Development of an 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, and functions as a plug-in for the Learning Management System (LMS) Moodle. With the help of STACK, Moodle can provide questions for online tests. These questions typically require a mathematical expression as a response and the responses are assessed algebraically. STACK is not only able to determine whether a student's answer is correct, but can also provide appropriate feedback for various answers. Partial scores can even be assessed for an incomplete answer. However, in order to take advantage of STACK's rich functionality, questions must be designed carefully. Well-designed questions can be valuable educational resources, especially in an e-learning environment. 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 meta data, including subject, difficulty level, targeted grade, and publicity level. Once they are uploaded and stored in the system, all users would be able utilize any questions open to the public. We expect that sharing such 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 that they can gain practical work experience, and deploy Wi-Fi networks for students to access the Internet using their own laptop computers. Portable digital devices, such as smartphones and tablet computers, are also gaining popularity and are now ubiquitous in an educational environment. Because of strengthened ICT infrastructures and the presence of these devices, e-learning has become increasingly popular. One of the most important functions of an e-learning system is the ability to administer online tests as a way to evaluate a student's comprehension of the course material. Typically, students read the test questions, enter their answers into an online form, and the answers are automatically assessed by an e-learning system. However, most existing online tests are only capable of assessing answers

in a true/false, multiple-choice, numeric value, or simple description format. Only a small minority of systems can assess the validity of algebraic mathematical expressions. Maple T.A. and STACK [1, 3, 4] are two examples of such systems. Maple T.A. is a commercial software product that 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.

Since we have been using Moodle as a LMS in our class, we adopted STACK to administer online tests involving mathematical expressions for science and math subjects. As we show later, STACK has a rich set of functions to 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 them is the complexity of authoring test questions. The higher quality the question, the more difficult it is to create. In order to overcome this issue, we developed a question-authoring tool for STACK [5]. We believe 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 to be used as a platform for sharing questions or other items.

The remainder of this paper is organized as follows. In the next section, we provide a brief review of STACK along with several examples of questions. In Section 3, we discuss several problems associated with STACK and describe how they have been overcome. We then introduce the Item Bank System and describe how it works in Section 4. In the final section, we provide a conclusion to the paper.

2. Brief review of STACK

System for Teaching and Assessment using a Computer algebra Kernel (STACK) is a computer aided assessment package for mathematics that was developed by Sangwin at the University of Birmingham, UK. STACK v.2 is fully integrated with Moodle, a learning management system (LMS). The integration was done in SOAP and offers users the ability to include questions in online tests that treat mathematical expressions as answers. The latest version of STACK is compatible with Moodle's quiz module and 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 question (MCQ), which are often included in online tests, are not sufficient because these questions formats cannot accurately represent a student's comprehension level. For example, in 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 through guessing. When there are a large number of questions presented to a student, it becomes possible to better evaluate a student's overall comprehension. However, it remains unclear whether the student understood each question correctly within the context of the test. Therefore, questions requiring students to input manual responses in the form of algebraic expressions provide a more accurate method for evaluating comprehension, especially for scientific subjects. In order for this to work, the mathematical expressions provided by students would have to be assessed algebraically. However, there are only a few systems capable of doing this, and STACK is one of them. The need and applications of computer-aided assessment for scientific subjects were discussed in detail in [3].

With STACK in place, students can provide answers to test questions in the form of mathematical expressions (e.g. polynomial expressions, matrix expressions, and functions),

STACK evaluates the provided answers and generates responses that not only confirm or deny the accuracy of the answer, but can also include valuable feedback. STACK uses Maxima, a computer algebra system, to assess mathematical expressions provided by students.

Figure 2.1 is an example of a simple differential equation

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

that was given to students as an online test in our class. Though the question is quite simple, it includes two elements that require review in order to evaluate the students' understanding of it. The first is to check for the presence of any miscalculations and the second is to determine whether an arbitrary constant was added. Although the correct answer of the question is Ce^{-2x}, which would be entered as `C*exp(-2*x)`, there are two typical incorrect answers. One is `C*exp(2*x)`, which is an example of a miscalculation. The second common incorrect answer is `exp(-2*x)`, which does not include an arbitrary constant. Accordingly, we can frame statements that provide feedback. Examples of this are "Incorrect answer. Your answer should satisfy the ODE, but 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).

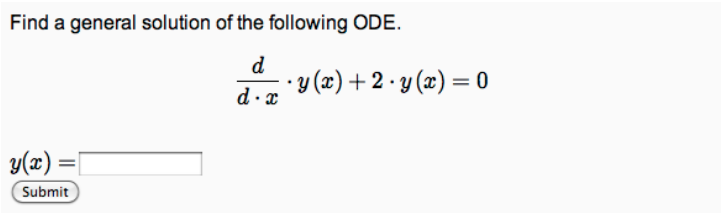

Figure 2.1 An example of a question asking students to solve a simple differential equation.

In the first example shown in Figure 2.2 (left), students can ascertain why their solutions are incorrect by reading the feedback provided by the system. They learn that a solution to a differential equation should satisfy the differential equation. This is a very basic concept of differential equations, but some students do not immediately recognize it. 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 call attention to this common mistake. Suitable feedback can be derived by analysing answers against a "potential-response-tree", which can provide feedback to students based on their responses. This functionality is one of the most distinguishing features of STACK. In order for the system to work, teachers must take the time to determine potential responses. This is a difficult, but necessary task.

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 with its feedback and grading functionality. Questions that have been carefully designed to provide feedback such as the one shown in Figure 2.2 can produce significant educational benefits. Therefore, sharing questions with educational value is important in an e-learning environment.

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

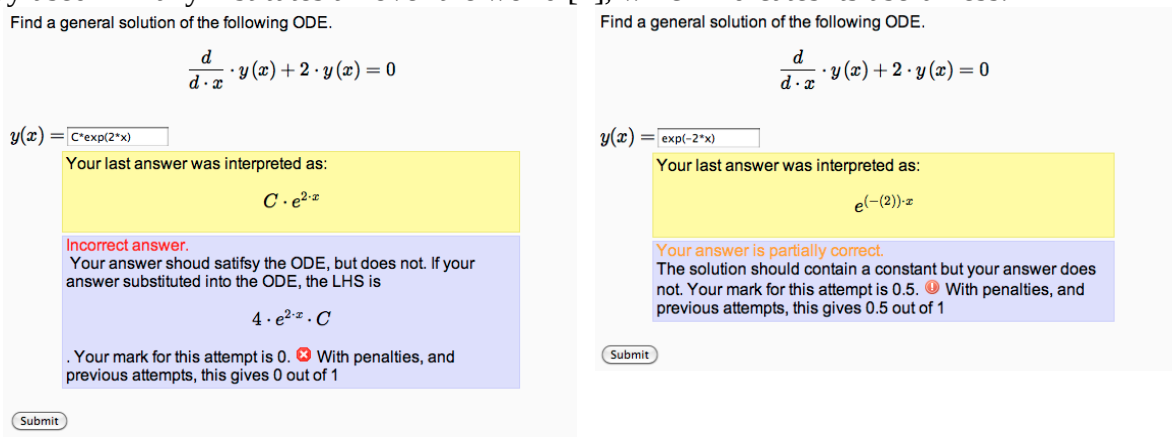

Figure 2.2 Examples of feedback provided for incorrect (left) and partially correct (right) answers.

3. Problems and solutions in using STACK

As described above, STACK can provide a rich set of functionality to aide 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 concerned installing STACK on a computer. STACK consists of 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 (CL), and problems usually arise relating 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 of tools on our server [4]. The second problem with STACK is the language environment it uses. STACK's language environment is independently set from the one used in Moodle. This situation is inconvenient since 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 was no longer independent, but instead inherited from Moodle. The third issue with STACK was its processing speed. From a user's standpoint, it can take a long time for the system to process answers, thus consuming the attention of students. This problem was handled in the version 2.2 release of STACK, as processing speed was significantly improved through the use of caching. The fourth issue is that there is no perfect input method for mathematical expressions. This issue is yet to be solved, but 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 answer, and this is one of its most important functions. However, 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 were shared, thereby allowing any registered user access to them, it would effectively solve the fifth problem and could help broaden the applications of e-learning to math and science subjects. In order to make a platform for sharing questions, an Item Bank System must first be developed.

4. Development of 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 paper, we outline the development of an "Extended Item Bank" block as a Moodle plug-in. This block is the basis of the Item Bank System.

4.1 Collection Phase

In order to share questions; it is vital to first collect them. It is therefore necessary to create a simple, user-friendly interface to encourage users to register questions. We developed an "Extended Item Bank" block, shown in Figure 4.1, as a plug-in for Moodle. Any user can register questions using the "Register Item" link and search registered questions from the "Search Item" link.

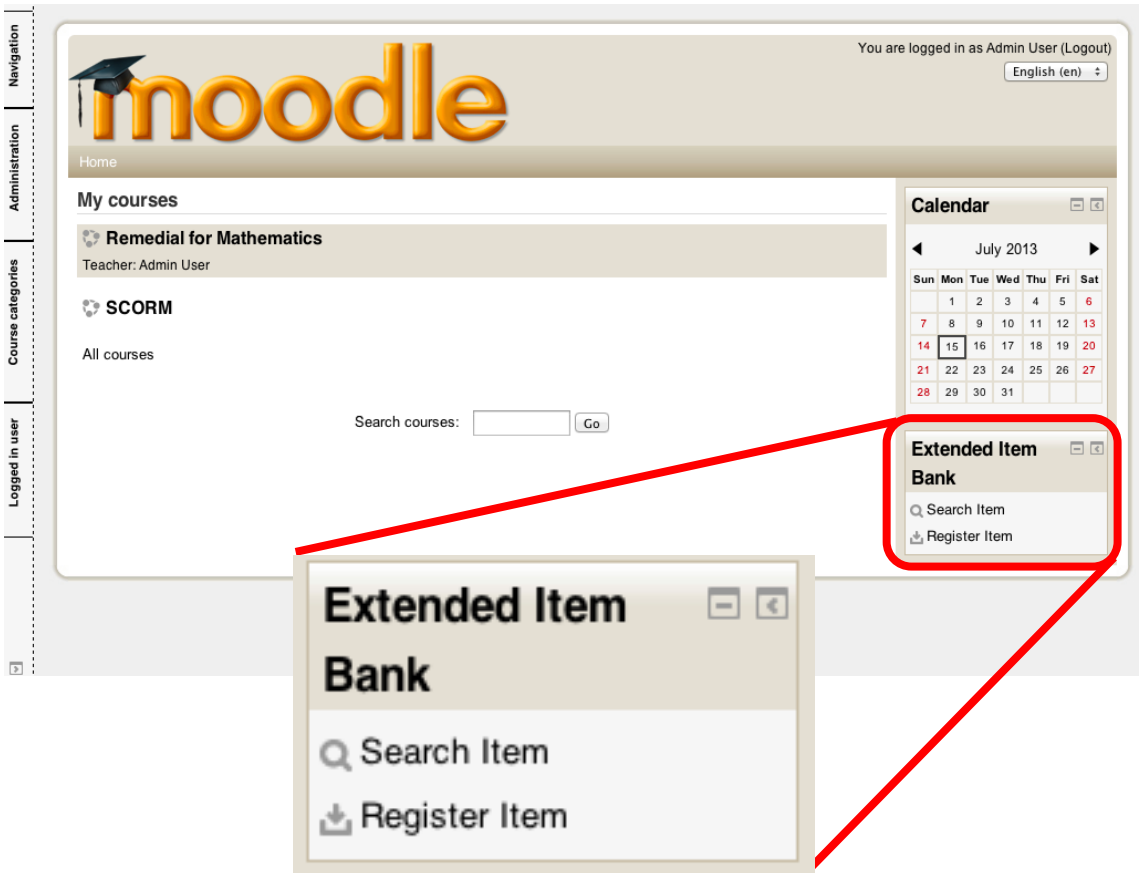

Figure 4.1 Extended Item Bank block.

Upon selecting the "Register Item" link from Extended Item Block, the registration screen shown in figure 4.2 opens. When users register a question in the Item Bank, they should include meta data such as grade, difficulty level, publicity level, and key words. Questions can be registered by uploading an XML file through the interface. As an alternative way to register, existing STACK questions on the Moodle server can be registered to the Item Bank System by adding meta data

information. This way, it is possible to register and classify existing questions effectively. Meta data elements can be set from an administration screen. Both STACK question types and general Moodle quizzes can utilize the Item Bank System. Users can search through questions in the system by selecting the "Search Item" link and search based on the specified meta data.

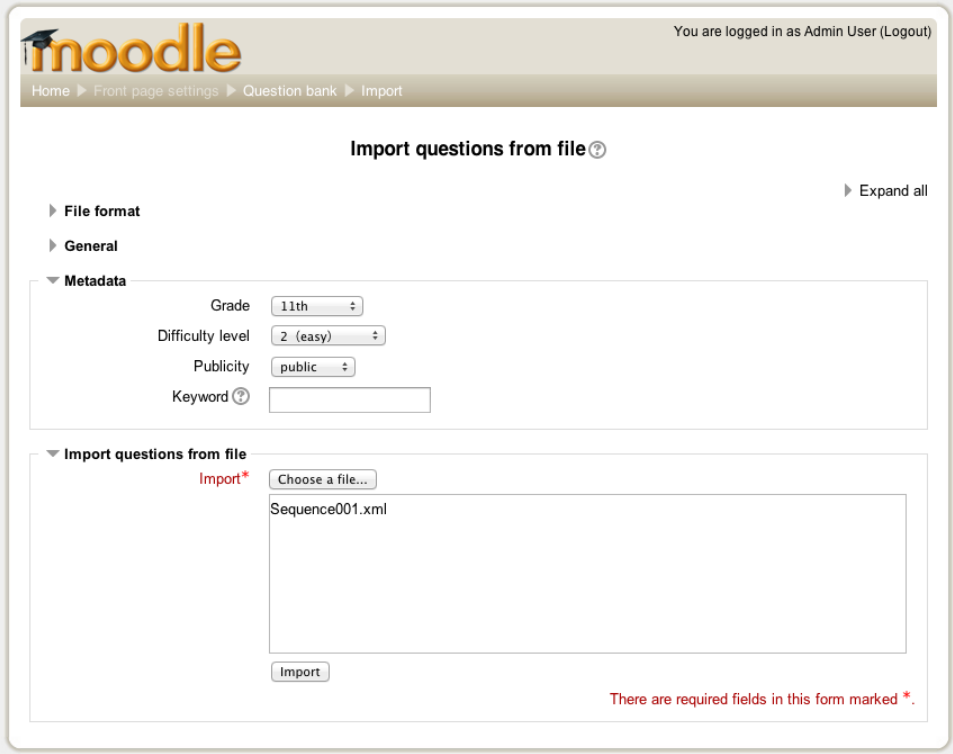

Figure 4.2 Screen for registering questions.

4.2 Use Phase

The Use phase would provide 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 could then import the file to their servers for later use. The Use phase would also provide time for registered questions to be tested straight from the Item Bank System, which would create stored logs. The log would be used to reconsider the difficulty level and improve the quality of the questions in the system.

4.3 Build-up Phase

In the Build-up phase, we intend to further improve the Item Bank System based on stored data as well as add value to collected questions that have not yet been implemented. For example, we would review the responses to specific questions to come up with a list of incorrect responses to include in a multiple-choice question. This type of question would be more suitable for mobile devices. Furthermore, this phase would allow time to gather trial data that could more accurately determine the true difficulty level of questions, as this is set objectively when each question is first registered.

5. Conclusion

One of the most distinguishing features of STACK is the ability to provide pertinent feedback to students taking online tests by analysing their responses against a potential response tree. Authoring questions suitable for the STACK framework may be difficult and time consuming, but they are also valuable educational resources. We think the cumulative effort to create suitable questions could be reduced if quality question were shared freely among educators. In order to facilitate this we developed the "Extended Item Bank" block as a plug-in for Moodle. The plug-in is the basis for the Item Bank System and a platform for sharing questions. This means that anyone can register questions and anyone can download questions for their own use. The plug-in was designed so that it could be also be compatible with existing Moodle questions.

In order for the plug-in to work properly, we made several modifications to STACK, including enhancing its plotting function [6]. This paper represents a major development because creating high-quality questions is one of the most important tasks in e-learning using STACK. We expect that sharing questions will further enhance and broaden the scope of e-learning in the future.

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