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Best Practices for Using Algorithmic Calculated Questions via a Course Learning Management System

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Best Practices for Using Algorithmic Calculated Questions via a Course Learning Management System

Abstract

Textbook publishers have created online algorithmic problem banks for books that have high enrollment. These banks allow an instructor to assign problems from the book with students submitting their answers via an online interface. The algorithmic problems ensure that each student gets a different combination of problem parameter values. Problems are graded automatically with partial credit and immediate feedback available. Instructors benefit by not needing to grade the problems. Students benefit by potentially having multiple attempts to solve each problem with feedback in between attempts. However, these online resources are only available for large enrollment courses where it is financially feasible for publishers to create them, and there is normally an extra cost to the students for access.

For instructors teaching courses without such publisher resources or for those wanting additional assignments outside the publisher systems, many commonly used Learning Management Systems (LMS) have similar functionality. A number of the LMS packages in current use such as Blackboard™, Moodle™, Brightspace™, and Canvas™ have the capability for creating calculated quiz questions with algorithmic features. This allows an instructor to design an online question with a range of values for one or more parameters in a problem such that each attempt will have a different correct answer.

This paper presents best practices for designing and using algorithmic calculated questions for quizzes and/or homework. The paper discusses ways to build the questions in advance, test possible answer combinations, and design likely wrong answers for partial credit and feedback. The pros and cons of using these calculated questions are reviewed. Examples and actual experiences from using the questions demonstrate that this is a beneficial way for instructors to enrich the learning experience while streamlining grading. This is an efficient way for a new engineering educator to gradually build a set of automated problems that can be modified to create new problems with minimal additional effort.

Background

Online homework problems have been offered by large adoption textbook publishers for some time. Typically, these systems allow instructors to assign problems from a textbook or an online bank of problems and students pay an extra fee for access. They log in to the textbook publisher's website system and submit their homework answers by selecting from multiple choices for each question or by entering the final numerical calculation result. The problems are often algorithmically randomized so that each attempt by a student has slightly different parameter values. Grading is automatic, partial credit may be available, and students get immediate feedback. These systems discourage students from thoughtlessly copying answers from other students. The automated nature of the systems relieves instructors from the tedious labor involved in receiving paper homework, grading, logging scores, and sharing feedback with students.

Prior research has had mixed results, but generally shows online homework supports the educational process. While Taraban, Anderson, Hayes, & Sharma[1] found little association between online homework and exam scores, research by Lass, Morzuch, & Rogers[2] concluded that online homework was associated with improved exam performance. Capaldi & Berg[3] developed and studied use of an online learning system for students including online homework problems. The analysis showed that students using the online system achieved significantly greater learning as demonstrated on exams. Knight, Nicholls, & Componation[4] discussed the efficiency of utilizing online homework, observing that assessments created in one class section could be readily imported to use in other sections. The automated grading and score recording greatly reduced the time demands on instructors and supported increased class sizes. They concluded exam performance could be predicted using the results of online homework. Davis & McDonald[5] reported that students performed significantly better when a combination of online and handwritten homework was used compared to just handwritten homework. However, they observed that some students became frustrated when they could not identify minor inaccuracies in their work within the online system.

The availability of online homework systems varies. Stowell[6] observed that commercial providers of online homework are generally limited in upper-level engineering coursework and typically are only available for the large enrollment classes of statics and dynamics. An experiment in creating online homework for a chemical engineering class found it was well received by both students and faculty. However, the profits from its adoption were modest, and the author concluded it was not presently financially feasible to provide commercial online homework systems for smaller classes. Pandian et al.[7] developed a web-based authoring tool called "CAPE" to assist instructors in creating online homework with diagnostics and corresponding feedback for students. They reported that instructors found some difficulties in using the tool, but that it was quite powerful in supporting intelligent tutoring.

Carter & Yuhnke[8] utilized online homework constructed within the Blackboard[9] learning management system. They constructed homework assessments in two parts. The first part used multiple choice and matching questions, and students were given two attempts at these questions. The second part used algorithmic computational problems where parameter values changed with each attempt. Students were allowed unlimited attempts at questions from the second part. Student feedback indicated the immediate grading was positive, but the limitations on partial credit were a disadvantage. The main issue seemed to be problems the instructors had in selecting an appropriate tolerance to allow for rounding errors.

Overall, online homework offers a means of engaging students in the material to foster greater learning; provides immediate feedback to students; and greatly reduces the time required for an instructor to administer the assignments. While online homework provided by a textbook publisher is simpler for instructors to use, upper level engineering courses and courses with smaller enrollments are unlikely to have online textbook publisher homework available. The LMS algorithmic calculated questions present a means for instructors to construct their own online homework assignments without needing to do computer programming or resort to an assisted authoring tool. Commercially available learning management systems such as Blackboard, Moodle[10], Brightspace[11], and Canvas[12] provide the ability for an instructor to construct algorithmic calculated questions and assemble them into online homework assignments or quizzes.

This paper shows how algorithmic calculated questions can be designed and utilized in order to aid the educational learning process. A key motivator is to share best practices so that educators, particularly those new to academia, can more easily adopt this tool. Time is a precious resource in academia for both educators and students. Online algorithmic calculated questions can be a positive course element if implemented properly.

Calculated Questions with Algorithmic Parameters

Quantitative analysis questions can be created with randomized algorithmic parameter values such that a different combination of data is seen each time the question is attempted. Depending upon the LMS, the maximum number of random combinations of the parameters may be capped. There are at least two types of calculated algorithmic questions that are available within LMS packages.

The most commonly available type requires the student to enter the numerical result of the calculations. These questions require the student to analyze the information, calculate a final answer, and type it into the response box. The LMS compares the final answer to the correct results for that set of data. If the student's answer is within a tolerance factor set by the instructor (to allow for rounding errors), the question is automatically graded as correct. One of the larger commercial LMS packages, Moodle, also allows the student's answer to be evaluated against one or more alternate formulas constructed to calculate the answer a student would get if a typical conceptual error was made. This expands the ability to award partial credit beyond just rounding issues. If the answer is within the instructor-defined tolerance factor for another formula programmed to receive partial credit, the question is automatically graded at the pre-set level of partial credit.

The second type of calculated question is similar to a multiple choice question. Calculated multi-choice questions present the student with a random combination of data, and a set of multiple choice answers calculated by formulas. If the student selects the answer that was calculated by using the correct formula and/or procedure, the question is automatically graded to receive full credit. If the student selects an answer calculated with a formula/procedure that would be used as part of a typical conceptual error, the question is automatically graded at the instructor's choice of partial/no credit. At present, it appears this type of algorithmic, multiple choice calculated question is available only to users of the Moodle LMS.

One of the most powerful things about these questions is that, in some systems, they can be designed to be synchronized with other questions so a series of separate, related problems can be solved using the same randomized set of parameter values. For example, a student could be given a set of random parameters representing the height, width, and length of a box. One question could ask the student to calculate the area footprint of the box while a second could ask about the volume of the box. This allows the student to demonstrate mastery of different concepts while not having to start over with a new random set of data.

The experience of several semesters in building and using calculated questions has been instructive. There are several things an educator should keep in mind when beginning to use calculated questions. These are shared in the spirit of offering our "advice from the trenches!"

Getting Started
It is helpful to start on a small scale and gradually build a bank of questions to use. Calculated questions take a while to design, construct, and test. The learning curve can be steep initially. Once the first several examples of questions are built, it becomes much easier to copy a question and modify it to work with a new problem. Start building the first question for practice at least a few days before it is needed to allow for time to get beyond the learning curve.

Find a helpful website or guide for your particular LMS that covers calculated questions. Having this ready at hand facilitates quick searching for answers to question design issues. Some LMS websites have forums where questions can be posed and answered. Visitors may be able to search answers given to previous questions for guidance. Large educational institutions that use an LMS may also have help pages, forums, or dedicated instructor support. Check the LMS publisher site for a list of available functions that can be used in programming answer formulas. These include taking the square root of a number, rounding to the nearest whole number, rounding up or down to a whole number, and raising a number to an exponent. Sometimes logical functions such as Minimum or Maximum are available. These functions simplify the process of writing formulas to calculate the correct or typical wrong answers and offer greater sophistication in the concepts that can be incorporated.

Some examples of LMS publisher help pages for Moodle, Blackboard, Brightspace (created by D2L – desire2learn), and Canvas (created by Instructure) include the following:

- https://docs.moodle.org/30/en/Simple_calculated_question_type
- https://docs.moodle.org/30/en/Calculated_question_type
- https://docs.moodle.org/30/en/Calculated_multichoice_question_type
- https://docs.moodle.org/20/en/Simple_calculated_question_type#Available_functions
- https://en-us.help.blackboard.com/Learn/9.1_2014_04/Instructor/110_Tests_Surveys_Pools/100_Question_Types/Calculated_Formula_Questions
- https://documentation.desire2learn.com/en/creating-arithmetic-questions
- https://guides.instructure.com/m/4152/l/63943-how-do-i-create-a-simple-formula-quiz-question

Building and Using Calculated Questions
Calculated questions work best with specific, focused questions as opposed to data analysis that requires multiple steps since a small math error at an early step could mean that a student would earn no credit from the final answer.

Since the questions can get rather complicated to design it helps when starting out to get into a routine of doing a few steps. First, build the text of the question in a word processing software complete with the "wild cards" that indicate to the LMS what the names of the randomized parameters are. Having the text of the question written out allows copying and pasting of the text into the LMS when constructing the question. For example, Figure 1 shows the text of a calculated question that has two randomized parameters with {Emp} = the number of employees and {Produce} = the number of boxes produced in a year. This example was constructed within the Moodle LMS.

Charles Shoe manufactures handmade wooden jewelry boxes. A total of {Emp} employees each work 160 hours per month carving and assembling the boxes. In 2016 the company plans to make {Produce} boxes to meet expected global demand. What is their productivity at this level of production?

Figure 1 Calculated Multiple Choice Question Example

When working on the design of a new calculated question, it is helpful to first type out the formulas used to solve for the correct answer and any formula for typical wrong answers that can be awarded partial credit. Following this routine encourages working out the logic of the answer, what kind of mistakes a student might make, and how much partial credit is warranted. Working through this in word processing software that you're familiar with is much easier than trying to set it up in the LMS when you start working with calculated questions. The LMS field where the formula will be placed may not be large enough to see the entire formula without scrolling to the side. It's easier to debug formula errors when the entire formula is visible. Watch out for spaces between parts of the formula. This may cause an error in the LMS. The LMS may require a formula to have explicit mathematical operators such as ({Length}*{Width}) as opposed to ({Length}{Width}). Table 1 shows an example of the formulas used in Moodle to give students a choice of four potential answers to the calculated multiple choice question from Figure 1 and the associated percentage of the credit awarded for selecting each answer.

Table 1 Example of Formulas for Potential Question Answer Choices in Moodle

Formulas for Potential Answers	Credit Given
{={Produce}/(12*160*{Emp})}	100%
{={Produce}/(160*{Emp})}	25%
{={Produce}/(12*160)}	25%
{=(12*160*{Emp})/{Produce}}	70%

Students benefit from seeing immediate feedback when they get a problem wrong. It's easier to think about the content of this feedback as the question is being designed. Type out any reference notes you wish to put into the LMS question such as page numbers from the textbook that discuss the topic of the question and feedback notes for the incorrect answers. This allows the feedback options in the LMS to direct students to the specific page or section of the textbook they should review. This enables students to independently seek quick clarification and reduces their need to contact the instructor. If multiple formulas can be programmed in for different conceptual errors, the feedback can be tailored for each potential error.

It is a good practice to use short, descriptive, and generally reusable abbreviations for parameter names. Long, descriptive names are great until you have to try to type them into a complicated formula or try to copy and modify the question for a new problem with different data. Typing out and proof-reading a long complicated answer formula is easier if the names are short. If the parameters have standardized names for a variable like "Int" for Interest Rate or "Vol" for Volume then the formulas typed in for one calculated question can be more easily modified for an entirely new calculated question on the same subject.

Second, build a spreadsheet model to solve the calculated problem to test out your formulas before you put them into the LMS question. Have a data block in the spreadsheet that shows the labels for all problem variables, identifies the randomized parameters by name, and includes your settings for those parameters' minimum value(s), maximum value(s), and number of decimal places. If your LMS has other potential settings for algorithmic parameters, include those as well. While the formulas and functions are obviously different for a spreadsheet than an LMS formula answer, this step is still valuable for building the question.

Having the parameter value settings worked out in advance makes constructing the calculated question in the LMS faster and less prone to error. Put one set of values for the randomized parameter(s) in the data block for the spreadsheet model to use in the calculation and test out the formulas. Program the spreadsheet model formulas to calculate the correct answer and the most likely wrong answers from common mistakes.

The spreadsheet works out the logic for the correct answer making it easier to program the formula into the LMS. It will also help in programming partial credit answers if the LMS offers this functionality. Have answers round to the number of decimal places you will set the LMS calculated question to use. Consider having labeled columns in the spreadsheet model to show the tolerance factor and number of decimal places for each calculated answer. This also aids in question construction.

Figure 2 depicts a spreadsheet constructed to work through the logic of the calculated multiple choice question example from Figure 1. Figure 3 shows how the question would look to the student once the LMS has graded it. Note, the spreadsheet depicted shows the minimum and maximum values for the randomized parameters, the possible answer calculations for one combination of parameter values, and the tolerance allowed for answers.

Charles Shoe wooden jewelry box Productivity example problem						
Data Block:			**var. Wildcard**	**Min**	**Max**	**Decimals**
Production per year	5222	boxes/yr	{Produce}	5,000	6,000	0
Resources Used	Amount	Units				
# of Employees	22	employees	{Emp}	20	30	0
Labor hours per employee	160	hours/month				
Labor hours per year	42,240	hours/year				
			Decimals	Tolerance		
Labor Productivity	0.1236	boxes/hour	4	3.0%		
Potential wrong answers:						
Solved for hours/box	8.0889	hours/box				
Didn't account for 12 months	1.4835	boxes/hour				
Didn't account for # of employees	2.7198	boxes/hour				
Monthly hours & hours/box	0.6741	hours/box				

Figure 2 Calculated Question Example Spreadsheet

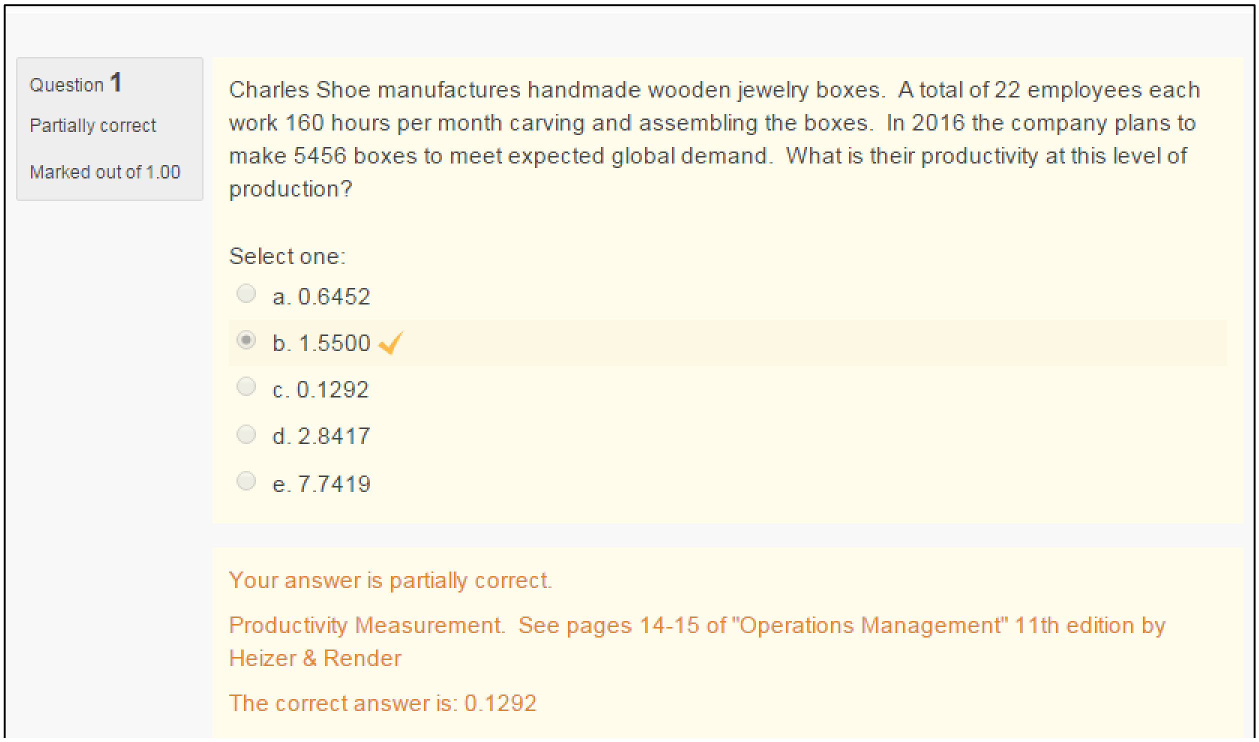
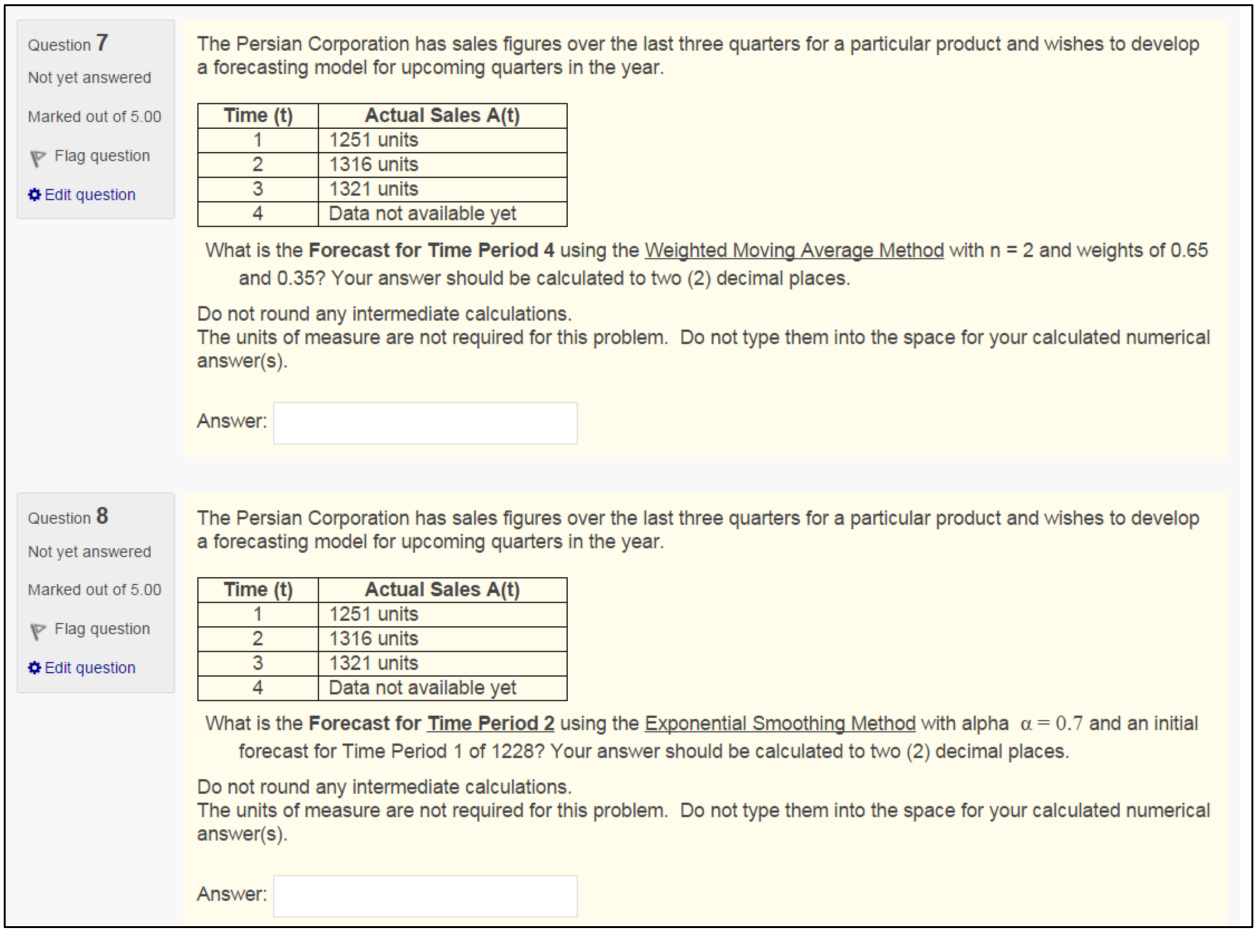


Figure 3 Example of a Graded Calculated Multiple Choice Question in Moodle

Third, Murphy's Law awaits the unwary instructor….always test out the calculated questions and ensure that if your LMS allows synchronized questions they are properly utilizing the same set of randomized parameter values. Figure 4 shows two calculated questions in Moodle that are synchronized. The same set of randomized parameter values is used for two different questions. Synchronization reduces the cognitive load on students by retaining the same set of randomized data values while allowing multiple questions to be asked. Rather than multiple answer choices, the student must calculate a final answer and type it into the response box.

This is where the spreadsheet model built to accompany the problem really helps. When working correctly, the spreadsheet model allows the instructor to test out different combinations of the randomized parameter values to ensure that the min and max values of different parameters will not combine produce invalid, unrealistic, or undesirable results. If the resulting calculation produces a negative number when that's not a valid answer, the range of possible values for a given parameter or parameters may have to be narrowed. The spreadsheet model serves as a critical way to test the correct functioning of an algorithmic calculated question in the LMS. Once built for the first calculated question on that topic or type of question, the spreadsheet model can be rapidly adapted when designing new questions.



Question **7**
Not yet answered
Marked out of 5.00
Flag question
Edit question

The Persian Corporation has sales figures over the last three quarters for a particular product and wishes to develop a forecasting model for upcoming quarters in the year.

Time (t)	Actual Sales A(t)
1	1251 units
2	1316 units
3	1321 units
4	Data not available yet

What is the **Forecast for Time Period 4** using the Weighted Moving Average Method with n = 2 and weights of 0.65 and 0.35? Your answer should be calculated to two (2) decimal places.

Do not round any intermediate calculations.
The units of measure are not required for this problem. Do not type them into the space for your calculated numerical answer(s).

Answer:

Question **8**
Not yet answered
Marked out of 5.00
Flag question
Edit question

The Persian Corporation has sales figures over the last three quarters for a particular product and wishes to develop a forecasting model for upcoming quarters in the year.

Time (t)	Actual Sales A(t)
1	1251 units
2	1316 units
3	1321 units
4	Data not available yet

What is the **Forecast for Time Period 2** using the Exponential Smoothing Method with alpha $\alpha = 0.7$ and an initial forecast for Time Period 1 of 1228? Your answer should be calculated to two (2) decimal places.

Do not round any intermediate calculations.
The units of measure are not required for this problem. Do not type them into the space for your calculated numerical answer(s).

Answer:

Figure 4 Example of Synchronized Calculated Questions in Moodle

Once you are sure the programmed answer formula(s) are working correctly, check the tolerance factor(s). LMS questions should permit an answer to have a real or relative tolerance factor to allow for some differences in rounding intermediate calculations. Consider whether a fixed number or a percentage is better for your question. For a relative (percentage) tolerance, closely review the magnitude of the calculated correct and typical wrong answers. A tolerance of +/-1% may be fine if the resulting calculation produces a result of 50, but it may be way too large for a result of 5,000 and far too small for a result of 0.050. Sometimes the typical wrong answers are only slightly different than the correct answer. If the tolerance allows wrong answers to overlap correct answer values, then you may need to increase the number of decimal places and/or reduce the amount of tolerance. If the correct and wrong answer are so close that tolerance is problematic, it may be better to construct the question as a calculated multiple choice question provided that is a functionality offered with your LMS.

One very nice aspect of calculated questions is the ability to quickly adjust a question to correct a mistake or allow partial credit for a potential mistaken answer the instructor had not considered. Students may be quite ingenious in how they misunderstand the question or the technique! If you find a large number of students made the same mistake and it's not one you allowed for, you may be able to figure out the error they made; modify the question to allow for a new wrong answer; and automatically re-grade the question for partial credit with minimal additional work.

If the formula for the correct answer was wrong, it can be fixed after the fact and all the students' re-graded automatically for that question. If a minor error is discovered while students are working on a quiz, an instructor with access to the LMS may be able to edit the question immediately on the spot and direct students to click back to that question again.

When starting to use these questions it's also important to consider the audience. Students may not be familiar with this type of question in the LMS. If they have not experienced randomized algorithmic questions before, the need to calculate answers without showing their work to get partial credit may be daunting. A little familiarity with these questions goes a long way towards alleviating text anxiety. Give students a chance to see and practice with calculated questions before using them for a high stakes quiz or exam. Students will need to be educated about entering only a number and potentially a sign if the result is negative. Some LMS questions may allow students to enter units of measure in the same response box next to the calculated numerical answer. If units of measure can be entered, consider whether to use that option in constructing the question as partial credit can often be based on entering the units.

Students may be reluctant to switch from the more familiar traditional paper homework to the online algorithmic assignments due to normal resistance to change. It may be necessary to persuasively educate the students about benefits they will receive by using online homework including the ability to submit the work with greater time flexibility; the immediate feedback; the consistency in partial credit grading; and the option of earning a higher score through multiple repetitions. Making a change to online algorithmic questions suddenly with little notice is not advised. Students get used to a routine, and may react negatively to an abrupt change without persuasive arguments in favor of the change. Posting a few examples of the calculated questions for students to practice with no risk to their grade may help with the introduction. Another option is assigning homework problems for which solutions to the static problems in the book are available to students. In this way, students can be encouraged to solve the static problems first, potentially by setting up an Excel spreadsheet model, determining they got the right answer, and then working on the algorithmic versions. While this takes more time to complete, it also ensures students feel confident of their technique before completing the homework for a grade.

Algorithmic questions for homework and out of class quizzes are not feasible unless students have ready access to computers to complete the assignments. While many students nowadays have personal laptops and/or desktops, this is not universal. Students may seek to complete assignments using a mobile device such as a smartphone or tablet. Mobile devices may be feasible for access depending upon browser compatibility with the LMS. One approach is to allow sufficient time between issuing the assignment(s) and the deadline(s) for students to complete them in a computer lab on campus or make other arrangements. If a quiz or exercise is to be performed during class time, it is best to book a computer classroom or lab for this time.

How Different LMS Products Handle Calculated Questions

Many of the large commercially available LMS packages offer the ability to construct algorithmic calculated questions. This section briefly describes the terminology and features provided for these questions by several common LMS packages. Figures showing examples of how these questions look in several different packages are shown in Appendix A.

Moodle has a fairly extensive capability for designing calculated questions. Both numerical calculated answers and calculated multi-choice questions are available for use. Questions can be formatted to require students to enter units of measure along with the numeric answer. Images, videos, and math equations can be inserted into the question using the rich content editor Questions can be synchronized so that multiple questions will utilize the same combination randomized parameter values. Moodle has a cap of 100 possible combinations for each question created. If the question is copied for use in a second section's LMS site, a different set of 100 possible combinations can be generated.

Blackboard has "calculated formula questions" where the instructor defines the parameter names, the range of values, and the number of decimal places. Answer formulas are typed out with the capability for inserting mathematical operators and functions. Blackboard has a convenient graphical user interface for entering formulas. The tolerance factor and number of decimal places for the answer choices can also be set by the instructor. Questions can be formatted to require students to enter units of measure along with the numeric answer. Answers can be required in either normal or exponential format. Feedback for correct or incorrect answers can be added to the question. The instructor can enter metadata for each question useful for organizing a bank of questions. Blackboard does not currently offer the ability to program multiple possible answers for a single question or the functionality of creating calculated multiple choice questions.

Brightspace from D2L (desire2learn) refers to these questions as "arithmetic questions." Multiple parameters with ranges of values and decimal places can be used. The random number choices can be set to "step" values so that random numbers can be chosen in increments such as [100, 200] with a step of 10 might produce random values including for example, 100, 110, 120 The answers can have multiple formulas with different decimal place precision options and tolerance levels. Brightspace allows the instructor to upload an image file to be incorporated into a question. There are various arithmetic functions available for use in formulas. The rule on rounding is fixed automatically to "round to half even" where a decimal place that ends in 5 is rounded down if the nearest number is even (e.g. 24.5 becomes 24 while 27.5 becomes 28). The instructor can include text in constructing the question to offer students hints as they work the problem and feedback after it is graded. Partial credit may be set for incorrect answers. Brightspace does not currently offer calculated multiple choice questions or the ability to synchronize questions to use the same randomly generated parameter values.

Canvas from Instructure uses the term "formula question" for this functionality. Instructors can set multiple parameters with a range of values and different numbers of decimal places. Canvas caps the number of different combinations of randomized parameters that may be created at 200. Images, videos, and math equations can be inserted into the question using the rich content editor included with Canvas's user interface. The format for writing questions is similar to those shown earlier in the paper, except Canvas uses square brackets ([ ]) instead of the curved brackets ({ }). The number of decimal places and a tolerance factor are set for each potential answer formula. Three types of feedback can be entered into the question: for correct answers, for incorrect answers, and for general question information. Canvas does not currently offer calculated multiple choice questions. Canvas does not make use of spreadsheet functions, so if questions are related to engineering economics, financial functions must be replaced with their equivalent equations.

Advantages of Using Calculated Questions

- If a course is not using a textbook with publisher-supported algorithmic questions, the calculated questions offer a way to get some of the benefits of this capability. Even if a course does have publisher-supported online problems, calculated questions in the LMS further support the instructor.
- Instructors (particularly those getting started in academia) tend to be very busy. Grading student work can be very tedious, time-consuming, and uses time that could be devoted to activities that are more highly rewarded. Calculated questions greatly reduce the time demand for administering assignments, grading work, logging scores, and providing good feedback. While the set-up is also time intensive this initial investment will pay back for large courses, courses with multiple sections, or courses that will be taught repeatedly.
- Students also tend to be very busy and often distracted. Delayed feedback may be overlooked, ignored completely, or not fully comprehended due to knowledge lost during the delay. The ability to repetitively practice the same concepts with immediate feedback aids timely learning.
- Students benefit from practice in solving problems. These automated questions make it much easier for an instructor to include greater practice in the course.
- Students can work practice questions outside of class freeing up valuable lecture time and allowing students to pick a time and place of their choosing.
- Multiple combinations of randomized algorithmic parameter values makes it more feasible to offer multiple attempts at each question to further encourage mastery of the technique.
- The ability to ask questions that have randomized algorithmic parameter values ensures each student sees a different set of data. This reduces the motivation for students to copy answers from another student during a quiz or exam.
- Students may come to rely too much on more knowledgeable colleagues for help with homework to their detriment on exams. Calculated questions encourage transfer of the method of solving problems rather than just thoughtless copying of answers.
- Grading for partial credit is automatically made consistent across all students. Offering partial credit, when the LMS supports it, for different answers becomes much easier.
- The rapidity of the grading, standardization of the award of credits, and the automated provision of feedback can reduce the instances of students challenging grading decisions.

Disadvantages of Using Calculated Questions

- Only the final answer is graded so the students' technique in reaching the answer is not seen or evaluated.
- Students that suffer from test anxiety may be quite intimidated by a calculated question that presents them with a blank space to type the answer in.
- The questions take much longer to create than a static paper & pencil question.
- Subtle conceptual errors that cause a minor difference in answers may be lost in the tolerance factor allowed and thus not be possible to program for partial credit.
- Potential answers resulting from typical conceptual errors can be anticipated and the LMS may allow an instructor to award partial credit for these errors. However, if a

student makes a simple math error beyond the tolerance factor, the answer may be scored as a 0. By using calculated multi-choice questions, students are given feedback that their result does not match one of the options, providing the opportunity for early correction.

- The limit on the number of randomized combinations of parameters may be smaller than the total number of students taking the course that semester so some offline sharing of answers is still possible.

Conclusions

Overall, online algorithmic questions can aid students in learning the material while removing a great deal of the tedious labor from the instructor. The cycle time for grading, feedback, and recording of scores is dramatically shortened. Options for partial credit can be more easily extended. Automatic grading of partial credit increases consistency and reduces the likelihood of grade challenges. A great textbook without online homework that has not been updated in a while can still be used because writing algorithmic versions of the problems lessens the risk of students sharing copies of answers. All of these benefits are particularly important for new educators that are just getting started in academia and juggling competing priorities for teaching, research, service, and personal responsibilities. Educators that have been teaching for a while have a greater reserve of course materials to drawn on, but these calculated questions remain a useful tool due to the benefits in student learning.

Using calculated questions for online homework, quizzes, or practice exercises still requires an investment of time and effort by the instructor. The investment is made in advance of the assignment as opposed to afterwards as is the case with paper assignments. Once an instructor has gotten over the initial learning curve the time investment drops quickly. Manual grading of paper assignments requires time that is directly proportional to the number of students in a course. Online assignments require time to set up, but the class size is not a significant issue. As the pool of questions deepens with more instances and expands to cover additional topics, the ease of building assignments and exams increases. Calculated questions can help instructors as educational institutions respond to cost reduction pressure by increasing class sizes and offering more online coursework.

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Appendix A. Examples of Calculated Questions in Various LMS Packages

An engineering economic analysis was constructed in Moodle, Brightspace, and Canvas. The text of the question is: “Sage Lorimer receives a tax refund of {PV} and decides to invest it for {N} years at a nominal annual rate of {r}% compounded monthly. What is the Future value of this investment?” The Present Value, time horizon *N*, and nominal interest rate *r* are algorithmically randomized values. To solve the question, students need to convert the nominal annual interest rate into a monthly effective interest rate and calculate the Future Value with *N**12 months of compounding.

Moodle LMS

Figure A-1 depicts creating the calculated question in Moodle starting with setting up the problem text and general feedback students will see after they attempt the question. The editing screen allows different format options and insertion of images and links. Lastly, the instructor is able to see a preview of the setting to assess whether the question is working correctly.

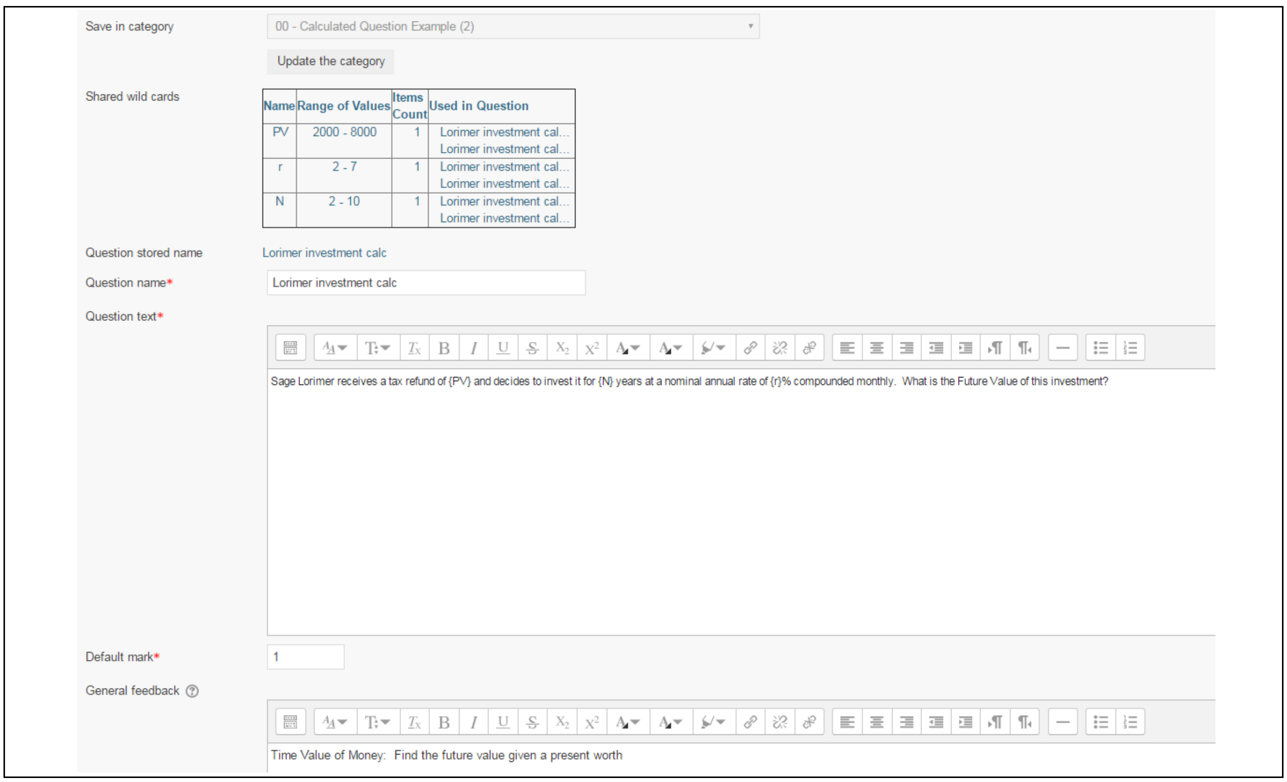

Figure A-1 Inserting Calculated Question Problem Text and General Feedback into Moodle

Figure A-2 shows how different formulas can be inserted as potential answers. The instructor also sets the number of decimal places, tolerance, and amount of partial credit for each answer. Specific feedback to indicate the type of conceptual error made is inserted with a separate editing section for each answer. The calculated question can be set to synchronize the randomized data values across multiple calculated questions so that each student will see the same set of randomized parameter values. This is shown in Figure A-3.

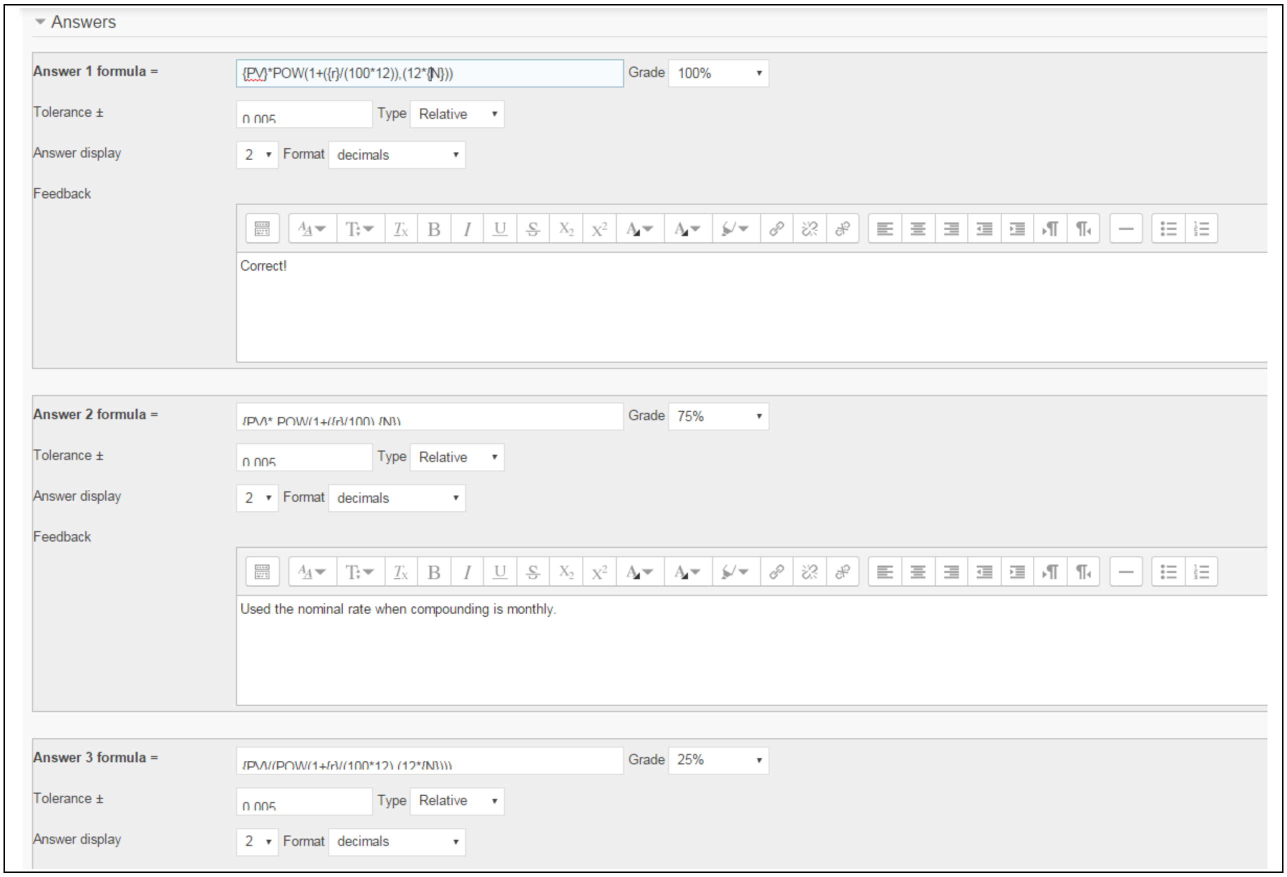

Figure A-2 Inserting Potential Answer Formulas and Specific Feedback into Moodle

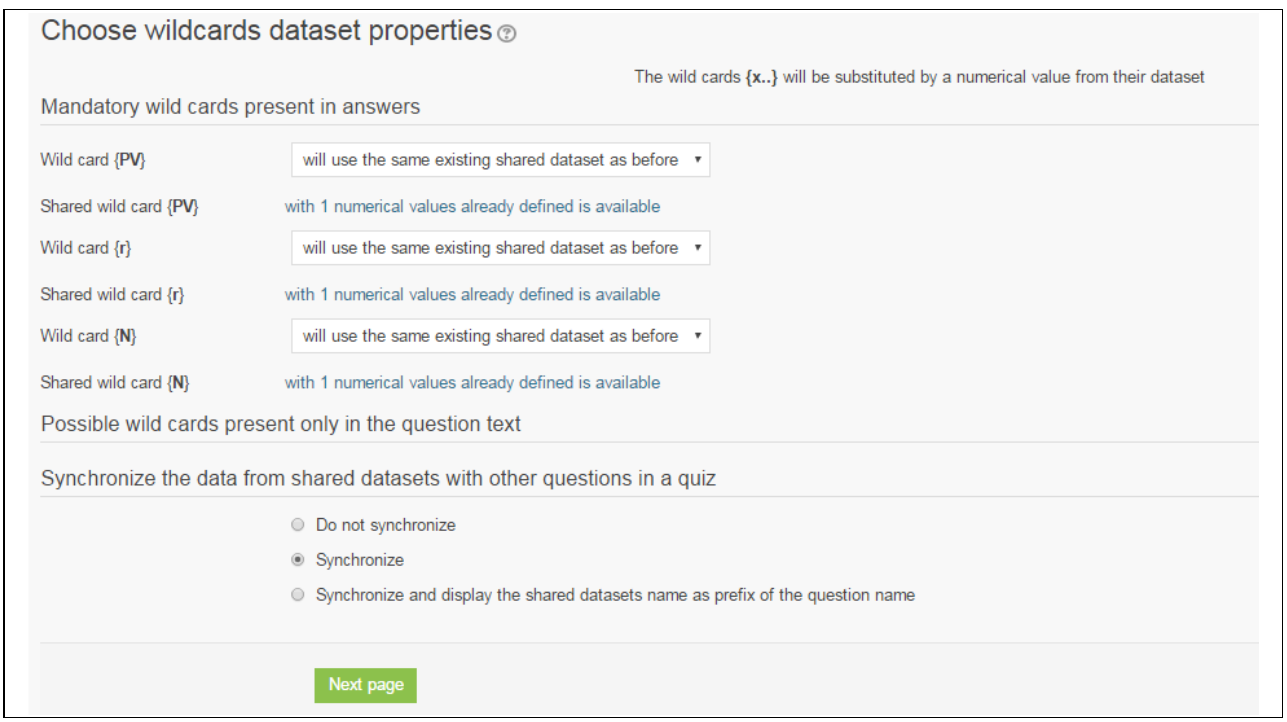

Figure A-3 Setting the Synchronization and Parameter Dataset Storage Features in Moodle

Figure A-4 illustrates one of the last steps in creating a calculated question in Moodle is setting the minimum, maximum, and number of decimal places for the randomly generated parameter values. It’s also possible to select different probability distributions to use in generating the random values.

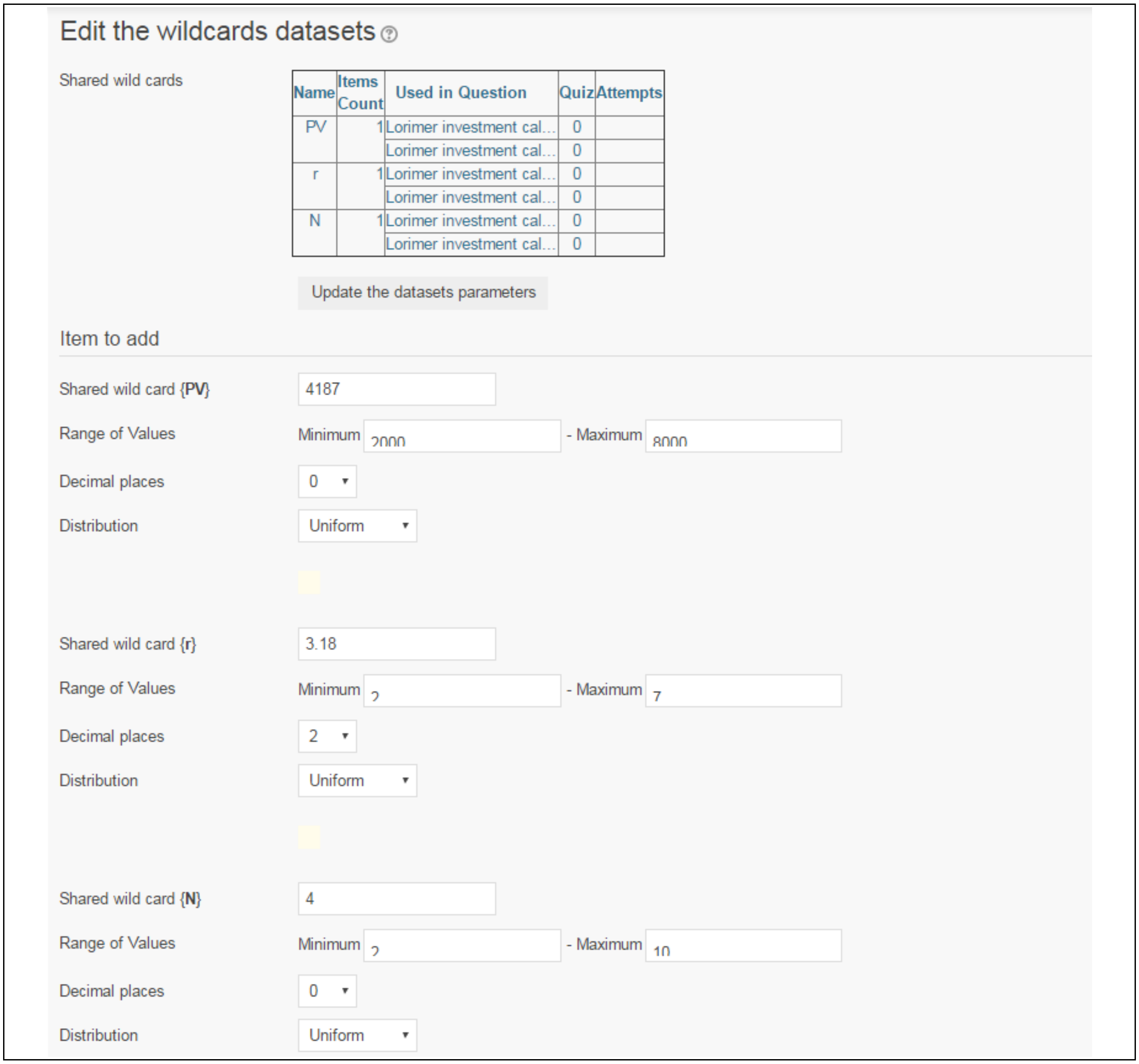

Figure A-4 Setting the Bounds for the Random Parameters in Moodle

When the problem is completely constructed, the LMS has the ability to preview the question and submit an answer. Figure A-5 shows what the question would look like if a student entered a response that was incorrect but got partial credit for an answer reflecting a standard conceptual mistake.

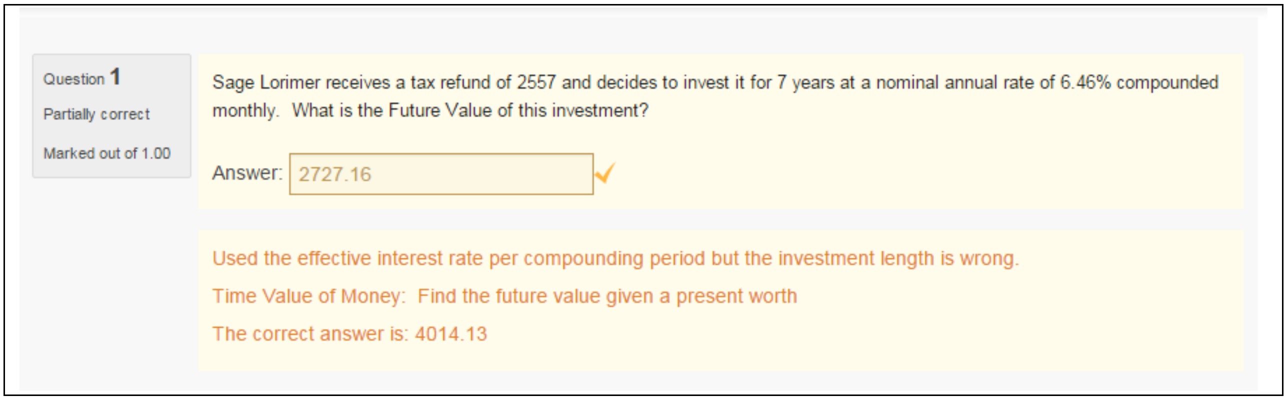

Figure A-5 Previewing the Calculated Problem in Moodle

Brightspace

Below is an example of the editing screen for constructing calculated questions in Brightspace. The LMS has settings for labeling the question title, constructing the formula, setting tolerance limits, adjusting the parameter value bounds between 0 and 100. The user has to decide if partial credit will be awarded for getting the units of measure correct and whether the evaluation should be more or less generous in terms of credit.

Edit Arithmetic Question

General

Title

Future Value - Variable Driven (optional)

Question Text

Skip Toolbars for Question Text.

More Insert actions.

Show All Components

Image

Insert an Image
Description:

Formula
{pv}*(1+({r}/1200))^({n}*12)
Test

Answer Precision
0
enforce precision

Tolerance
Tolerance:
units +/-
percent +/- 1

Units
Units:
Worth:
0
% of Points

Evaluation Options:
Evaluation Options:
Case Insensitive
Case Sensitive
Regular Expression

Variables

Add Variable 1

#	Name	Min	Max	Decimal Places	Step	Remove
1	pv	2000	8000	0	33	

2	n	2	10	0	1
3	r	2	7	2	0.01

Collapse question hint

Question Hint

Skip Toolbars for Question Hint.

More Insert actions.

Show All Components

Expand question feedback

TEST ARITHMETIC QUESTION

Variables

Name	Value
pv	5762
n	5
r	6.83

Original Formula

{pv}*(1+({r}/1200))^({n}*12)

Actual Formula

5762*(1+(6.83/1200))^(5*12)

Solution

8100

Range

8019 - 8181 (8100 ± 1.0 %)

Canvas
The first image in Figure A-6 shows how the question is built within the LMS. The second image in Figure A-7 shows the overall settings for the quiz question.

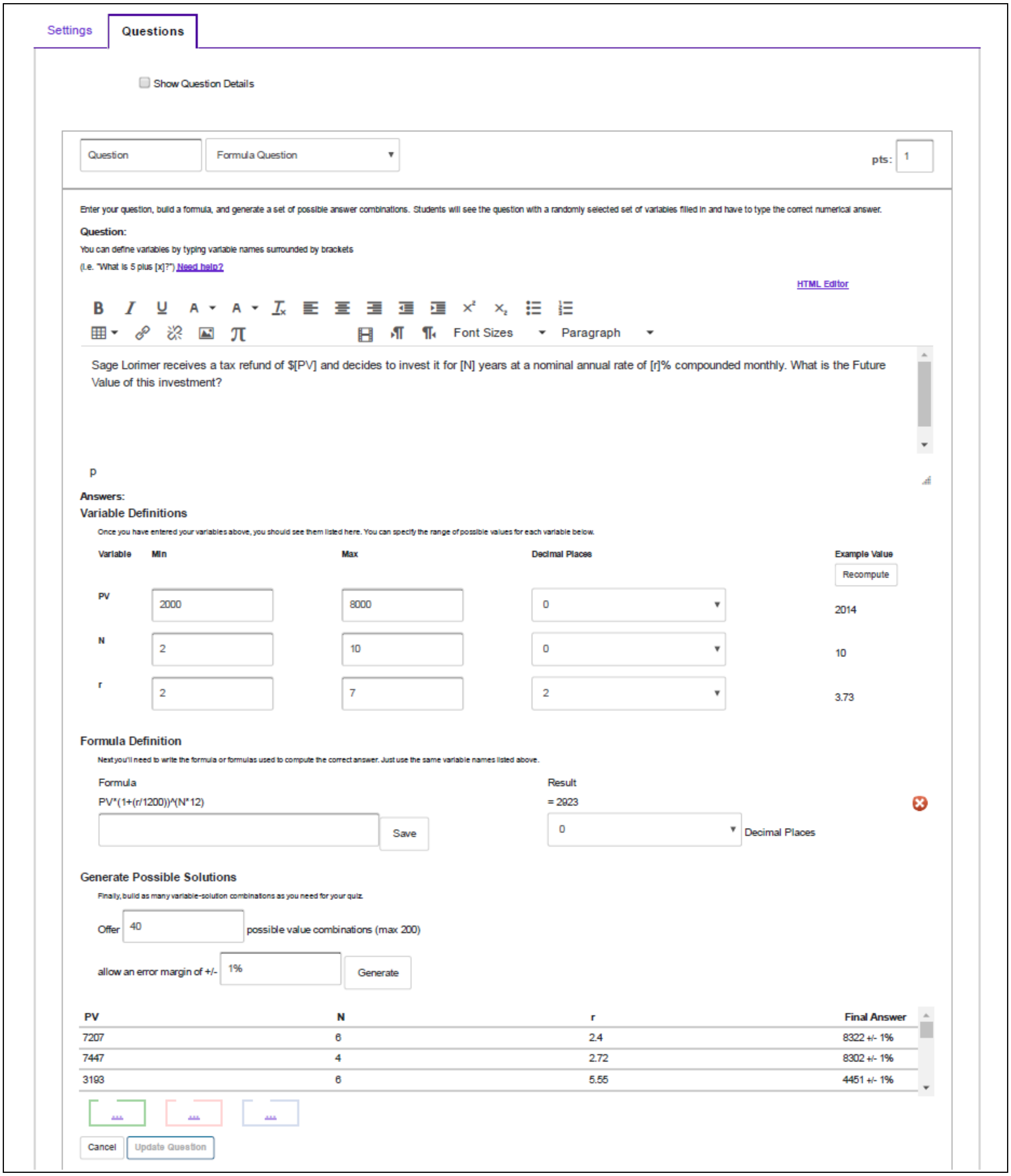

Figure A-6 Constructing a Calculated Question in Canvas™

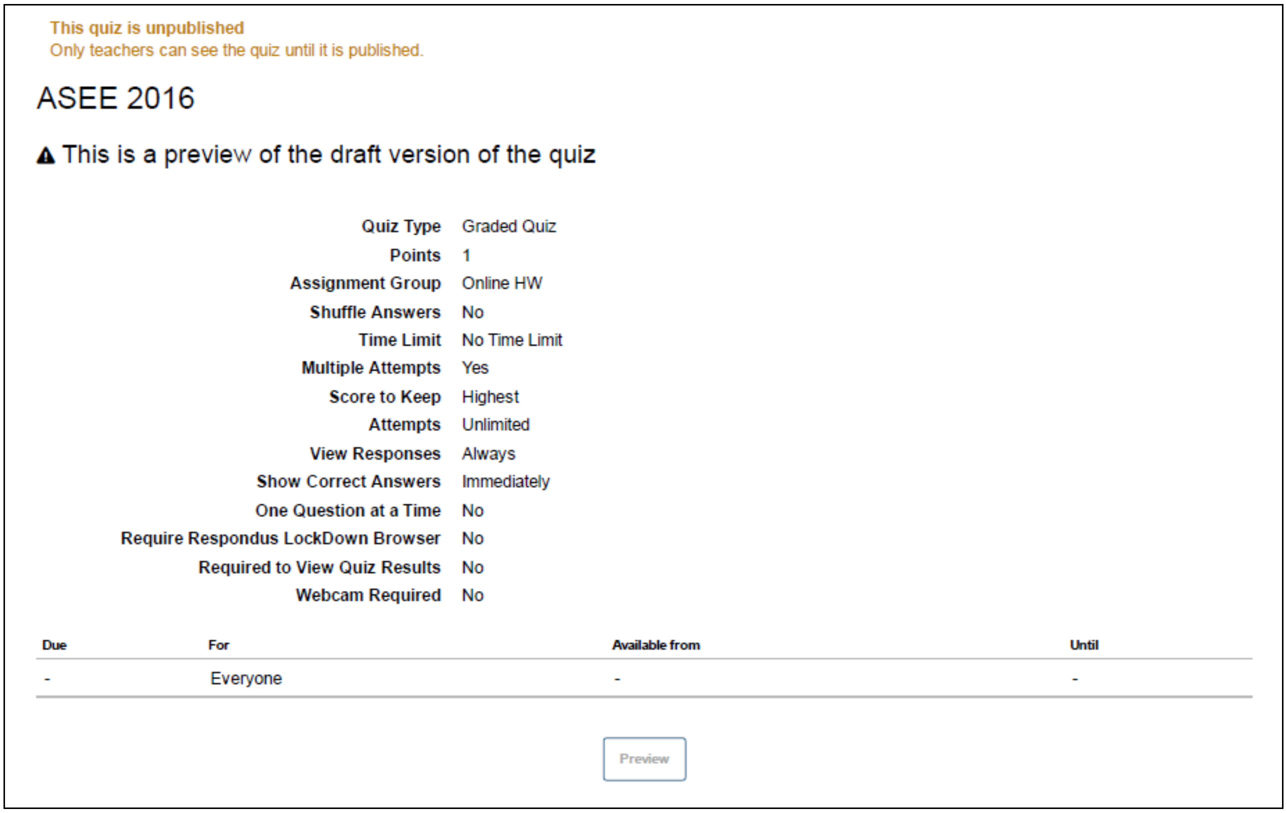

Figure A-7 Preview of the Global Settings for a Calculated Question in Canvas

The image in Figure A-8 shows how the question appears to students taking the quiz within the LMS.

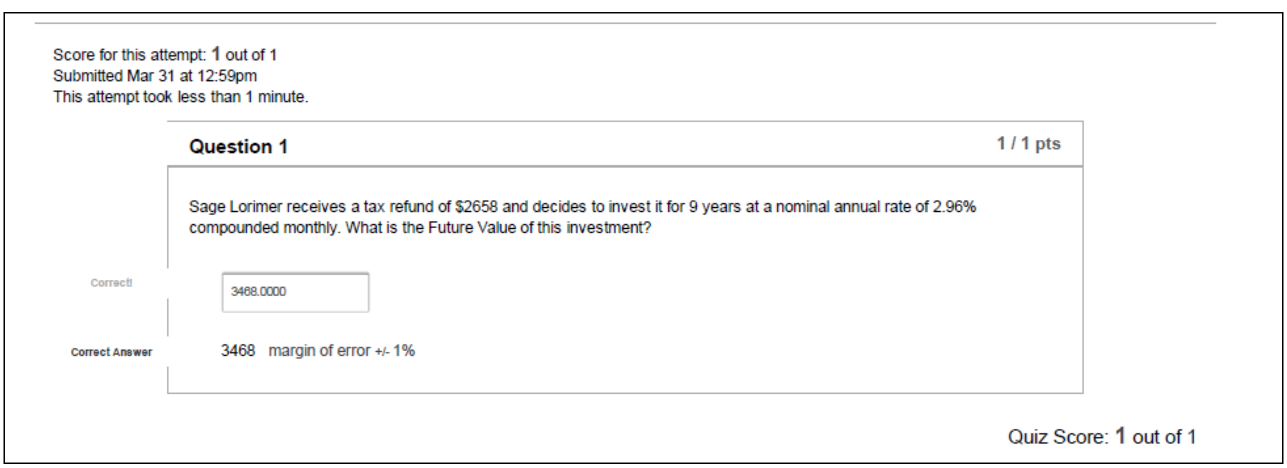

Figure A-8 Example of Previewing a Calculated Question in Canvas