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Development of Application Design to Support Mathematics Learning in the Subject of Three-Dimensional Geometry for Class XII High School Students

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Abstract. This study discusses the design of applications as a medium to help students solve three-dimensional geometry problems. Three-dimensional geometry is one of the abstract mathematics subjects. Students need good spatial abilities to understand and solve three-dimensional geometric problems well. However, in reality, many students find it difficult due to their lack of spatial abilities. This problem can happen because students work on a three-dimensional shape in a two-dimensional plane that they cannot interact with and explore. Therefore, an application will be designed through this research to overcome these two problems. This study uses a five-element user experience framework to find and understand the actual problems experienced by students and continue each stage of user-oriented design. This study's results expect to help students better understand and solve three-dimensional geometric problems.

Keyword*: application; user experience; user interface; three-dimensional geometry; high school students*

1 Introduction

Geometry is one of the subjects in mathematics that must be studied by elementary to high school students. Each level has a learning sequence starting from pure geometry, analytics, and transformation (Sholihah dan Afriansyah, 2017). As for the subject matter, the geometry studied at school consists of two-dimensional and three-dimensional geometry. Three-dimensional geometry is part of the geometry that discusses the relationship between points, lines, and planes (Novita et al.: 2018). Also, three essential competencies consist in geometry that XII high school students must learn. First, students are taught to solve problems related to distances between points, then about the distance from a point to a line, and the last distance from a point to a plane.

Learning three-dimensional geometry for class XII already involves distance measurement between shapes. According to essential competencies, students must be able to solve geometric problems not only from analytical problems but

also from visual objects (Kariadinata, 2010), which in class XII student material is the distance in space. The space distances can form if the questions are informed points, lines, and planes. However, these points, lines, and planes are not always parts that exist in shape but can come from the new one. With the lines and planes formed in these shapes, it is often difficult for students to imagine these shapes because they involve more than one object.

One factor that makes the spatial process difficult is the student's need for spatial ability, primarily when they work geometry in a two-dimensional plane. Capturing and rotating an element requires good visual-spatial skills when imagining objects from different perspectives to solve three-dimensional geometry problems (Febriana, 2015). According to Meier (1996), there are five indicators contained in spatial ability: 1) spatial perception: namely the ability related to how to see an object from a vertical and horizontal perspective 2) spatial visualization: the ability to show a change and locking of the constituents of an object either three-dimensional or two-dimensional 3) mental rotation: the ability to rotate objects in both three dimensions and two dimensions 4) spatial relations: the ability to understand the structure and parts of an object and also the relationships that these objects produce with others 5) spatial orientation: the ability to Observe an object from a different point of view.

Also known, a two-dimensional field such as paper or blackboard is a medium that cannot be interacted with. When students have difficulties in carrying out spatial processes, the choice they have to solve the problem is to draw again. According to Van Hiele, in phase-based learning theory, drawing is a skill that students must have when they want to understand geometry. Drawing becomes very important because at each level of learning geometry, according to Van Hiele, there is always a process of drawing. This drawing process also allows students to add information about the object they want to complete. However, research conducted by Rahmad et al. (2013) found that one of the indications that cause students to have difficulty understanding three-dimensional geometry is the lack of skills in drawing and using tools to draw three-dimensional and also because they tend to rely on formulas.

In addition to the ability to draw itself, the media also plays a role in students' success in solving three-dimensional geometry problems. Such as the use of blackboard and paper media will limit the process of exploring images by students, so media that can observe, manipulate, hear, and read is needed (Kadir & Yani, 2012). The teacher's ability is also crucial because some teachers need to start using assistive devices, so they do not help stimulate students' ability to understand the shapes. Students also tend to be afraid first, primarily if many plans form in one shape. Teaching media are also not diverse because most schools still use books and worksheets. In addition, students are also too used to

learnSing with visual shapes that are always the same, so when they face different visual objects, these students will experience confusion and need more time to understand and solve the problem. Based on this description, this research must produce a product that can facilitate students when studying and solving geometry problems.

2 Methodology

The method used in this study is qualitative, with a framework using the Five Elements of Users' Experience. This framework comprises five levels of designing a product, starting from the research process and data collection to produce a prototype. The five design levels consist of Strategy, Scope, Structure, Skeleton, and Surface, where each stage is interconnected from the bottom up. The data obtained at the strategy level will influence the following process in this framework. These results will also ascertain the difficulties students experience when working on three-dimensional geometry so that when they continue to design, the resulting product is needed and genuinely oriented to its users.

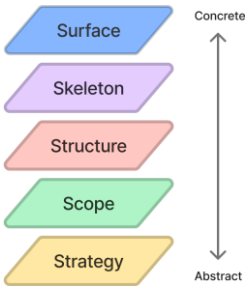

Figure 1 Five-elements of user experience

3 Results

Based on the background of the problem and the method proposed, the following results obtained.

3.1 Strategy

Data collection at this stage will help build product objectives, user needs, and persona. Data is collected by doing interviews and observations of 8 students of class XII in high school/equivalent who studied three-dimensional geometry. Students must answer five questions. Each of the questions represents basic competence in class XII three-dimensional geometry. This problem has different types to determine students' abilities in understanding the question, redrawing the pictures of questions, and understanding the pictures they draw again.

In working on the questions, it will observe six points from students. It starts with how students understand shapes. It can see how they commonly use the values and signs to identify images. Then the drawing activities were carried out by students. After that, the third point that will observe by students is how they separate the planes that formed in the shapes. Knowing what students are doing at this point will help to understand how students make decisions in solving problems, especially for images with a point of view that is difficult to understand.

Furthermore, the fourth point that will observe is their habit when drawing the object, whether they use specific tools to help them understand an image and draw again. The fifth point is to find out whether students can change the perspective of shapes because the planes formed in shape tend to be hard to understand, so for some students, apart from removing the plane, another way he can do this is to change the perspective of the shape. The last point is whether students have the habit of re-examining the pictures they make because their results influence the continuation of their problem-solving process.

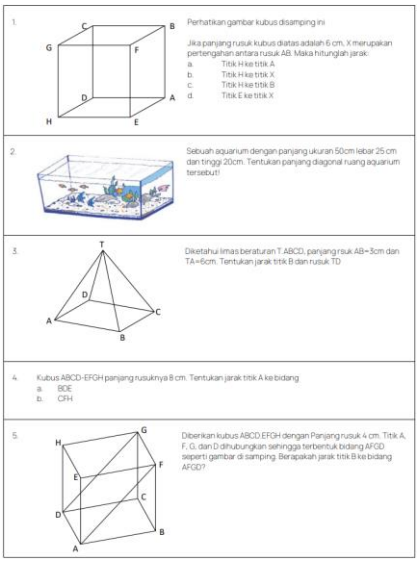

Figure 2 List of observation questions

In addition, there are also several considerations regarding the type of questions that students need to solve, such as 1) From the point of view, it is different from what the students usually do, 2) There are variations of the shape, 3) Some questions do not have an object, requiring students to draw pictures without examples in the questions.

After doing observation, the next step is to interview the student. This process will help to confirm the findings from the observations. It also obtains general information about students' habits and life to form a user persona. Apart from the user persona, the results obtained from these observations and interviews will help identify user needs and product objectives.

3.1.1 Observation Result

From observations and interviews conducted with students, several findings affect the process and results when students work on questions. There are several ways for students to determine the pictures that they will make. The student will immediately copy the object if there is an object in the question. It can see the different shapes from each edge on the front view of a shape. However, if there is no object, students usually use the information directly mentioned or derived from usually known measurements.

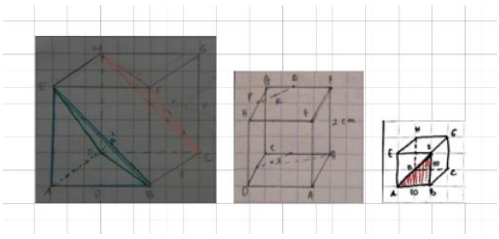

Figure 3 Student image size comparison

When students redraw their shapes, they also tend to use the number of boxes in their paper works books as a benchmark. Some students use many boxes, and some use a smaller number.

Of the eight students who observed and interviewed, all usually redraw the object in their paperwork which is usually a grid paper. When drawing, students often use some help. As in pictures 3 and 4, some use dash lines to show the spatial shape, and some use solid and colored lines.

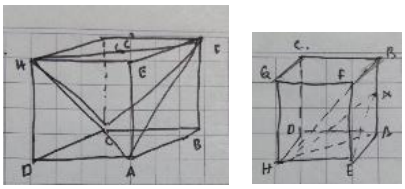

Figure 4 If there are many fields in a shape

When redrawing the shape, some students need to correct themselves in placing the point position. The point can place anywhere as long as it is the same as the

information given in the question. For example, there is a shape ABCD.EFGH, the order in placing these points must follow paths A, B, C, D, and E must be parallel to A, followed by F, G, and H. However, if the question is known, it is the shape of The ABDC.EFGH point placed must also follow A, B, D, C, E, F, G, H

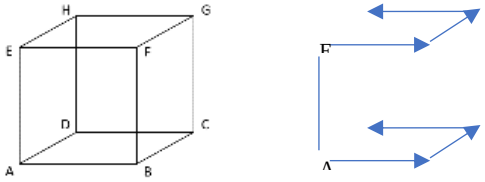

Figure 5 Build point sequence

When a new plane has formed on a shape, most students will take the plane out. However, there is also one student who works directly on the main shape. He will only move the plane if he finds it difficult to solve the problem.

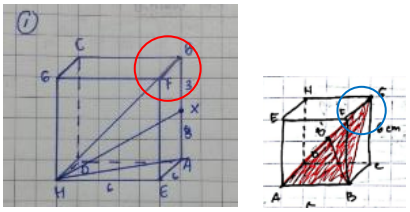

Figure 6 Student drawing results: effect of the position of the diagonal line in space

Students often lose the diagonal lines of space because of the orthogonal lines they make. It happens because students use the box grid in the paperwork as a benchmark for making tidal angles or angles formed between frontal and orthogonal lines.

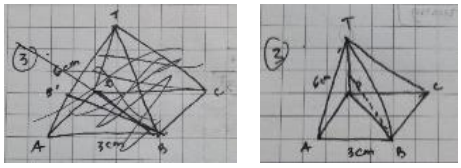

Figure 7 Prism image on the same problem (left)-(right)

Students also often lose lines when drawing prisms. In figure 7, the image on the left one gets crossed; the perpendicular line should be able to form towards the apex. Also, the oblique line TB is still visible, but this student is still determining if the shape produces the plane she needs. So she tries to change the shape, which

is missing the vertical line straight to the top of the T. This often happens when students draw a pyramid.

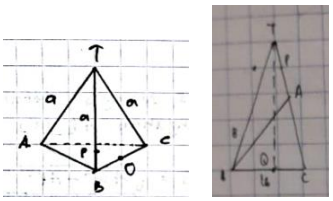

Figure 8 Triangular Pyramid

In addition to rectangular prisms, there are also triangular prisms. From this shape, we can see that the shape produced by students has no volume. The prism looks more like a plane.

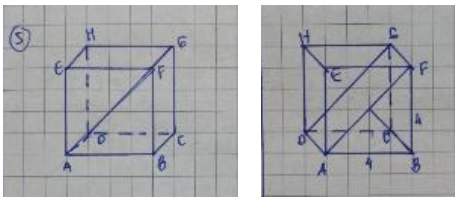

Figure 9 Changing Perspective

Because their drawing area is a math notebook which is a two-dimensional plane, there are two ways that most students do. It is to change the viewpoint and move the point on the shape. After that, they will draw the plane again.

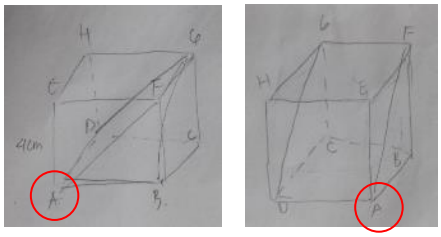

Figure 10 moving points

These two methods can replace the spatial rotation function that usually occurs in mind. It will help them to gain information.

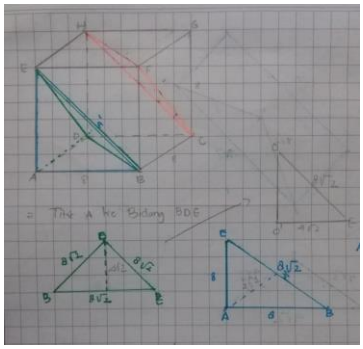

Figure 11 a picture of a student having difficulty moving the points

Even though changing perspective and rotating points is a solution, some students are afraid to do it. Because from their perspective, the image result is different from what they originally made. He feared that the difference would also affect the value of a side that was not even real. However, after changing the perspective and rotating the perspective, the resulting image is different, so they will have the perception that because visually if the shape is different, the size is also different.

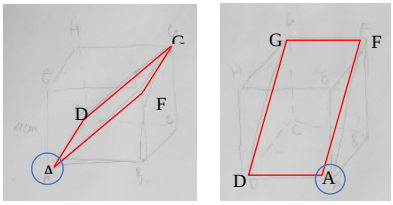

Figure 12 Visuals of different planes of the same

3.1.2 Interview Result

There are four parts to the interviews conducted with students.

Table 1 Table 1: interview results

First part: The experience of students learning three-dimensional geometry at school	> some teachers describe many planes in one form without removing these planes > Some teachers also do not use aids, visual aids, or anything that can distinguish a plane in terms of construction > The teaching materials used do not vary > The visual type of images that create are also always the same > When explaining space, some teachers associate the shape with the classroom. Some students thought it helped them, but some could not do it anymore According to the students, the things above were enough to influence their drawing habits and their ability to understand the plane and find ways to solve the geometric problems they were working on.

The second part: Student experience	> What is most difficult for students is if there are many planes in one shape > With so many planes, students often lose the plane they are looking for > Students agree that their ability to solve geometry can improve if they practice a lot
Third part: Students' experience with the visual images they are working on	> Visuals that are always the same can make them bored working on questions > If not familiar with the visuals, they will be afraid that they cannot solve the problem > While drawing, the student just tried to imitate the shape. It happens if they do not understand the shape and try to collect information about the shape > Some students need help such as rulers, colored writing instruments > Those who do not use assistive devices use techniques such as using dash lines or color blocks to help understand the objects > When drawing, students tend to draw on lined paper and use plain paper as a medium for them to make sketches > According to some students, cleanliness and tidiness are very important when drawing
Fourth part:	> One student who is an Olympiad is more focused on solving the mathematics aspect > Three students like mathematics but have difficulty learning mathematics in high school, and three do not like mathematics. They all fear being unable to solve problems and affecting their grades. Then there is one person who does not want to be too long associated with mathematics > Students stated that the teachers who taught in their classes did not make use of technology and that teachers preferred to use books as materials > Only a few subjects allow using technology, such as laptops and smartphones, for presentations and sharing teaching materials > Students who prefer using smartphones explained that devices are more concise and easy to be carried anywhere. Smartphones are also popular because of the applications they use to help students learn using the photo feature. > Also, some students use Chromebooks because they are taking an online course. Then some use laptops because they have many features > The information references needed by students tend to be text and audio-visual, but there are 3 out of 8 students who need features that can explain this information, like teachers in class > Students have many assignments, so they have a pretty hard time exploring things > Students use notebooks to keep good information obtained while studying at or outside school. Students use notes, so they do not have to look for the information in the original resource

	> Students' favorite social media are Instagram and TikTok. While using Instagram, students now rarely use the feed, more using the story feature > Some learning applications are familiar to the student, like Qanda, Ruangguru, RoboGuru, and also Quipper

Based on the results of the observations and interviews before, there are several recommendations obtained to help students learn and solve three-dimensional geometry problems, including:

1. It is easier for students to determine the shapes they want to find
2. Students can name the point correctly according to the position that informs in the question
3. Students do not lose the lines when drawing (especially for cubes and pyramids)
4. Students can distinguish the front and back of the shape so that they understand the spatial shape
5. Students can rotate the shapes without having to redraw them
6. Students can identify the image of the plane to be issued
7. When rotating the shape, Students can understand the shape and size of the object
8. More than one plane can be formed in shape, but students still have to see the differences easily
9. Students can save their work and still access it if they want to study it again

3.2 Scope

Recommendations obtained at the Scope stage will be developed to find the right features for users. These features are explained through user stories.

Table 2 User Story 1**:** As a user, I want to make it easier to define shapes

As a user, I want	> Have multiple build options > The builds I use frequently are the easiest-to-see/will be placed in first place > Change the perspective of the shape in perspective or isometric mode > There is a difference between shapes, especially cubes and blocks, other than the known size	> It does not take too long to draw from scratch > So that You do not have trouble looking for the shape > So that You can see the wake in various modes > So it does not mix up when choosing shapes (lines of the same length are the same color)

Feature:
- Features for drawing: Solid, there is a choice of shapes. Shapes that frequently use are in the front position,
- Changing view:
  - In order to be able to change the visual plane formed in shape to be perpendicular
  - See the whole shape in perspective and isometry

Table 3 User Story 2: As a user, I want to name the point correctly, so I understand the image (avoiding carelessness)

As a user, I want my	> Point positions are not to be swapped.	> So that the image that I have made follows the question / is not wrong to continue the image
	> The Wrong point can be fixed.	> In order to be able to fix if it is wrong when typing a point or fix the point position
	> My point is still visible even though behind the shape	> So that I can still see all the point
	> Add a point inside a line	> In order to make wake up
	> The selected point is different from the one that was not selected	> In order not to be mistaken when selecting the point being worked on

Feature:
- The shape **moves automatically** in one way when it has finished naming a point.
- (to prevent the student from unknowingly placing the points incorrectly. The feature will help order points same as the question)
- **Delete:** can remove the wrong component/image by deleting or "holding and carrying" (erase/hold and drag)
- **Undo:** for minor errors, there is no need to remove the component
- The added point is not limited to the shape or space angle but can also be inside the line
- **Opacity:** to help adjust the color density of shapes and planes
- **Point:** to name the point
- The currently selected point has a different color than the unselected point.

Table 4 User Story 3: As a user, I want a rotatable shape so that it does not lose the diagonal and orthogonal lines

As a user, I want	> The perspective of the shape is changeable	> So it is not fixated on one perspective
	> Can add a line from a point	> In order to be able to draw new planes on the shape
	> The plane that creates has a different color from the shape	> So I know the point I took

Feature:
- **Rotate button:** to rotate the shape (so as not to disturb the points or lines on the shape)
- **Connect lines:** connect new or existing points
- **Color:** it can change the color and also the planes according to what you want

Table 5 User Story 4: As the user, I want it to be easier to see the shape so I do not get confused between the front and back that I am working on

As a user, I want	> There is a distinction between the front and back of the shape > The point on the back of the wake can still be seen clearly > There is an opacity option to adjust the density of the shape's color	> So that the spatial shape is apparent. Also, when rotated, the front and back are clearer > So that the position of the front and back points is not confused > So that it is clearer to see the plane position that formed in shape
Feature: > To help adjust the color opacity in shapes and planes, color density can be adjusted to bring out the point that is behind the shape		

Table 6 User Story 5: As a user, I want the shape to be visible from many sides, so I do not have to draw on each side like when using a two-dimensional drawing plane like paper

Sebagai pengguna, saya ingin	> Be able to rotate shapes	> So that I do not have to redraw from a different side
Feature: > **Rotate:** to rotate the shape without bothering the point or line		

Table 7 User Story 6: I want the plane that forms in shape still there, so there is no need to take out the plane, which often confuses me

As a user, I want	> No need to move the planes that formed in the shape > Rotate the plane on the horizontal and vertical planes	> So there is no need to redraw on a new plane > So that it is easier for me to see in a flat and straight plane so as not to get confused
Feature: > Just like perspective and isometrics, there is also a button that can activate the position of the selected plane to a vertical position so that it becomes flat and perpendicular, and a button to return to its initial position		

Table 8 User Story 7: I want to identify the planes that form in shape easily, even if there contains more than one plane. I do not want to be confused between one plane and another

Sebagai pengguna, saya ingin	> There is an option to give a different color to the selected plane	> So that one plane and another are not mixed
Feature : > **Color,** in order to change the color of the selected area > **Opacity,** to help set the thickness of the plane		

Table 9 User Story 8: I want to be able to save previous work so I can review it again if I need to

As a user, I want to	> Be able to save specific/previous work > There is history/recent wor	> So that it can be studied if necessary > So I can track the work I have done
Feature: > **Save,** if you want to save work and review specific work (requires login to the application) (students have a habit of studying the homework again, especially when going to exams)		

3.3 Structure

The structure is in the third stage of these five stages. This stage connects the strategy and scope to the next level in the skeleton stage. This stage will determine the end result of the product that the user will use. In the structure stage, it is made based on the stages for new users and also the stages when making a build. For new users, the process includes entering the application. Continuing to enter the canvas that can access with the create new, open, and recent buttons. The user can access open only if he has saved his previous work and logged in to the application. However, if they do not go through the login process, students can keep working but cannot save their work. Whereas through recent work can only access some previous work. If there are other jobs, the old ones can be lost.

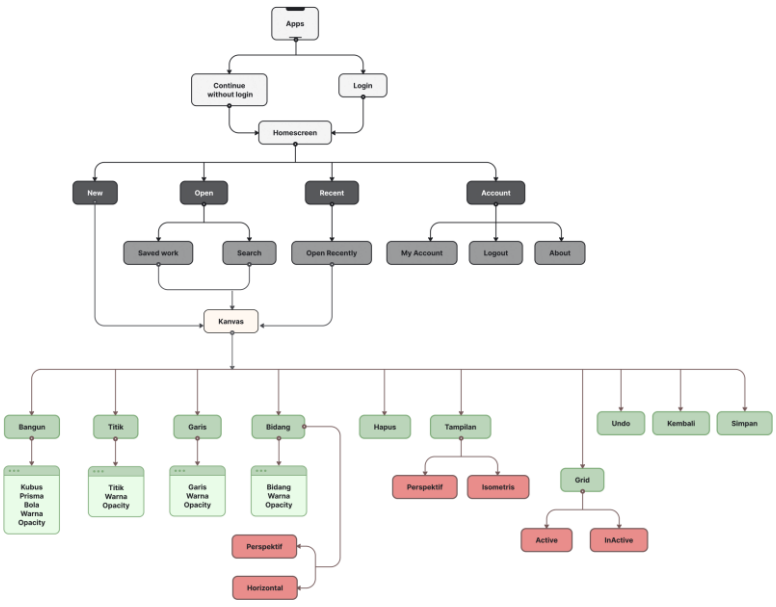

Figure 13 Information Architecture

Based on students' habits when working on problems, they always start by drawing, continue adding points, and connecting them with the line. For Olympiad students, he starts by knowingly analyzing the values in the questions to use or determine the best equation. Done with identifying and drawing the shapes, the students will recheck the question to find out what they need to solve the problem. The main features for drawing consist of shape, point, line, and plane options. Then there are also features such as activating the grid. That feature will help students who get used to using the squares on math paperwork to measure the shape size.

To prevent students from making mistakes, when adding a point, the shape will automatically rotate the shape so that students are confident in placing the point. Then there is also an undo feature that can use if the student misplaces the point. The automatic rotation of the shapes can prevent students from misplacing a point, but students can still misname it.

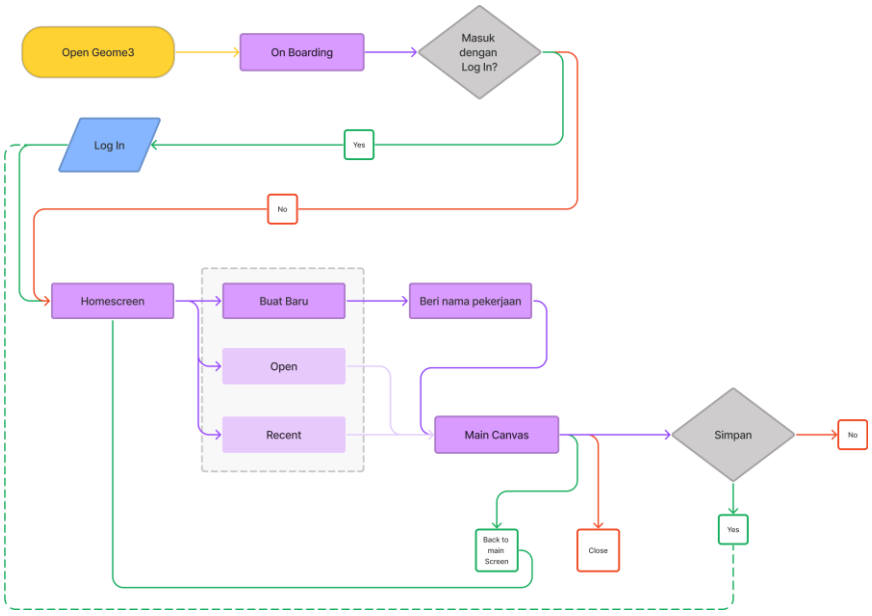

Figure 14 User flow

3.4 Skeleton

In the skeleton plane, three things must consider: interface design, navigation design, and information design. Interface design includes the design for components such as buttons, lists, and other interface components. Navigation design is a particular product from the interface that will adapt to the information. Meanwhile, information design presents communicative information.

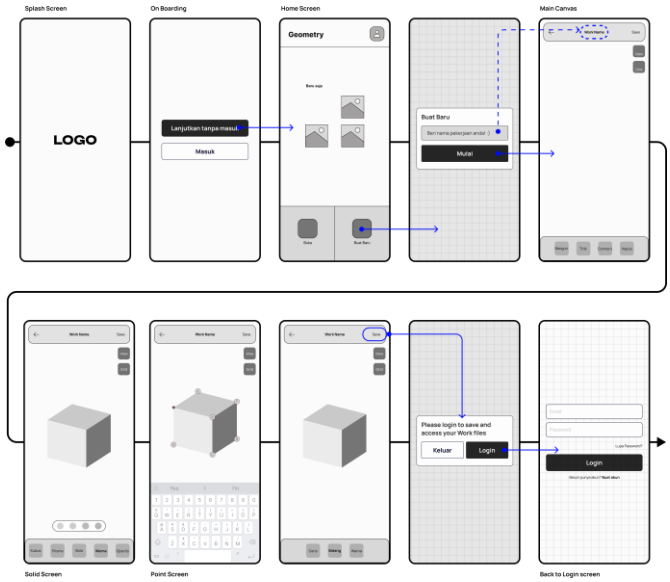

Figure 15 Wireframes

Next is made a wireframe, which is a place for interface design, Navigation design and information design to be put together. In the design, the screen starts from onboarding and continues to the home screen. While onboarding, the user can log into their account or continue without logging into the account. On the student home screen, there are also options for students to create new work, open work they have previously saved, or access what they have work. The recent work is different from the saved one. It will only show some of the last work and is not permanent. The one they just worked on also does not require access to the user account. Before entering the canvas, the user is asked to provide a name for the job. Entering the main canvas, users can access the main drawing tools: shape, point, line, area, and delete.

3.5 Surface

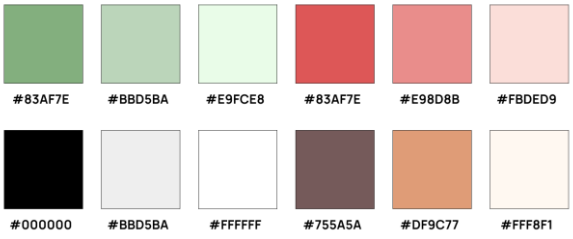

Figure 16 Colors

The surface has a focus on the user's sensory experience. One of them is vision. Vision is an area to develop the user experience from visuals, not only aesthetically but also how these visuals help the product run well.

It is the same with designing other visual designs. Color is needed to help lead users. Color can help impact users' perceptions when using a product. In addition, color also acts as a visual identity and can build a brand owned by a product.

Figure 17 Typography and components

Based on the previous wireframes, the next step is combining that wireframes with colors, typography, and components. After that, make the interaction between each element and component so users can run and test this application to gain user experience.

Figure 18 Interface

4 Conclusion

Something is needed to help students learn and solve three-dimensional geometry problems. Based on secondary data from previous research, they need a media that they can explore but does not confuse them. The media must be able to help students draw well and make them understand the shapes they draw. Research is continued on users using the Five Elements of Users Experience framework. The research conducted with this framework found the user needs. Some of the results in this study confirm previous secondary research, and other results serve as a reference for design recommendations to be implemented. The media that will use is an application. Because even though students have their favorite devices, such as laptops or chrome books, they all have smartphones and spend much of their time with them. This design is still a high-fidelity prototype with results starting from the user entering the application, using the drawing tool until finished using the application.

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