Authoring Quizzes with Interactive Content on the Mathematics e-Learning System STACK

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Abstract. The mathematics e-Learning system STACK is a quiz system where students do not select answers from options provided by teachers but instead submit mathematical expressions. This kind of e-Learning system is especially useful for mathematical science subjects. STACK is usually used for drill practices of mathematical sciences. In this paper, we propose its usage for self-learning. In order to realize self-learning using STACK, we developed interactive content using the CindyJS framework of Cinderella, a type of dynamic geometry software, and embedded it in questions for students to investigate and interact with by themselves.

1 Introduction

In the last few decades, information and communication technology (ICT) infrastructure has developed greatly in schools and universities thereby boosting the popularity of e-Learning worldwide. Online learning content can be distributed through learning management systems (LMSs) from which students can download and learn material. Online assessment systems, in other words, computer-aided assessment (CAA) systems are also an important feature of the e-Learning system as they can automatically assess whether students' answers are correct or incorrect. Students can use the system as drill practice while their level of understanding can be evaluated by it. One of the most common types of question in online assessment systems are multiple-choice questions (MCQs), in which potential options are provided by the teacher and students select a single response as their answer.

While online assessment systems can be used in scientific subjects, MCQs are not sufficient to evaluate the level of students' understanding of the subjects. For example, in a test on calculation, students can, by guesswork, simply "choose" an option from the list of potential answers, which may be the correct answer. In order to avoid this kind of problem, it is preferable to adopt other question types in which students provide mathematical expressions as answers by calculation, or what we call the "Mathematics e-Learning system." STACK [1] is one such system, while there are some others such as Maple T.A. [2], MATH ON WEB [3,4], Numbas [5], WeBWorK [6], and so on.

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Mathematics e-Learning systems are useful in drill practices for calculation because students receive instant feedback on whether their answers are true or false. Furthermore, STACK can be used for self-learning through its mechanism of sending feedback according to students' answers, in what is known as a "Potential Response Tree (PRT)." A simple example of feedback for the correct answer to a question on differentiation $\dfrac{d}{dx}\cos(2x)$ is shown in Fig. 1. This is a common feature, even in other mathematics e-Learning systems. In STACK, if a student inputs the answer $-\sin(2x)$, he or she may forget the rule of differentiation of the composite function, for which suitable feedback is given as shown in Fig. 2. When a student inputs the answer $2\sin(2x)$, he or she may know the rule of differentiation of composite function but may calculate the differentiation of trigonometric function carelessly. In this case, suitable feedback is given to the student as shown in Fig. 3.

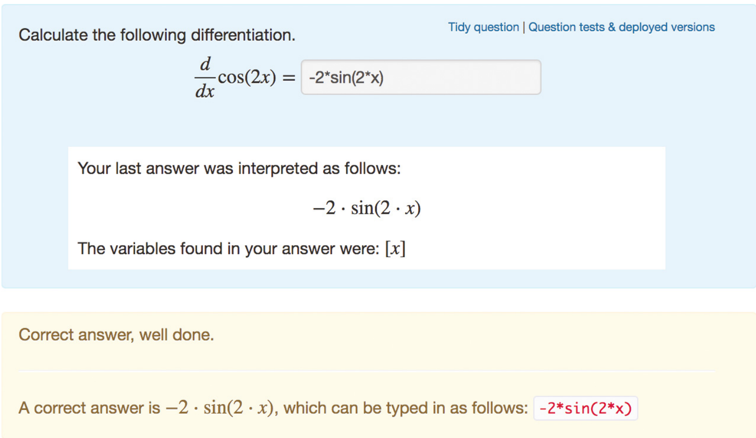

Fig. 1. An example of feedback for a correct answer in STACK.

With the help of PRT, students can recognize their misunderstandings when they input incorrect answers. However, they have to find a trigger to solve problems when they look at the questions. For example, let us consider the question related to geometric figures displayed in Fig. 4. In order to solve the question, students must draw the circle $x^2 + y^2 = 9$ and point A in their notebook, and then guesstimate the trace of point P, which is a point that is midway between A and Q that moves on the circle.

It is important for students to be provided with a trigger to solve questions by themselves, but doing so is sometimes difficult. In this paper, we would like to suggest some solutions to this problem. One of the solutions is to embed interactive content into questions to help students consider about the questions. This will eventually boost self-learning in students.

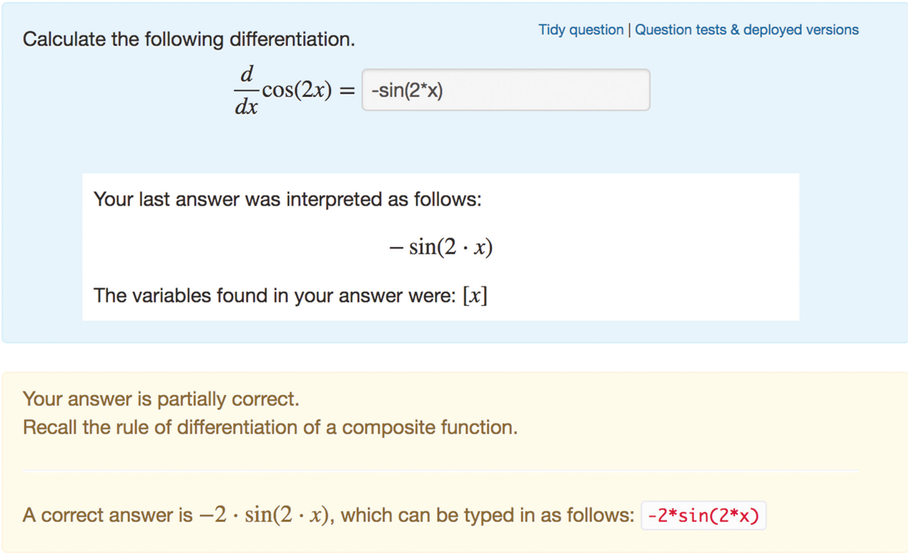

Fig. 2. An example of feedback for a partially correct answer in which a student may have forgotten the rule of differentiation of a composite function.

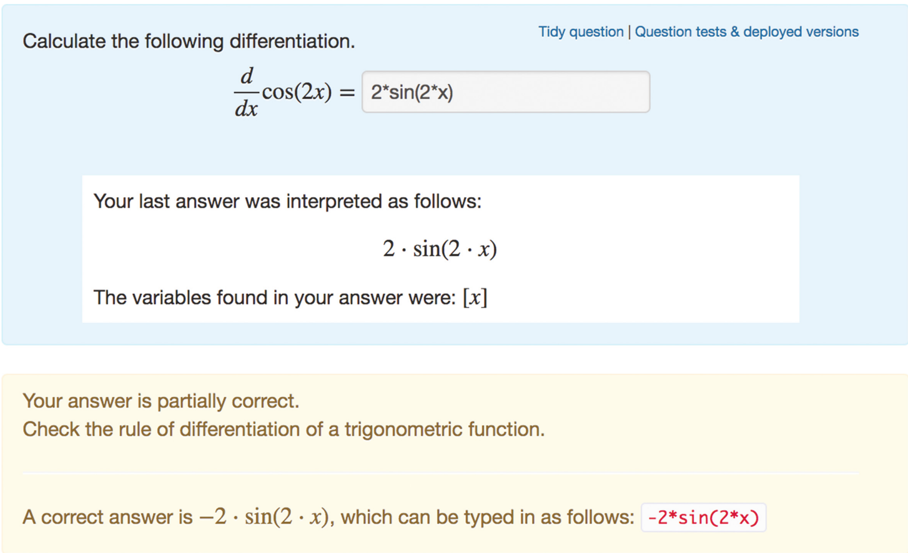

Fig. 3. An example of feedback for a partially correct answer in which a student may have miscalculated a differentiation of a trigonometric function.

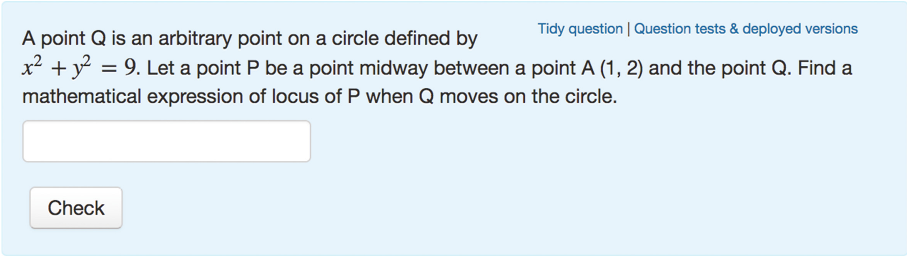

Fig. 4. An example of a question related to geometric figures.

This paper is organized as follows: in the next section, we describe how to embed interactive content; in Sect. 3, we discuss the effective use of STACK questions with interactive content; and, finally, in the last section, we conclude our paper.

2 Interactive Content Embedded in STACK Questions

Embedding interactive content such as animations, movies, applications, and quizzes in learning materials to help students learn their subjects is relatively popular, particularly in e-textbooks. Some quizzes that are connected with an LMS's are prepared in e-textbooks so that teachers can grasp how much students have learned using e-textbooks by viewing their learning logs [7].

In this paper, we concentrate on online tests with interactive content because there are more learning materials prepared by LMSs than by e-textbooks, and online tests are most important to understand the comprehension level of students.

2.1 How to Embed Interactive Content in STACK Questions

STACK questions can be authored using normal texts including TEX syntax. A graph of functions for one variable can be drawn in questions as standard and the plotting function can be enhanced to draw a graph of functions for two variables and implicit functions by minor customizations [8]. These graphs can be drawn dynamically according to the parameters defined in the question, but the graph itself is static rather than interactive.

In this paper, we pursue an approach to embed interactive content in STACK questions. Maple T.A. uses the computer algebra system (CAS) Maple to embed interactive content in questions by using its appropriate functions. STACK uses Maxima as the CAS and the plotting function of Maxima is restricted to use in STACK; thus, it is not impossible to use Maxima to realize interactive content in STACK.

STACK question texts are basically written in HTML format. Therefore, one possibility is to develop JavaScript applications using libraries such as JSX-Graph [9,10], through which rich interactive content can be developed. However, a certain level of programming skill is required for this. One of the advantages of authoring questions with STACK is that it does not require advanced programming skills. The algorithms of evaluating students' answers are automatically built by the PRT. Another way to develop JavaScript content is by utilizing dynamic geometry software (DGS) such as GeoGebra [11] and Cinderella [12]. GeoGebra offers JavaScript API to interact with the GeoGebra applet. Cinderella's CindyJS [13] framework exports the JavaScript code to be embedded in the web. We adopted this framework to develop STACK questions with interactive content because it is simpler.

Although we do not explain how to prepare STACK questions in much detail here, let us briefly show how to prepare the question of Fig. 7 that we will see later as an example. The documents [14] can be referred to, to further understand the procedure.

Creating a Cinderella Content. We first developed an interactive content by using Cinderella, as shown in Fig. 5.

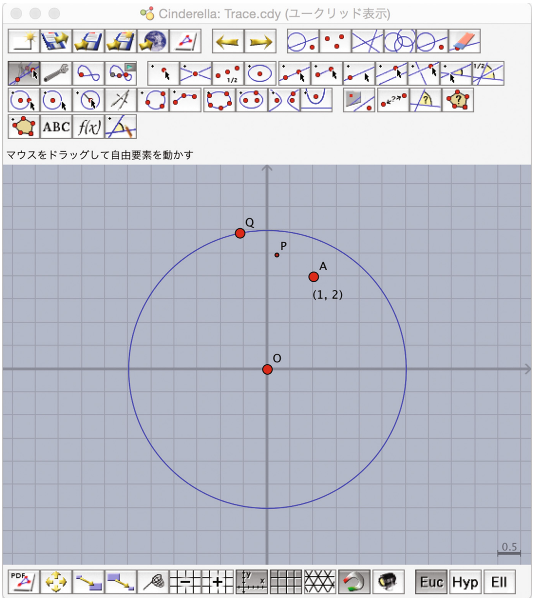

Fig. 5. An example of interactive content created by Cinderella.

Exporting to CindyJS. We can then export the created Cinderella content to CindyJS. The following exported code (with modification for display) is HTML text with JavaScript (CindyJS).

```
<!DOCTYPE html>
<html>
<head>
   <meta charset="UTF-8">
   <title>Trace.cdy</title>
   <style type="text/css">

   (snip)

   </style>
   <link rel="stylesheet" href="http://cindyjs.org/dist/v0.8/CindyJS.css">
   <script type="text/javascript"
   src="http://cindyjs.org/dist/v0.8/Cindy.js">
   </script>
   <script type="text/javascript">
       var cdy = CindyJS({
           scripts: "cs*",
           defaultAppearance: {
   (snip)
           },
           angleUnit: "°",
           geometry: [
               {name: "O", type: "Free", pos: [0.0, -0.0, 4.0], (snip)
               {name: "A", type: "Free", pos: [-2.0, -4.0, -2.0], (snip)
   (snip)
           ],
           ports: [{
               id: "CSCanvas",
               width: 556,
               height: 435,
   (snip)
           }],
           csconsole: false,
           use: ["katex"],
           cinderella: {build: 1898, version: [2, 9, 1898]}
       });
   </script>
   </head>
   <body>
       <div id="CSCanvas"></div>
   </body>
</html>
```

Embedding CindyJS to STACK Question. Once we have exported the HTML file (CindyJS) exported, we simply copy and paste it to the "Question text" area in an authoring interface of STACK question (Fig. 6). The copied and pasted part is indicated with a red line in Fig. 6.

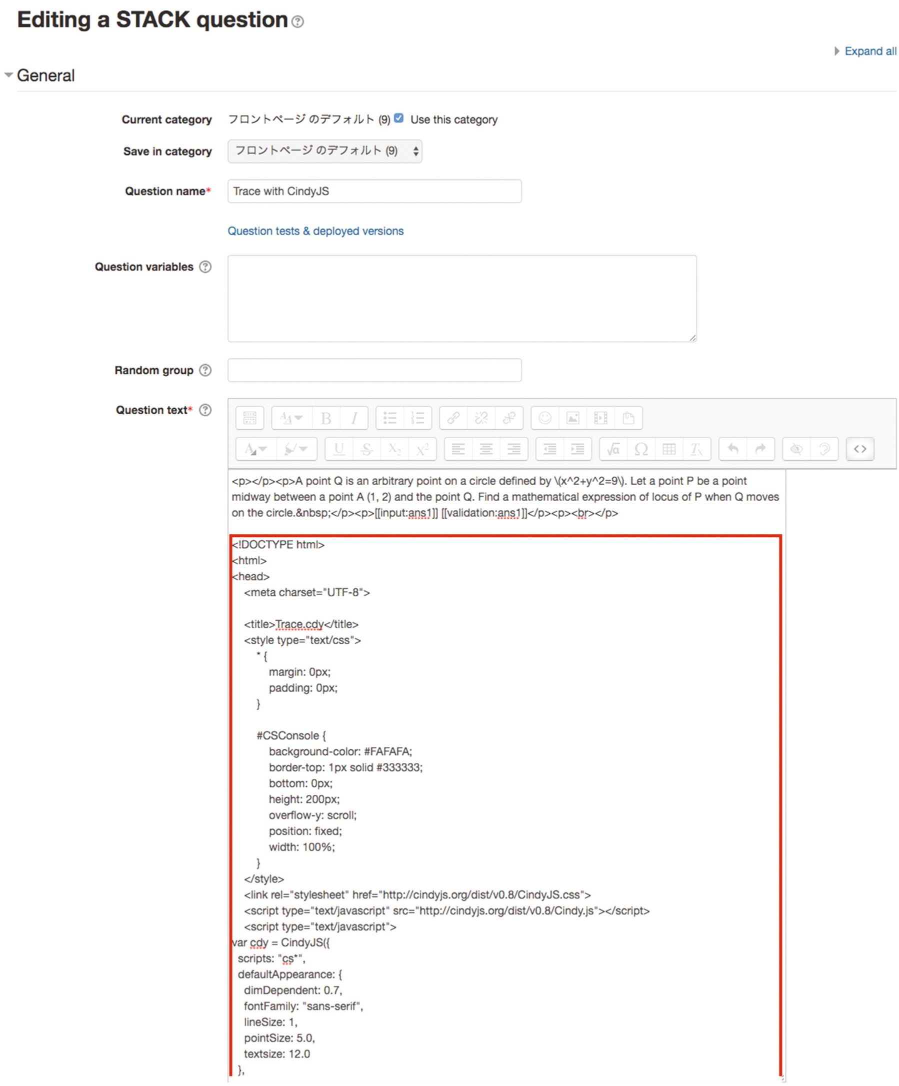

Fig. 6. Authoring STACK question with CindyJS copied and pasted.

2.2 Examples of STACK Questions with Interactive Content

In this subsection, we will provide some examples of STACK questions with interactive content.

Calculation of Mathematical Expression of a Trace of a Point. An example of a question related to geometric figures was shown in Fig. 4 in the previous section, in which students are required to calculate the trace of the

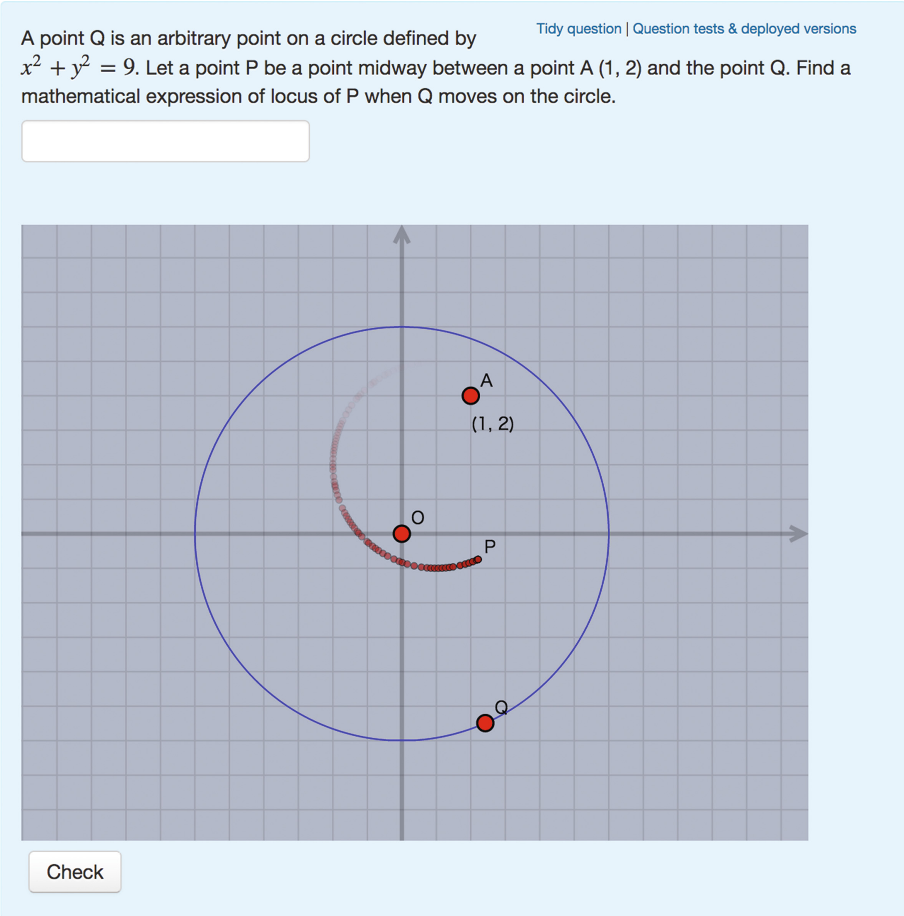

Fig. 7. An example of a question related to geometric figures with embedded interactive content.

point P that is midway between A and Q and that moves on the circle. The first step in solving the question is to sketch the trace on a paper. However, this is a difficult task for some students. In order to help these students, one of the solutions is to provide interactive content in the question as shown in Fig. 7.

Students can grab the point Q and move it on the circle, thereby drawing the trace. This could act as a trigger for students who were unable to solve the question in Fig. 4.

Evaluation of Stability of Fixed Points of a System of Ordinary Differential Equations. In order to evaluate the stability of fixed points of a system of ordinary differential equations, students mainly go through mainly three steps: the calculation of fixed points, the linearization of a system of ordinary

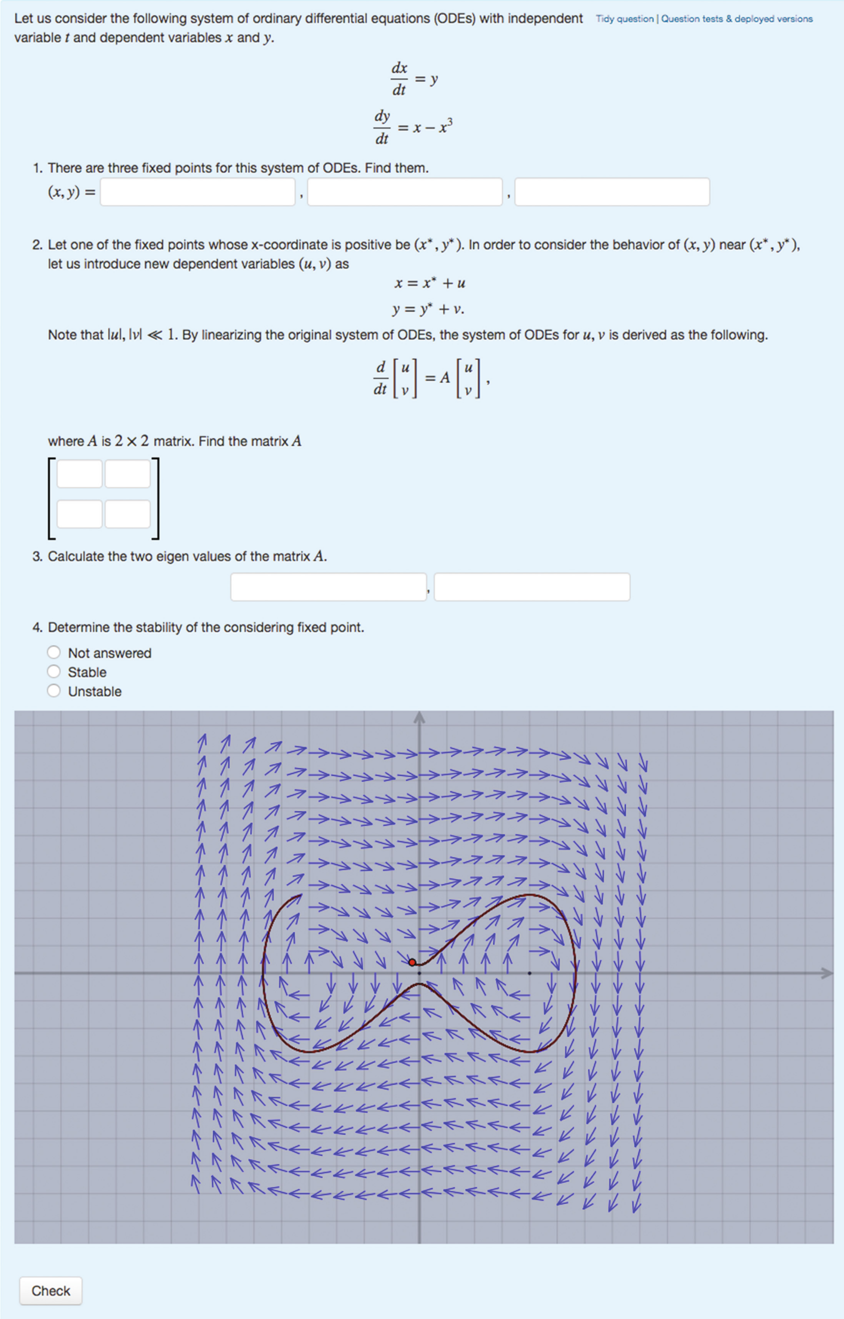

Fig. 8. Question on the stability of fixed points of a system of ordinary differential equations with embedded interactive content.

differential equations around one of the fixed points, and the calculation of eigenvalues of the Jacobian matrix of linearized equations. Therefore, there are many learning units that students must understand. Some students can solve the question by following the procedure mentioned above; they may leave in their results even if they make no sense. It is important to understand the picture of the behavior of orbits around fixed points in the question.

One example of the question on the stability of fixed points of a system of ordinary differential equations is depicted in Fig. 8. The interactive content is embedded to help students understand the picture of the behavior of orbits around fixed points in the question by drawing a vector field and an orbit that starts from the initial point indicated by the red dot. Drawing the vector field fits the purpose of grasping the global behavior of solutions of the system of ordinary differential equations, while drawing the solution orbit that starts from a specific initial state fits the purpose of following the behavior of the solution precisely. When students grab the red point and move it freely, the solution orbit is automatically calculated and displayed.

3 Discussion: Effective Use of Questions with Interactive Content

In this section, we will discuss the effective use of questions with interactive content and the future development of these kinds of questions.

First of all, we have considered questions that would be more suitable if interactive content were embedded in them. If these kinds of questions are posed to students, self-learning would be encouraged. This is a new way of using questions in LMSs not only for assessment but also for self-learning.

We suggested two examples of questions with interactive content (Figs. 7 and 8), but they may provide too many hints for more competent students. Therefore, it is preferable to implement a toggle switch to view or hide the interactive content. If we include a penalty to students when they view the interactive content, they will try to think as much as possible by themselves. If students view the interactive content, the action is recorded to logs in LMSs and teachers can focus their attention on those students. Alternatively, interactive content could be viewed adaptively. For the future plan of development for STACK, an interactive model is considered. In the plan, "state" is added to the question model and questions are posed to students in response to their answers [15].

One of the advantages of STACK questions is that we can formulate them with random variables, which mean that parameters of differential equations can be randomly determined every time students attempt questions. This function is useful for drill practices of calculations. There is, however, one drawback of applying interactive content as suggested in this paper. Figures and plots in interactive content do not work directly with randomly determined parameters in questions. It is necessary to find a technical solution to this loophole in the future.

4 Conclusion

We have suggested the use of interactive content in online tests. Such content was developed using the CindyJS framework of Cinderella, a type of DGS. Interactive content can be embedded in STACK, a mathematics e-Learning system. Two examples were provided: one was the question of calculation of the mathematical expression of a trace of a point and the other was the question of evaluation of the stability of fixed points of a system of ordinary differential equations. In these examples, students could use interactive content by grabbing and moving the points. This operation helps them receive a trigger to solve questions, which eventually enhances self-learning.

However, it is preferable to use interactive content adaptively, for example, by toggling a switch to view or hide the content or by displaying such content in response to the students' answers. Furthermore, there is one drawback in the use of interactive content as suggested in this paper: figures and plots do not work directly with randomly determined parameters in questions. A technical solution needs to be found for this drawback in the future.

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