Item Bank System for the Mathematics e-Learning System STACK

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Abstract: *System for Teaching and Assessment using a Computer Algebra Kernel (STACK) is a computer-aided assessment system for mathematics, which functions as a plug-in for the learning management system Moodle. Using STACK, Moodle can provide questions for online mathematics tests. These questions typically require a mathematical expression as a response and the responses are assessed algebraically. STACK can be used to determine whether a student's answer is correct, as well as providing appropriate feedback for various answers. Partial scores can even be provided for an incomplete answer. However, the questions must be designed carefully to take full advantage of STACK's rich functionality. Well-designed questions can be valuable educational resources, especially in an e-learning environment. Thus, to promote the sharing of high-quality questions for use in online tests, we developed an Item Bank System for the mathematics e-learning system STACK. Using our system, users can submit authored questions in XML format to STACK along with additional metadata, including the subject, difficulty level, targeted grade and publicity level. After they have been uploaded and stored in the system, all users can utilize any of the questions that are open to the public. We expect that sharing these questions will further promote the effective use of mathematics e-learning systems.*

1. Introduction

In recent years, information and communication technology (ICT) infrastructures have improved in schools. Many now offer computer suites to students so they can gain practical work experience and Wi-Fi networks are available to allow students to access the Internet using their own laptop computers. Portable digital devices, such as smartphones and tablet computers, are also gaining popularity and they are now ubiquitous in educational environments. The improved ICT infrastructure and the presence of these devices mean that e-learning has become increasingly popular. One of the most important functions of an e-learning system is the ability to administer online tests to evaluate a student's comprehension of the course material. Typically, students read the test questions and enter their answers using an online form, where the answers are assessed automatically by an e-learning system. However, most existing online tests are only capable of assessing answers submitted in a true/false, multiple choice, numeric value, or simple descriptive format. Only a small minority of systems can assess the validity of algebraic mathematical expressions. Maple T.A. and System for Teaching and Assessment using a Computer Algebra

Kernel (STACK) [1, 2, 3, 4] are two examples of such systems. Maple T.A. is a commercial software product, which can be accessed from a wide range of learning management systems (LMS) such as Blackboard and Moodle. STACK is integrated with Moodle and is open source.

We have been using Moodle as a LMS in our class and we employ STACK to administer online tests that involve mathematical expressions for science and maths subjects. As we show later, STACK has a rich set of functions that support science education. For example, it is capable of providing appropriate feedback in response to a variety of answers. However, there are several problems associated with utilizing STACK in a classroom setting. One of these is the complexity of authoring test questions, where it is more difficult to create higher quality questions. In order to overcome this issue, we developed a question authoring tool for STACK [5]. We consider that well designed questions are a valuable teaching resource and sharing them will reduce the cumulative effort required to author high quality questions. To facilitate this, we decided to develop an Item Bank System for use as a platform to share questions or other items.

The remainder of this paper is organized as follows. In the next section, we provide a brief review of STACK and several examples of questions. In Section 3, we discuss several problems associated with STACK and explain how to resolve these problems. We then introduce the Item Bank System and describe how it operates in Section 4. In the final section, we provide our conclusions.

2. Brief review of STACK

STACK is a computer-aided assessment package for mathematics, which was developed by Sangwin at the University of Birmingham, UK. STACK v.2 is fully integrated with Moodle, a LMS. The integration was achieved in SOAP and it gives users the option of including questions in online tests that treat mathematical expressions as answers. The latest version of STACK is compatible with Moodle's quiz module and it is much simpler to install than previous versions.

When we evaluate a student's understanding of a scientific subject using an online test, simple questions types such as multiple choice questions (MCQs), which are often included in online tests, are not sufficient because these questions formats cannot accurately represent a student's comprehension level. For example, when answering MCQs, students can simply "choose" the correct answer from a list. Even if the student does not know the correct answer, there is a possibility of choosing the correct answer by guessing. Thus, it is possible to evaluate a student's overall comprehension better when a large number of questions are presented to a student. However, it is unclear whether the student understood each question correctly within the context of the test. Therefore, questions that require students to input manual responses in the form of algebraic expressions are more accurate for evaluating comprehension, especially in scientific subjects. In order for this approach to be implemented, the mathematical expressions provided by students would have to be assessed algebraically. However, only a few systems are capable of this and STACK is one of them. The need for and applications of computer-aided assessments in scientific subjects have been discussed in detail previously [3].

Using STACK, students can provide answers to test questions in the form of mathematical expressions (e.g. polynomial expressions, matrix expressions, and functions). STACK evaluates the answers provided and generates responses that confirm or deny the accuracy of the answer, as well as giving valuable feedback. STACK uses Maxima, a computer algebra system, to assess the mathematical expressions provided by students.

Figure 2.1 shows an example of a simple differential equation, i.e.,

$$\frac{dy}{dx} + 2y = 0, \tag{2.1}$$

which was given to students as an online test in our class. The question is quite simple, but it includes two elements that need to be reviewed in order to evaluate the students' understanding, i.e., it is necessary to check for the presence of any miscalculations and to determine whether an arbitrary constant was added. The correct answer to the question is Ce^{-2x}, which would be entered as `C*exp(-2*x)`, but there are two typical incorrect answers, i.e., `C*exp(2*x)`, which is an example of a miscalculation, and `exp(-2*x)`, which does not include an arbitrary constant. Thus, we can frame statements that provide feedback. Examples of this are "Incorrect answer. Your answer should satisfy the ODE, but it does not." if the answer was miscalculated, and: "Your answer is partially correct. The solution should contain a constant but your answer does not." if the answer did not contain a constant (see Figure 2.2).

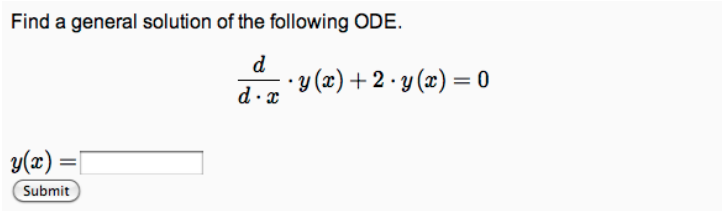

Figure 2.1 An example of a question that asks students to solve a simple differential equation.

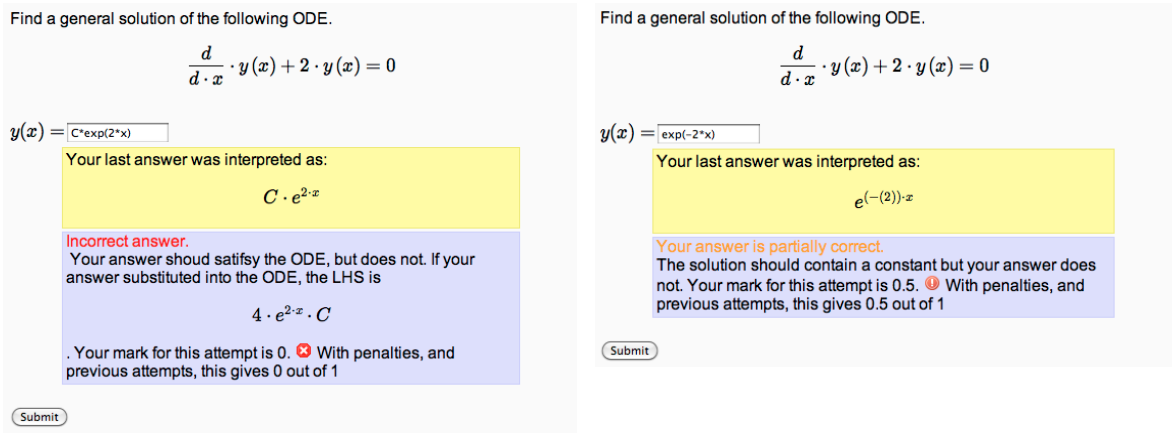

Figure 2.2 Examples of feedback provided for incorrect (left) and partially correct (right) answers.

In the first example shown in Figure 2.2 (left), the students can ascertain why their solutions are incorrect by reading the feedback provided by the system. They can learn that a solution to a differential equation should satisfy the differential equation. This is a very basic concept in differential equations, but some students do not recognize it immediately. A solution to a differential equation should contain arbitrary constants in response to the order of the differential equation as a general solution. However, students often forget to include constants. Therefore, the feedback shown in the second example of Figure 2.2 (right) can draw attention to this common mistake. Suitable feedback can be derived by comparing answers with a "potential response tree", which can provide feedback to students based on their responses. An example of a potential response tree is illustrated in Figure 2.3. This functionality is one of the most distinctive features of STACK. In order for the system to operate, teachers must take the time to determine potential responses, which is a difficult, but necessary, task. If a question has higher complexity, it is more difficult to create the potential response tree.

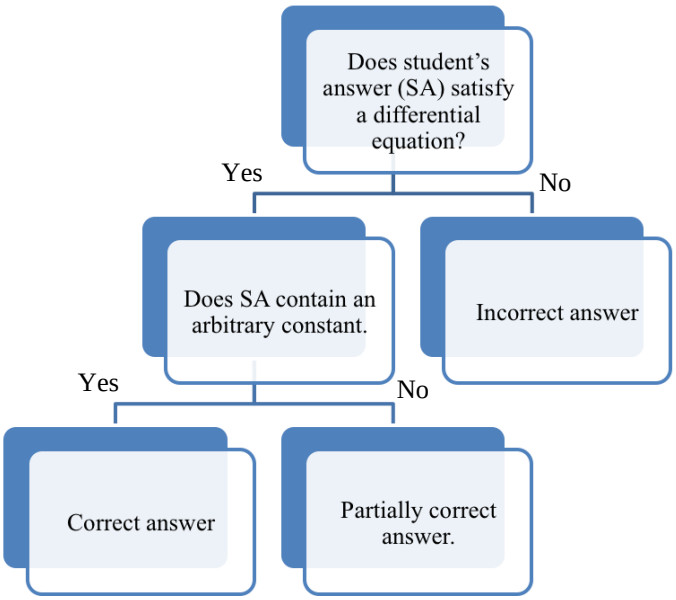

Figure 2.3 Potential response tree for the question in Figure 2.1.

Let us consider other examples. Figure 2.4 shows an example of a complex potential response tree for a second order differential equation $\frac{d^2y}{dx^2}+4\frac{dy}{dx}-5y=0$, where the solution is $y(x)=Ae^{x}+Be^{-5x}$. Many potential answers might be provided by the students, which are all listed in the potential response tree. Thus, the tree should be well designed or well structured to give suitable feedback and reasonable scores, which helps the students to study by themselves using the maths e-learning system STACK. Well-designed questions can be valuable educational resources, especially in an e-learning environment. Figure 2.5 shows an example of a question in the subject area of mechanics. There are three answer fields for this question. In order to answer the sub-questions, the students should understand the law of conservation of momentum and the law of conservation of energy. Therefore, the use of well-designed questions that require more than one concept, as well as the inclusion of a mechanism to give suitable feedback, allow student to learn each concept and the relationships among these concepts.

When assignments are given to students, their work must be graded and returned to them as part of the education process. A computer-aided assessment system such as STACK has the potential to help teachers save time because of its feedback system and grading functionality. Questions that have been designed carefully to provide feedback, such as the one shown in Figure 2.2, can yield significant educational benefits. Therefore, sharing questions with educational value is important in an e-learning environment.

We have provided a brief summary of STACK. It is important to note that STACK is currently used by many institutes all over the world [2], which indicates its usefulness.

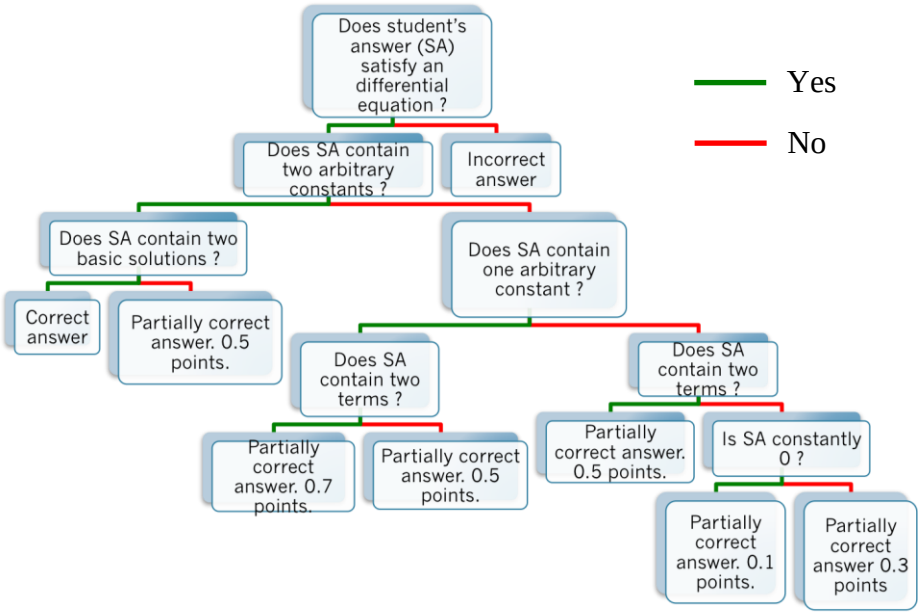

Figure 2.4 An example of the potential response tree for a second order differential equation.

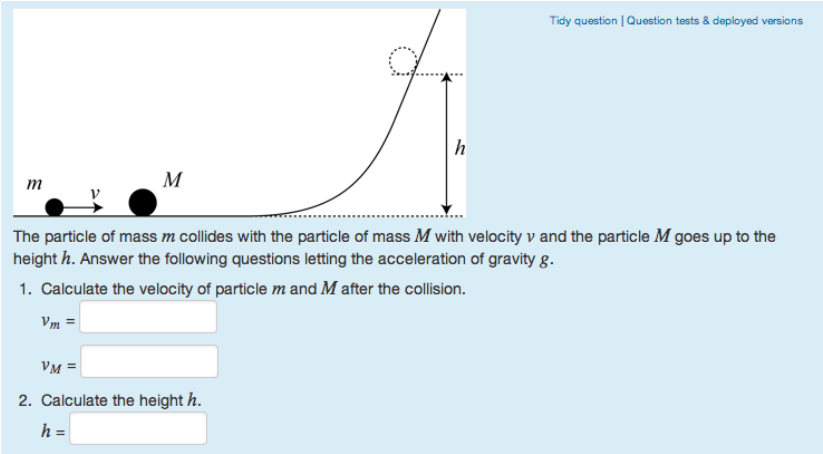

Figure 2.5 An example of a question from the subject area of mechanics.

3. Problems and solutions using STACK

As described above, STACK can provide a rich set of functionalities to aid science education. However, the system is not without its problems. In this section, we review some of the main issues associated with STACK and describe how we solved them.

The first problem is related to the installation of STACK on a computer. STACK comprises two main external tools: Maxima, a computer algebra system that is used to assess students' answers algebraically; and gnuplot, a function-plotting tool that is used to draw graphs. Maxima requires Common Lisp and the problems that usually arise are related to the compatibility of these tools. We solved this problem by writing a document that describes the best combination of tools and by preparing binaries for the tools on our server [4]. The second problem with STACK is the language environment it uses. STACK's language environment is set independently from the one used in Moodle. This situation is inconvenient because STACK is a subsystem of Moodle. We made minor changes to STACK's source code when we localized it for Japanese [4]. Following our

modifications, STACK's language environment is inherited from Moodle instead of being independent. We are preparing a Japanese language pack for the latest version of STACK. The third issue with STACK was its processing speed. From a user's perspective, it can take a long time for the system to process answers, thereby affecting the attention of students. This problem was handled in the version 2.2 release of STACK, where the processing speed was improved significantly using caching. The fourth issue is that there is no perfect input method for mathematical expressions. This issue is yet to be solved, but it should be addressed in the future.

The final major problem associated with STACK is the topic of this paper. As we mentioned above, STACK can provide appropriate feedback to specific types of answers, which is one of its most important functions. However, authoring questions is elaborate and time-consuming work, especially when we create questions with more complex potential response trees, as shown in Figure. 2.4. Nevertheless, the current interface for authoring questions is not convenient to use. In response, we developed a question-authoring tool using Microsoft Excel (Excel) and Visual Basic for Applications (VBA) [5]. In order for questions to be effective at promoting education, they must be formulated well. If well-structured questions are shared, thereby allowing any registered user access to them, this would solve the fifth problem in an effective manner, and this could help broaden the applications of e-learning to maths and science subjects. In order to make a platform for sharing questions, we developed an Item Bank System.

4. Development of the Item Bank System

There are three key phases in the development of an Item Bank System: the collection phase (collecting questions), use phase (questions are used) and build-up phase (the Item Bank System evolves). In this study, we outline the development of Mathbank.jp, http://mathbank.jp/en/, which is our Item Bank System.

4.1 Collection Phase

In order to share questions, it is necessary to collect them first. Thus, it is essential to create a simple, user-friendly interface to encourage users to register questions. We developed the Item Bank System shown in Figure 4.1 as a Moodle system. Any user can register questions using the "Regist" link and search for registered questions from the "Search" link after user authentication.

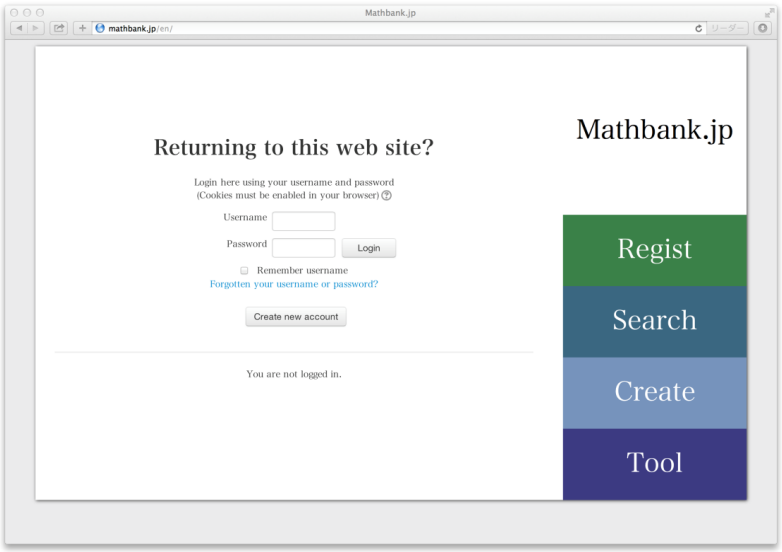

Figure 4.1 Front page of Mathbank.jp.

After selecting “Regist”, the registration screen shown in Figure 4.2 opens. When users register a question in the Item Bank, they should include metadata such as the grade, difficulty level, publicity level and key words. Questions can be registered by uploading an XML file via the interface. Alternatively, existing STACK questions on the Moodle server can be registered to the Item Bank System by adding metadata information. This makes it possible to register and classify existing questions in an effective manner. Metadata elements can be set from an administration screen. Both STACK question types and general Moodle quizzes as a gift format can utilize the Item Bank System. Users can search through the questions in the system by selecting the “Search” link and perform searches based on the metadata specified. A user can create questions on the Item Bank System itself by selecting the “Create” link and various tools, e.g., a question-authoring tool developed using Excel and VBA [5] is provided on the site after selecting the “Tool” link.

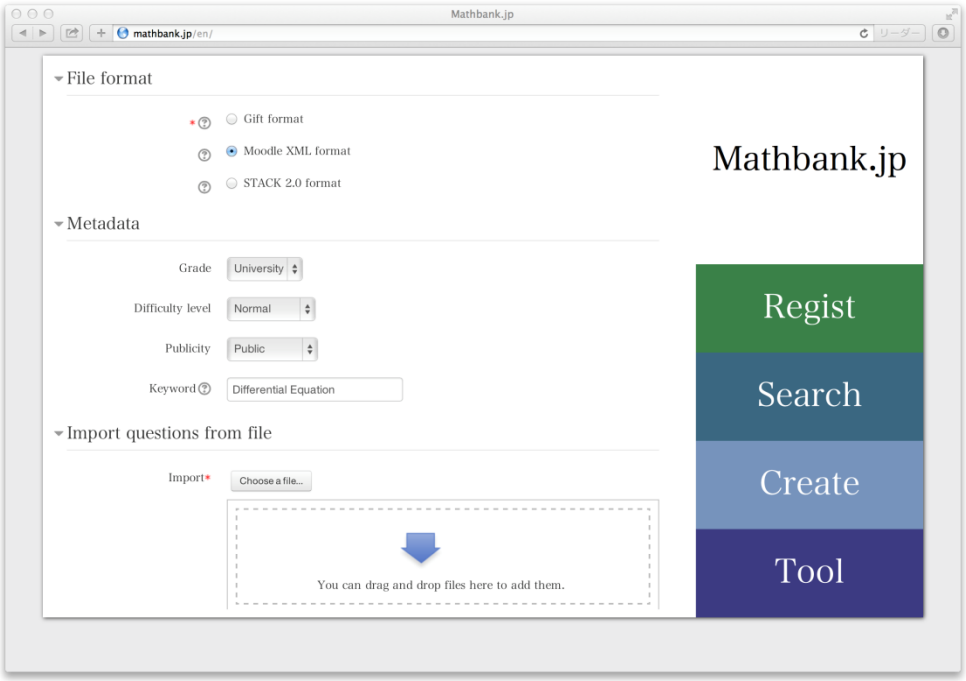

Figure 4.2 Screen for registering questions.

4.2 Use Phase

The use phase provides time for the Item Bank System to be tried and tested. After searching through the list of questions, users can download STACK questions in an XML format. Users can then import the file to their servers for later use. The use phase also provides time for registered questions to be tested straight from the Item Bank System, which creates stored logs. The log is used to reconsider the difficulty level and to improve the quality of the questions in the system.

4.3 Build-up Phase

The build-up phase aims to improve the Item Bank System further based on stored data, as well as adding value to collected questions that have not yet been implemented. For example, we can review the responses to specific questions to generate a list of incorrect responses to include in a MCQ. This type of question may be more suitable for mobile devices. Furthermore, this phase

allows time to gather trial data, which could determine the true difficulty level of questions more accurately, because this is set objectively when each question is first registered.

4.4 Feedbacks from Users

About six months have passed since we opened the Item Bank System to the public. Nineteen users and about 40 questions were available on the system as of April 13, 2014. Many users have said that it is convenient to share questions that are listed on the system because they can produce other questions based on the shared questions, which results in time savings. However, metadata such as the grade, difficulty level, publicity level and the key words used to classify the registered questions should be considered based on the feedbacks from users. For example, if we classify questions based on the grade metadata, the grade is not common to all schools because the progress schedule depends on each specific school. Some users have said that the questions should be classified based on the subject.

5. Conclusion

One of the most distinctive features of STACK is the ability to provide pertinent feedback to students taking online tests by analysing their responses using a potential response tree. Authoring questions that are suitable for the STACK framework may be difficult and time consuming, but they are also valuable educational resources. We consider that the cumulative effort required to create suitable questions might be reduced if quality questions were shared freely among educators. In order to facilitate this, we developed the Item Bank System, which is a platform for sharing questions. This means that anyone can register questions or download questions for their own use. The system was designed to be compatible with existing Moodle questions.

In order for this system to work properly, we made several modifications to STACK, including enhancing its plotting features [6]. The Item Bank System is a major development for STACK because creating high-quality questions is one of the most important tasks during e-learning using STACK. Furthermore, some users have considered sharing questions with other mathematics online testing systems as well as STACK, e.g., MATH ON WEB Learning College Mathematics by webMathematica [7], which should be promising future work. We expect that sharing questions will further enhance and broaden the scope of e-learning in the future.

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