THREE-DIMENSIONAL WEB-BASED PHYSICS SIMULATION APPLICATION FOR PHYSICS LEARNING TOOL

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Abstract: The purpose of this research is to present a multimedia application for doing simulation in Physics. The application is a web based simulator that implementing HTML5, WebGL, and JavaScript. The objects and the environment will be in three dimensional views. This application is hoped will become the substitute for practicum activity. The current development is the application only covers Newtonian mechanics. Questionnaire and literature study is used as the data collecting method. While Waterfall Method used as the design method. The result is Three-DimensionalPhysics Simulator as online web application. Three-Dimensionaldesign and mentor-mentee relationship is the key features of this application. The conclusion made is Three-DimensionalPhysics Simulator already fulfilled in both design and functionality according to user. This application also helps them to understand Newtonian mechanics by simulation. Improvements are needed, because this application only covers Newtonian Mechanics. There is a lot possibility in the future that this simulation can also covers other Physics topic, such as optic, energy, or electricity.

Keywords: Simulation, Physic, Learning Tool, HTML5, WebGL

INTRODUCTION

Physics is one of the science subjects for students to learn in core educational phase (elementary until senior high school). Physics subject abstracted natural phenomenon as mathematical equations which provides understanding of the world from quantified view. Because of the nature of such abstraction, students might feel confused upon theories and formulas given in physics study. To help students understand the concepts, application of theories and formulas in real life is important. The conventional method is utilizing physics props in school's science laboratory.

Computer simulation may be used as an alternative instructional tool, in order to help students confront their cognitive constraints and develop functional understanding of physics. Providing computer simulations would provide a better dynamic for students in classroom, and also provides teachers with easy-to-use teaching tool for explaining physics theories and formulas with direct, real-world examples. Computer simulation provides virtually limitless physics props, and students can access the simulation at any given time.

WebGL is a cross-platform, royalty-free web standard for a low-level 3D graphics API based on OpenGL ES 2.0, exposed through the HTML5 Canvas element as Document Object Model interfaces.

WebGL provides graphical capabilities on par with desktop application while allowing application to run on average modern browsers. Using WebGL as its core technology, this thesis to create three-dimensional web-based physics simulation application for physics learning tool is hoping to provide easy-to-use tool to make studies of physics subject, especially for elementary to senior high school students, more efficient and attractive. It is hoped that efficiency gained through this tool would trigger technological advances with better student understanding and performance, and increase Indonesia's educational quality in the long term.

The purpose of this research is to develop a three-dimensional web-based physics simulation application for the purpose of education, especially as physics course learning tool, using HTML 5, JavaScript, and WebGL technology. Benefits of this research are to provide students with learning tools for physics subject, to provide teacher with simulation tools to aid teaching sessions and to increase students' interest in learning physics.

METHOD

The methodology used for this research begin with information gathering which consists of literature study, analysis of user and analysis of similar applications. Literature study is done through

collecting data and information in the form of books, e-books, and journal related to the topic. Data from user are collected through online questionnaire. Analysis of similar application acquired from using and testing features of other applications with similar purposes, in this case are e-dukasi.net and Physion. All the data collected are then compiled to address the needs and find the solution requirement. The next step is to create a model based on the analyzed requirement. The model is then implemented by using WebGL and javascript. After the program is finished, we conduct a direct testing to the potential users and collect the data from them. The data is evaluated and used to make conclusion of this research.

Literature Study

Physics rationalize abstract life concepts into mathematical equations through measurements. Measurement units are standard names assigned to the quantities of specific qualities of physics phenomenon. According to ref [1], the study of relation between a force and the acceleration it causes is called Newtonian mechanics. This was first understood by Isaac Newton (1642-1727).

According to ref [2], simulation involves building a dynamic model of a process or system, then performing what-if analysis to see how changes would affect the actual process. By mimicking its operation system is better understood, explore more alternative strategies, optimize performance, and train personnel – all at a fraction of the cost and time it would take to experiment with the real system. Ref [3] explains that WebGL is the new standard for 3D graphics on the Web. With WebGL, developers can harness the full power of the computer's graphics rendering hardware using only JavaScript, a web browser, and a standard web technology stack. Before WebGL, developers had to rely on plug-ins or native applications and ask their users to download and install custom software in order to deliver a true 3D experience.

WebGL is part of the HTML5 family of technologies. While not in the official specification, it is shipped with most browsers that support HTML5. Like Web Workers, Web Sockets, and other technologies outside the official W3C recommendations, WebGL is an essential component in an emerging suite that is transforming the modern browser into a first-class application platform. According to ref [4], JavaScript is the programming language of the Web. The overwhelming majority of modern websites use JavaScript, and all modern web browsers—on desktops, game consoles, tablets, and smart phones—include JavaScript interpreters, making JavaScript the most ubiquitous programming language in history. JavaScript is part of the triad of technologies that all Web developers must learn: HTML to specify the content of web pages, CSS to

specify the presentation of web pages, and JavaScript to specify the behavior of web pages.

According to ref [5], Instructional Design is the linking science that applies logic and scientific methods to the problems involved in designing and developing instruction. Instructional design developed from discipline of psychology education around early twentieth century. Ref [6] explained that multimedia can be defined as presenting words (printed text or spoken text) and pictures (photos, animations, illustrations). Multimedia Learning is building mental representations from words and pictures. Multimedia instructions involve presenting words and pictures that are indented to promote learning.

According to ref [7], objects in a 3-D environment have width, height, and depth. These dimensions correspond to the dimension in most 3-D system used for modeling. Mathematical model that uses these models to define 3-D geometry is called Cartesian coordinate system. In 2009, Ref [08] conducts a study titled "The Effect of Combining Real Experimentation with Virtual Experimentation on Students' Success". Their purpose is was to investigate the effect of combining Real Experimentation (RE) With Virtual Experimentation (VE) on students' conceptual understanding of photo electric effect. Two groups were set up for this study. Participants in the control group used RE to learn photo electric effect, whereas, participants in the experimental group used RE in the first part of the curriculum and VE in another part. Achievement test was given before and after the application as pre-test and post-test.

The result seems promising. The study have proved that combining Real Experimentation (RE) with Virtual Experimentation (VE) have a significant effect on students' evolving skills, attitudes and conceptual understanding. According to the mentioned results above, ref [08] at the end of their study suggest the following implications can be given for the development of physics teaching-learning process: (1) The computer-based simulations should be used in all physics lessons. (2) The physics teachers should encourage using simulations in their lessons. (3) The physics laboratories should be practiced by combining Real Experimentation (RE) with Virtual Experimentation (VE).

RESULT AND DISCUSSION

Application Design

Three-Dimensional Physics Simulator is simulation software designed to simulate Newtonian mechanics. It functioned not only as a simulator, but also as learning tools. It is connected to a system to provide tutorials and exercises for its users. Three-DimensionalPhysics Simulator aims to enhance physics learning. This application can

only be running in online mode, which means you need internet connection or intranet network. The user data such as login data, score, exercise data and simulation are stored in the server database. Three-DimensionalPhysics Simulator use PHP as programming language and MySQL as the database. Three-DimensionalPhysics Simulator also uses cannon.js as the main physics engine.

Three-Dimensional Physics Simulator does not enforce user to register while using the application. User can still access the simulation page, do simulation, browse tutorial, and browse available exercise even you are not logged in. Other functionality will be unlocked after you logged in to the system. There are three roles for logged in user: mentee, mentor, and administrator. Each has special functionality in their user page. For example mentee can view their score history. Mentor can upload new exercise, delete the uploaded exercise, and also review their mentee history. Administrator can manage user's account such as ban user, delete user and approve mentor's uploaded exercise.

To test user understanding of the materials, it also provides exercises which result will be saved in a scoring system. This system serves as the user's study track record. Methods used for evaluation is using constructed-response test such as short-answer and essays item. User as mentee can browse all available exercise. Each exercise has specific topic. User can try to solve it and submit their answer. System then will display the score. User can try to solve the question as many times as possible. They can view their solving history in user page. System will record the result every time user solves an exercise. Hence they can review their learning process progress.

For the mentor, there is special features in their user page to get all score data of their mentee. It helps mentor to track their mentee learning progress. They can also use these data to evaluate their mentee. The basic concept of Three-DimensionalPhysics Simulator is to help users visualize physics theories into real-life images, in this case a simulation. Its main emphasis is to translate abstract physics concepts into visual elements in computer display in which users can interact and change physics values in order to see what happens next. Rather than forming vague images in mind, users can see their calculations simulated into concrete images using the application.

Three-Dimensional Physics Simulator is a learning tool, and thus it also incorporates tutorials and exercises in its system. Tutorials served as learning material for users to understand physics better. Tutorials are meant to be read and then tried on the simulator so users not only know how a physics concept is explained but also how it works in real life situation. Exercises are important to test how much users have understood the materials provided. A scoring system is connected to exercises to provide track records for user assessment. Three-Dimensional Physics Simulator also provide mentor-mentee concept. Every mentee can have one mentor. This concept works the same as teacher-student in real life. As a mentor, they can track their mentee progress through their score history. Mentor can also provide special exercise to utilize their mentee learning process.

This application provides many teaching method that can be adapted. Below are some of the teaching methods Three-Dimensional Physics Simulator can offer: (1) Tutorial, Three-Dimensional Physics Simulator comes with basic tutorial for physics course. User can browse and learn from tutorial available. This tutorial later on can be added according to the needs. (2) Demonstration, as a teacher or mentor, sometimes it is difficult to explain abstract material. Physics is one of the examples. Physics course brought phenomenon in real life into some mathematics calculation. Without certain explanation and example will be hard to explain the materials. Three-DimensionalPhysicsSimulatorprovidessimple way to help teacher or mentor bring the phenomenon into close-to real life occurring through simulation. While presenting the theory, at the same time mentor can also demonstrate the occurrence in the computer monitor. This might help the mentee or student to understand more rather than imagining in their mind only. (3) Simulation, rather than imagine what happened, user can test and simulate. Understanding theory will be difficult if only a matter of words. Using simulation will enhance and let the user to know what actually happen based on the theory. (4) Discovery, Three-Dimensional Physics Simulator provide simulation page. User can freely do anything regarding the properties they give to the objects. There is a lot possibility for them to discover new occurring in the physics course. Finding something new might help boost their interest in learning physics. (5) Problem Solving, this application also provides exercise that can be solved by every mentee. Their mentor can track their progress through their mentee score. Exercise given has two main purposes. First, it is to help mentee understand more about the physics topic. After reading the tutorial or trying simple simulation, they are challenged to do it for another case, which is available through the exercise. Second purpose is the scoring for the exercise can help them to evaluate their learning progress. Not only for themselves, but also their mentor can track their learning progress too.

System Design

The system design is started by designing a use case diagram to show all possibilities of use that any user of the system can do. This is done to ensure all functionalities are covered by the system. The use case diagram is shown in Figure 1.
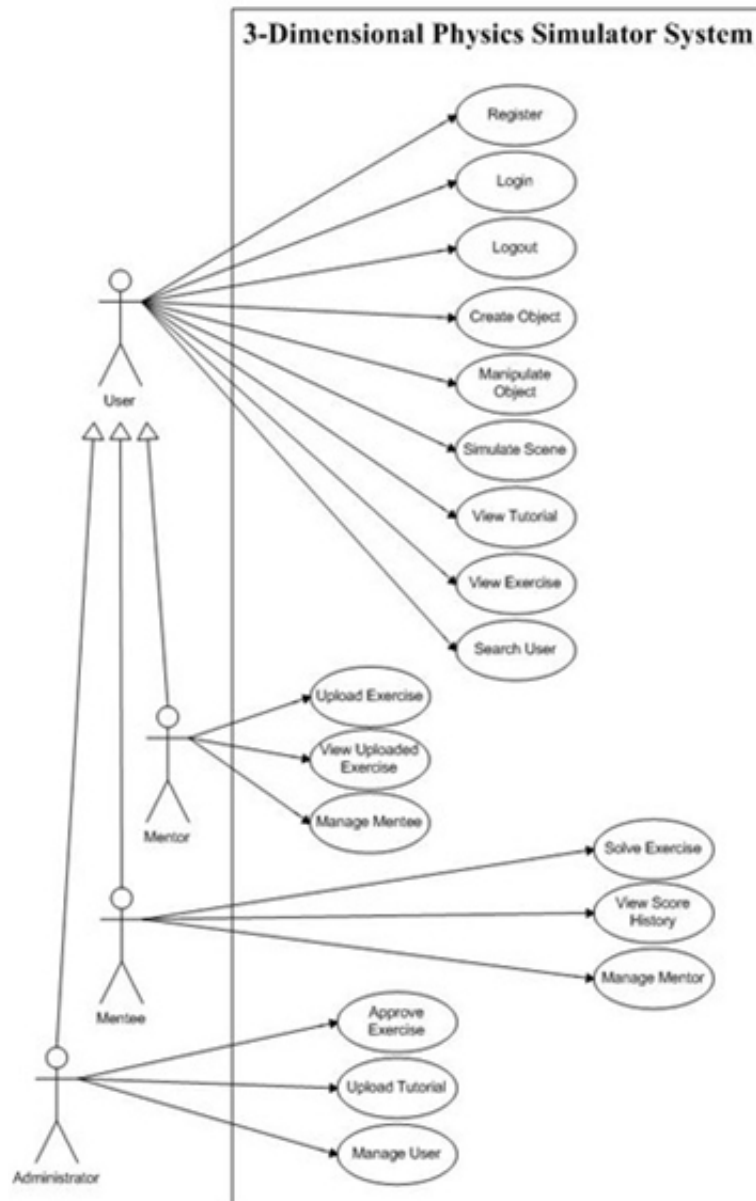
3-Dimensional Physics Simulator System

Register

Login

Logout

Create Object

Manipulate Object

Simulate Scene

View Tutorial

View Exercise

Search User

User

Upload Exercise

View Uploaded Exercise

Manage Mentee

Mentor

Solve Exercise

View Score History

Manage Mentor

Mentee

Approve Exercise

Upload Tutorial

Manage User

Administrator

Fig. 1: Use Case Diagram

Each use case then will be described in detail by using use case narratives to show the flow of each case. For system architecture model, class diagrams are used to model each entity that will be included in the system. These entities will reflect the actual code that is used to implement the system. The detailed class diagram is shown in Figure 2.

System Implementation

Users can login into the application either as a mentor or as a mentee. Users can also login as a guest, which will be offered limited capabilities of the system. Users can also register as a new member of the system. These login and register pages are shown in Figure 3. Figure 4 below shows the simulation page which will appear after the user login into the system. Here, they can put many kinds of physic objects as they like into the scene and configuring its properties. After that, they can begin the simulation to show them what will happen to the objects in real-time.

As described before, the application will include exercises to let every mentee evaluate themselves whether they already mastered the topics or not. These exercises can also be used by the mentor an evaluation tool to evaluate their mentee. Every time a mentee answer the questions, the system will then record the scores which can be viewed any time by the users. The example of exercise page is shown in Figure 6.
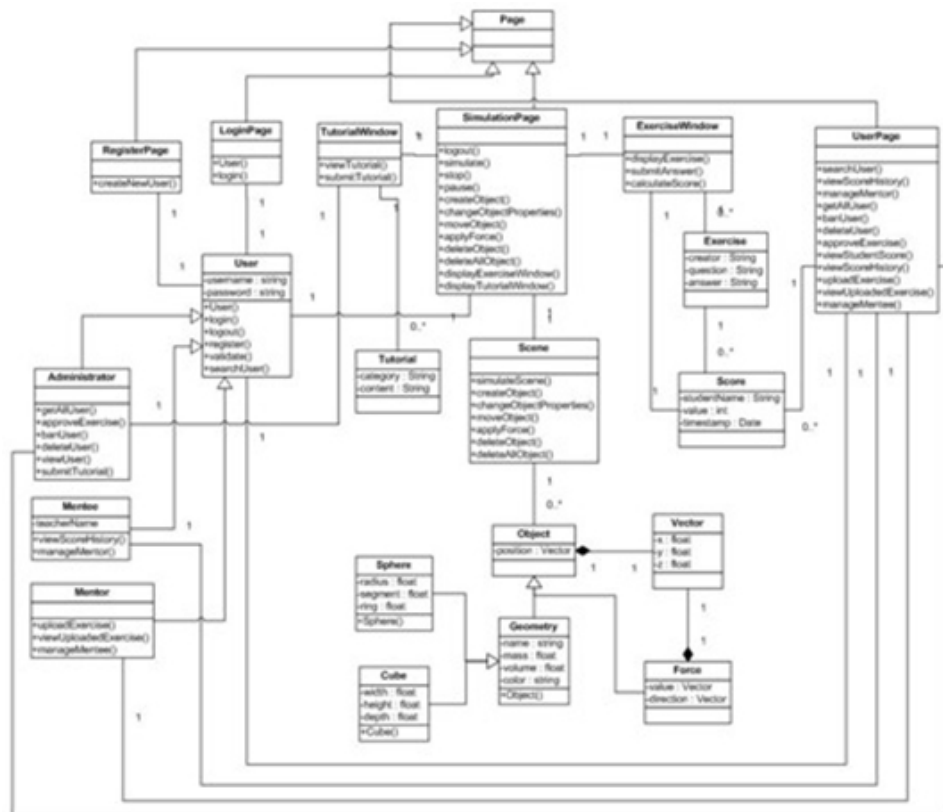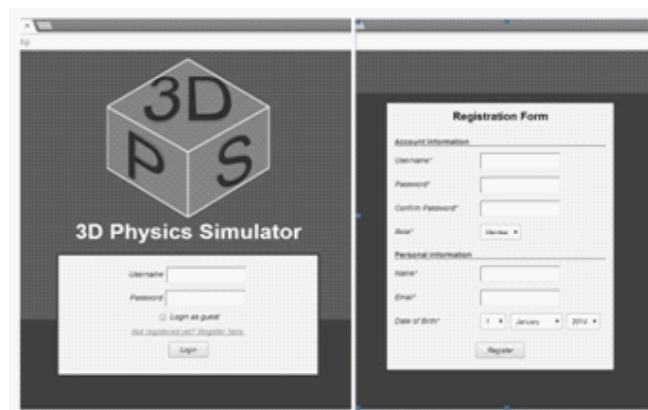
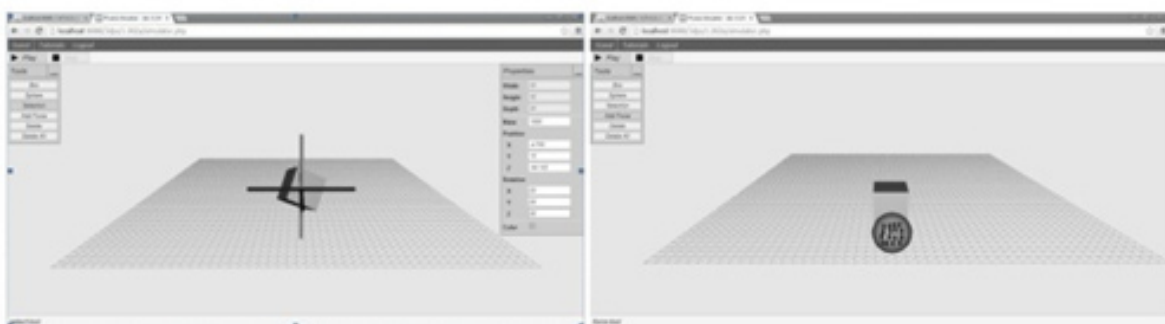Fig. 2: Class Diagram

Fig. 3: Login Page and Registration Page

Fig. 4: Simulation Page

Fig. 5: Tutorial Page

Fig. 6: Exercise Page

Evaluation

Evaluation was conducted on the "Eight Golden Rules" by ref [9], five multimedia elements according to ref [10], comparison with similar application and also according user's reviews. Every aspect described is tried to meet in eight golden rules as we design and implement the system. This is to ensure the good quality of user experience as well as more comfortable learning environment. While every element of multimedia in the system is also included, video element is discarding at the end since this element are not really needed for the system. Video usually take a lot of bandwidth for a web-based system and for our purpose, the video can actually be replaced by animating or simulating the objects in real time. However, in the future, videos may be used as additional learning materials to show material that can't be easily animated in real time.

As we also use other similar application to find the needs of our system, we also re-evaluate every feature that is not present on the other systems or feature that can be improved. Three-Dimentional Physics Simulator overcome the other compared system in a certain ways such as:

Table 1: Comparison with other similar applications

Category	e-dukasi.net	Physion	Three-DimensionalPhysics Simulator
Graphic	2D	2D	3D
Tutorial	Yes	No	Yes
Exercise	Yes	No	Yes
Material	Yes	No	Yes
Interactivity	Limited	Yes	Yes
Scoring system	Yes, not stored.	No	Yes, stored in user database

User's reviews are collected through online questionnaire. These user feedbacks are very important component of the evaluation as we need to know what the user think about our system and how well the system can replace the real physic practicum. Some of the questionnaire produced results are shown below:
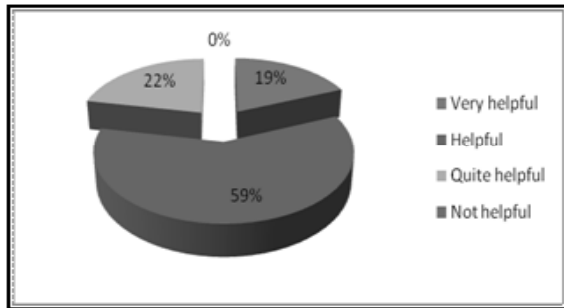

Fig. 7: Do you think tutorial provided by Three-DimensionalPhysics Simulator helps your understanding about the delivered material?
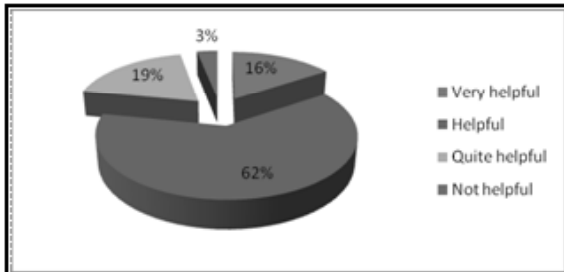

Fig. 8: Do you think simulation feature provided by Three-DimensionalPhysics Simulator helps your understanding about delivered material?
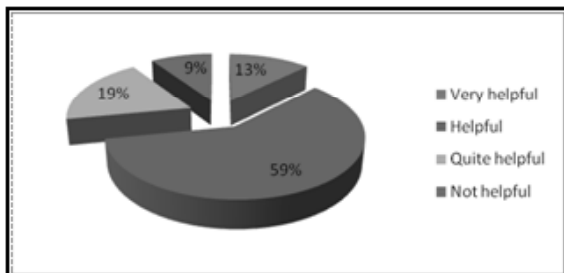

Fig. 9: Do you think exercise provided by Three-DimensionalPhysics Simulator helps you evaluate the delivered material?
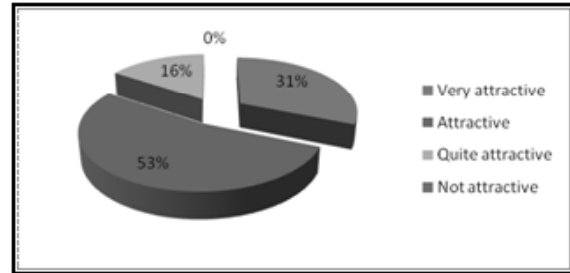

Fig. 10: Do you think Three-DimensionalPhysics Simulator more attractive rather than doing direct Physics practicum, especially for "Newtonian Mechanics" material?

CONCLUSION

Successfully develop an application titled Three-Dimensional Physics Simulator. This application is an online web application that help learner visualize Physics occurrence into computer simulation. From all respondents, 78% amongst them think simulation feature provided by Three-DimensionalPhysics Simulator helps their understanding about delivered material. Also 78% of the respondents agree that tutorial provided helps them understand the delivered material. Besides the simulation and tutorial, there is also exercise to evaluate their learning process. About 72% of the respondents state that exercise provided them helps for evaluating the delivered material.

Three-DimensionalPhysics Simulator also able to increase student's interest in learning Physics. About 84% of the respondents find that using Three-DimensionalPhysics Simulator is attractive rather than doing direct Physics practicum. Three-DimensionalPhysics Simulator can run in every computer as long as the browser supports HTML 5 and WebGL. Internet connection also required to access the webpage.

Recommendations can be given to support further development of Three-Dimensional Physics Simulator are: (1) More variations for the Physics main topic. This application only covers some parts of the Newtonian Mechanic. For the future development, additional topic can be added such as light, fluids, or other main topics. (2) Increase the variations of objects that can be created inside the

simulation page. (3) More properties for each object to be customized, such as density. Force that can be customized in properties, such as directions and value. (4) More varied exercise such as, multiple choice, short answer, or even essay question. (5) Tutorial that using images or even video to further increase capability in delivering materials.

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