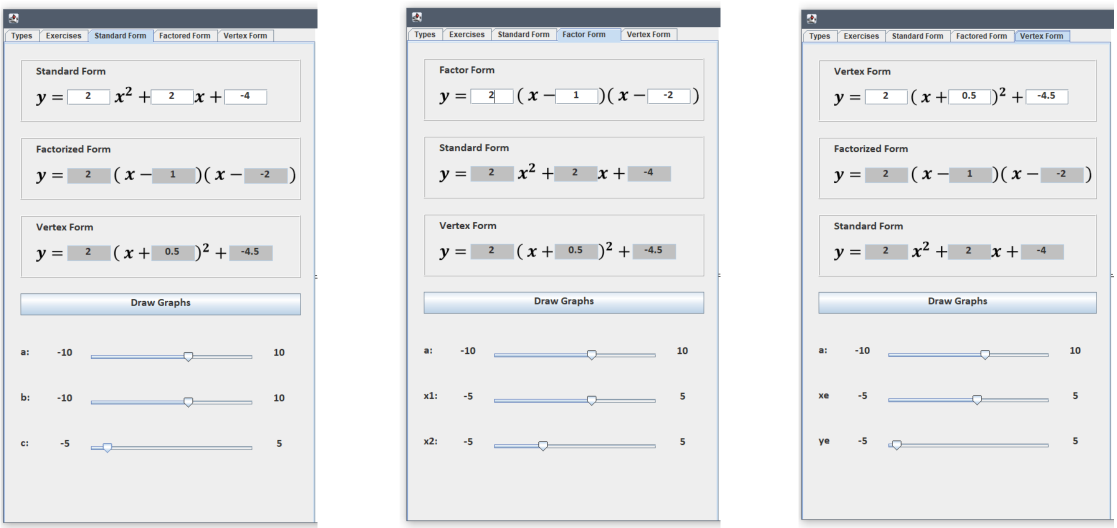

Figure 4: The interface for the three "Forms" menu

The second menu consists of three other menus to show the different forms of a quadratic equation, which is standard, factor, and vertex forms. These menus are meant to help students understand the relationship between the three forms. Through these menus, teachers can emphasize the different important information inherent in each form. These menus can also help students in see how each quadratic form can be used to find solutions of the quadratic equations. In addition, users should be able to experiment with the coefficients in one form and see how it affects the other quadratic form, which may enrich users' comprehension on interrelating different forms of a quadratic equation. Figure 4 displays these three "Form" menus.

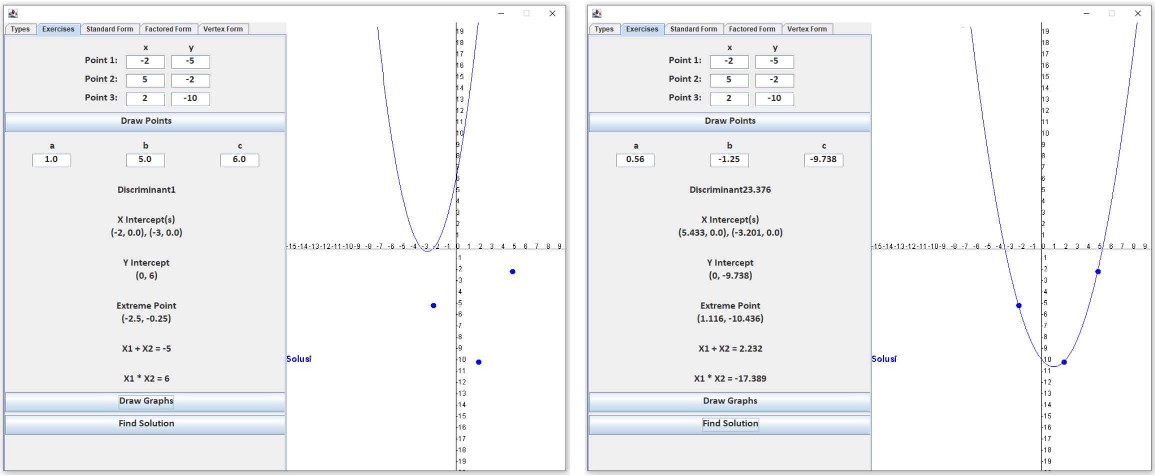

Figure 5: The interface for the "Exercise" menu. The left shows the graph from students' input in the textboxes. The right shows the solution when the "Find Solution" button is clicked.

To provide an interesting and interactive teaching aid, sliders are used to ease the users in experimenting with each coefficient in each quadratic form, as can be seen in Figure 4. This reasoning is also supported in (Fatoni et al., 2017). Aside from that, the last menu called "Exercises" is developed with a simple game where teachers can assign three points and students can guess the quadratic equation that passes the given points. Students input their answer in the textboxes and click the "Draw Graph" button to see whether they give the correct answer. A "Find Solutions" button is provided to help solve the game by calculating the correct coefficients and drawing the associated graph. This menu is displayed in Figure 5. A summary of the derived features is given in Table 2.

Requirements	Features
An offline teaching aid that uses both English and Bahasa Indonesia.	Offline computer software that supports both English and Bahasa Indonesia.
Simple and intuitive interface.	An interface with well-defined input mechanisms, consistent design, and clear error message for each incorrect input.
A mechanism to visualize quadratic equations into graphs complete with its associated information.	Menu "Types" with automatic graphs-generation from given quadratic equations where each graph can be clicked to display associated information.

Requirements	Features
A mechanism to represent a quadratic equation in various forms and to display the effect of changing a coefficient in one form to other forms.	Three “Form” menus where users can enter and modify a quadratic equation in one form and see how it is represented in other forms.
Interesting and interactive teaching aid.	Menu “Exercises” with a simple game where teachers can assign three points and students can guess the quadratic equation that passes the given points. Sliders are added in the three “Form” to help modify the quadratic equation.

Table 2: Mapping from Requirement to Features

Conclusion

A digital teaching aid in the form of offline computer software has been developed to address challenges in the teaching and learning of quadratic equations. A literature review was conducted to identify common challenges discovered in various studies from Indonesia and various other countries. Three common challenges were identified, which are inability to obtain conceptual understanding, difficulty in interrelating different solution methods, and dull teaching methods. In addition, the use of digital teaching methods was found to cause additional challenges in the form of accessibility and distraction. In total, there were five challenges that was addressed in this discussion.

The five challenges were mapped to five requirements. To improve students’ conceptual understanding, the teaching aid is equipped with the mechanism to visualize a quadratic equation into graph that students can interact with to display its associated information. Afterwards, a mechanism to represent a quadratic equation in standard, factor, and vertex forms are necessary to overcome students’ difficulty in interrelating different solution methods. Furthermore, the ability to interact with the coefficients and see the immediate effects on its visual representation can help students in building the relation among the three forms. The teaching aid should also be interesting and interactive to help students to have more motivation to explore and learn the materials. To make the teaching aid accessible to students in Indonesia, it should have Bahasa Indonesia support and be available offline. Moreover, simple and intuitive interface is required to reduce distractions in learning.

To fulfil the five requirements, five features are developed. First, the teaching aid is built in the form of offline computer software that supports both English and Bahasa Indonesia. Moreover, the software is made with well-defined input mechanisms, consistent design, and clear error message for each incorrect input to satisfy simple and intuitive interface. This software has three menus, “Types”, “Form”, and “Exercises”. The “Types” menu enables users to enter several quadratic equations and visualize the graphs where each graph can be clicked to display associated information. The “Form” menu consists of three other menus for standard, factor, and vertex forms. Through these menus, users can enter and modify a quadratic equation in one form and see how it is represented in other forms. Sliders are added in the three “Form” to help modify the quadratic equation. Lastly, menu “Exercises” has a simple game where teachers can assign three points and students can determine the quadratic equation that passes the given points.

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Contact email: dion.krisnadi@uph.edu