Power to Business Professors:

Automatic Grading of Problem-Solving Tasks in a Spreadsheet

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Abstract

This paper presents an innovative approach based on Excel files and a detailed implementation guide that allows a professor with proficient spreadsheet skills to develop individualized problem-solving tasks for assignments and examinations that test students on cognitive thinking processes beyond memorizing and drilling. The professor accomplishes this goal by requiring the students to model a business problem-solving task in a worksheet environment. Each student's work is marked automatically by a generic "plug and play" Visual Basic for Application (VBA) algorithm. The scores and feedback provided are tailored to each individual student and address not only the problem-solving outcome but also the problem-solving process. The learning objective discussed in this work is implemented at a Norwegian university business school.

Keywords:

Automatic grading

Problem-solving tasks

Spreadsheet

Summative assessment

Formative assessment

1. Introduction

Typical class sizes in introductory accounting and business economics subjects are quite large in higher education, and in these courses manual marking of assignments and examinations capture a significant portion of the professor's work capacity. However, traditional paper-based marking can be replaced by innovative use of information and communication technology (Marriott & Lau, 2008; Evans, 2013), and computer-aided assessment can significantly ease the professor's assessment load (Gikandi, Morrow, & Davis, 2011).

Spreadsheets (e.g., Excel) have become a de facto standard calculation engine in businesses worldwide, and instructors have used this digital tool to deliver drill-and-practice questions that are marked automatically (Drier, 2001; Lehman & Herring, 2003). However, such questions primarily test a student's ability to remember facts and understand concepts. Remembering and understanding represent lower-order cognitive processes (Andersen & Krathwohl, 2001).

Blayney & Freeman (2008) described an approach that instructors can use to create drill-and-practice rules-based questions in Excel that require students to enter cell-referenced formulas, thus promoting greater understanding of underlying concepts. The questions are marked automatically and provide individual feedback to the students. Nevertheless, drill-and-practice rules-based questions are designed to apply procedural knowledge, which is also a lower-order cognitive process (Andersen & & Krathwohl, 2001).

If students are able to achieve high marks strictly by memorization and drilling, the assignments and examinations will promote a surface-learning approach (Knight, 2002a). In higher education, however, we aim to encourage deep learning (Gibbs, 1992; Marton & Saljo, 1984; Ramsden, 1992). Students can obtain deep learning if they are also challenged with higher-order cognitive thinking, which involves analysis, evaluation, and synthesis (Andersen & Krathwohl, 2001; QAA, 2006).

The final examination is an important tool used to foster deep learning (Gibbs, 2006; Knight, 2002b). Consequently, we should design examination questions and problem solving-tasks that are difficult for students who have only a surface knowledge of the subject.

The objective of this paper is to present an innovative approach that a professor with proficient spreadsheet skills can use to develop individualized problem-solving tasks for assignments and examinations that test students on cognitive thinking processes beyond memorizing and drilling. The professor can accomplish this goal by requiring students to model a business problem-solving task in a worksheet environment.

In the following sections, the architecture and functionality of a financial problem-solving task that is marked automatically by a generic ("plug and play") Visual Basic for Application (VBA) algorithm are described. The key discussion focuses on how professors without programming skills can tailor automatically marked problem-solving tasks to their unique accounting and business economics courses. Accordingly, this article is written with the professor and the student in mind.

2. The architecture

The financial problem-solving application described in this article is an Excel workbook composed of four worksheets and two VBA code modules. Fig. 1 illustrates the general structure of such an application.[1]

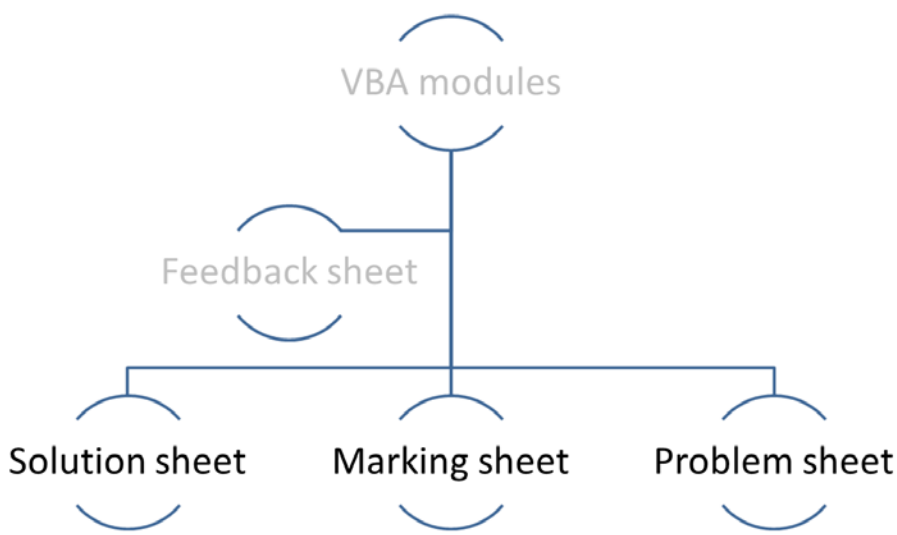


Fig. 1. The architecture of an interactive financial problem-solving application.

[1] Interested readers can obtain the reviewed workbooks and a detailed implementation guide by sending an email to bernt.bertheussen@uit.no

The professor begins by creating the Solution worksheet, the Marking worksheet, and the Problem worksheet. Finally, he/she can import the VBA modules, and the application is ready to run. The marking algorithm within the VBA modules is generic. A professor who structures the workbook application as described in the following sections does not need to make any changes to the code. The Feedback sheet is produced automatically by the marking algorithm. Several problem-solving tasks may be included in one single workbook.

The mechanism that evaluates the student's work is a generic VBA algorithm known in artificial technology terminology as "model tracing" (Koedinger & Aleven, 2007; Heffernan, Koedinger & Razzaq, 2008; Johnson, Phillips, & Chase, 2009). The model is composed of many small components or production rules. Taken together, the production rules form a complete model.

If used for summative evaluation purposes, the model tracing is initiated on the professor's request. The tracing algorithm compares the production rules in a complete solution with the rules of the student's work. Based on the evaluation, the student's individual solution process and solution result are scored automatically. The scoring algorithm provides a feedback report in plain English that explains the score. When applied to assignments, the formative information can promote student learning and improve performance (Evans, 2013; Hattie, 2007). In addition, the reports can support professors in explaining student grades.

We have chosen the Microsoft Excel spreadsheet for our financial problem-solving task for two reasons. First, Excel has become a de facto standard among business professionals worldwide. Equally important, the programming language (VBA) essential to the development of an automatic marking and feedback algorithm is integrated into Excel.

3. The Solution worksheet

Theoretically, a business decision should be made based on an economically rational foundation (Simon, 1957). This foundation typically consists of an economic model that leads to a decision critical calculation, and a rational choice can be made based upon this calculation. In a problem-solving task that is marked automatically, the problem-solving result is not the target of primary evaluation; instead, the analytical basis (in terms of a business model) that represents the student's problem-solving process is assessed.

We will use an investment decision to illustrate the concept. In the example outlined in this article, a student is asked to analyze the profitability of a proposed investment. To assess the profitability of this proposed project, the student must build a decision critical calculation, in this case, the estimated net present value (NPV) of the investment. To perform this calculation, the student must first develop a cash flow model that supplies the calculation with the required input. To create the model, the student must define and analyze a problem, remember the professional procedures, and apply these procedures to the relevant issue (Wood, Bruner & Ross 1976) using a worksheet.

To create an interactive problem-solving task, the professor must first develop the solution in a separate worksheet in the workbook. Fig. 2 illustrates the solution reviewed in this article. The solution is explained in Table 1.

	A	B	C	D	E	F	G	H
1	**Solution: Is Investment Project Profitable?**							
2	Adam Hansen has built popular wooden boats for many years. Now he considers investing in larger							
3	production capacity, but first he wants you to analyse the profitability of his project.							
4								
5	**Questions**							
6	*Q1: Calculate project net present value*	1 784 211						
7	*Q2: Should project be accepted?*	yes						
8								
9	**Facts**							
10	Investment in year 0	4,900,000						
11	Cash Flow from Operations (see Note 1)	1,620,000						
12	Disinvestment (see Note 2)	2,700,000						
13	Tax Rate	28%						
14	Declining Balance Depreciation Rate	20%						
15	Required Rate of Return before Taxes	14%						
16								
17				*Project Cash Flow in Year:*				
18	***Model** - projected cash flow year:*	*0*	*1*	*2*	*3*	*4*	*5*	
19	*Investment and Disinvestment*	-4 900 000					2 700 000	
20	*Cash Flow from Operations*		1 620 000	1 620 000	1 620 000	1 620 000	1 620 000	
21	*Taxes*		- 453 600	- 453 600	- 453 600	- 453 600	- 453 600	
22	*Saved Taxes due to Depreciations*	912 234						
23	*Increased Taxes due to Impairments*	- 310 980						
24	*Net Cash Flow after Taxes*	-4 298 746	1 166 400	1 166 400	1 166 400	1 166 400	3 866 400	
25								
26								
27								
28	*Note 1: This is Net Cash Flow before Taxes. Amount must be included first time in Year 1.*							
29	*Note 2: Disinvestment must be included in Year 5 in Cash Flow, but saved Taxes due to Depreciation should be included in Year 0.*							

Fig. 2. A solution worksheet exemplified.

Table 1
The solution worksheet.

Title and introduction The title, which hints at the problem addressed, is shown in cell A1 in Fig. 2. The title begins with a verb indicating that student activity is expected. Beneath the title (see rows 2:3 in Fig. 2), a short introduction to the problem appears.
Facts and simulations The input data to be used in the model are provided in the facts section (see A10:B15 in Fig. 2). The professor can decide whether the input shall be randomized whenever the student clicks the Retry button (see Fig. 4). Both the input values and the input locations can be randomized. The student's learning may increase if it is not sufficient to simply remember the formulas from the previous attempt, and formulas must be reconstructed at each retry. Thus, repeating the problem-solving task may be perceived as more meaningful for the student. When using the application, a student can easily simulate new facts and assess the impact of the changes on the decision, which is the main purpose of using the completed model. Accordingly, the facts should be shown without the student having to scroll. A real-life decision maker should not be required to understand all of the details underpinning the NPV calculation, but he/she must be able to interpret the calculationand use it to support his/her investment decision.
Model The model is shown in the shaded area located below the facts section (see A18:G24 in Fig. 2) and provides the foundation needed to implement the decision critical calculation in A6 and answer the question A7 in Fig. 2. It is easier for a student to create the model structure if he/she knows approximately where it should be located; this placement will also aid the algorithm in marking his/her work. The model should be located close to the facts section because these facts provide the model with input. Because it is easier to scroll vertically in the worksheet (PgDn/PgUp) than to scroll horizontally, the model is more user-friendly if it is located under the facts section and not next to it.
Decision condition and decision The decision condition (see B6 in Fig. 2) and the decision to be made (see B7 in Fig. 2) are located between the facts and introduction sections. The most important information for the model user (a decision maker) should be placed in the most central location of the screen. Therefore, the decision condition and the facts should be easy to locate in the first screen of the model such that the final user of the model is not required to scroll. The answer to the main question in this paper (see B7) is designed to verify that the student has understood the significance of the most relevant calculation in the model (see B6).

4. The Marking worksheet

The Marking worksheet for a financial problem-solving task is shown in Fig. 3. In this worksheet, the professor specifies how individualized data are generated for each student and how the student's work is scored by the automatic marking and feedback algorithm. The lower part of the Marking worksheet (see from row 56 in Fig. 3) is a copy of the Solution worksheet. The decision condition (A56), the decision (A57), the facts (A59:A65), and the model labels (A68:G68, A69:74) are replicated from the Solution worksheet. However, certain modifications and supplements appear in this worksheet (see Fig. 3 and Table 2).

	A	B	C	D	E	F	G	H	I	J	K
1	**PROBLEM SPECIFICATION**										
2	**Data generation**	*Rng Prbl/Sol*	*Rng Marking*								
3	Fact range	b10:b15	b60:b65								
4	Fact orientation	horizontal									
5	Fact randomization	yes									
6	Output condition range										
7	Simulation range										
8	Model selection										
9	**Grading**	*Rng Prbl/Sol*	*Rng Marking*								
10	Model range	a18:g26	a68:g77								
11	Model orientation	horizontal									
12	Calculation range	b6	b56								
13	Decision range	b7	b57								
14	IF formula with decision logic	yes									
15	Question range	b6:b7	b56:b57								
50											
55		*Score*	*Address*	*Sign*	*Decimals*						
56	*Q1: Calculate project net present value*	10	yes	50%	0						
57	*Q2: Should project be accepted?*	5									
58											
59	**Facts**		*AVG*	*SD*							
60	Investment in year 0	5,300,000	5 000 000	300 000							
61	Cash Flow from Operations (see Note 1)	1,280,000	1 600 000	200 000							
62	Disinvestment (see Note 2)	2,600,000	2 500 000	150 000							
63	Tax Rate	28%									
64	Declining Balance Depreciation Rate	22%	20%	2%							
65	Required Rate of Return before Taxes	18%	15%	2%							
66											
67				*Project Cash Flow in Year:*							
68	***Model** - projected cash flow year:*	*0*	*1*	*2*	*3*	*4*	*5*	*Score*	*Address*	*Sign*	*Decimals*
69	*Investment and Disinvestment*	50	- 25	- 25	- 25	- 25	50	10	no	50%	0
70	*Cash Flow from Operations*	- 50	20	20	20	20	20	5	yes	50%	0
71	*Taxes*	- 50	20	20	20	20	20	10	yes	50%	0
72	*Saved Taxes due to Depreciations*	100	- 20	- 20	- 20	- 20	- 20	15	yes	50%	0
73	*Increased Taxes due to Impairments*	100	- 20	- 20	- 20	- 20	- 20	15	yes	50%	0
74	*Depreciation*							10			
75	*Sales Revenue*							10			
76	*Net Cash Flow after Taxes*	17	17	17	17	16	16	10	no	50%	0

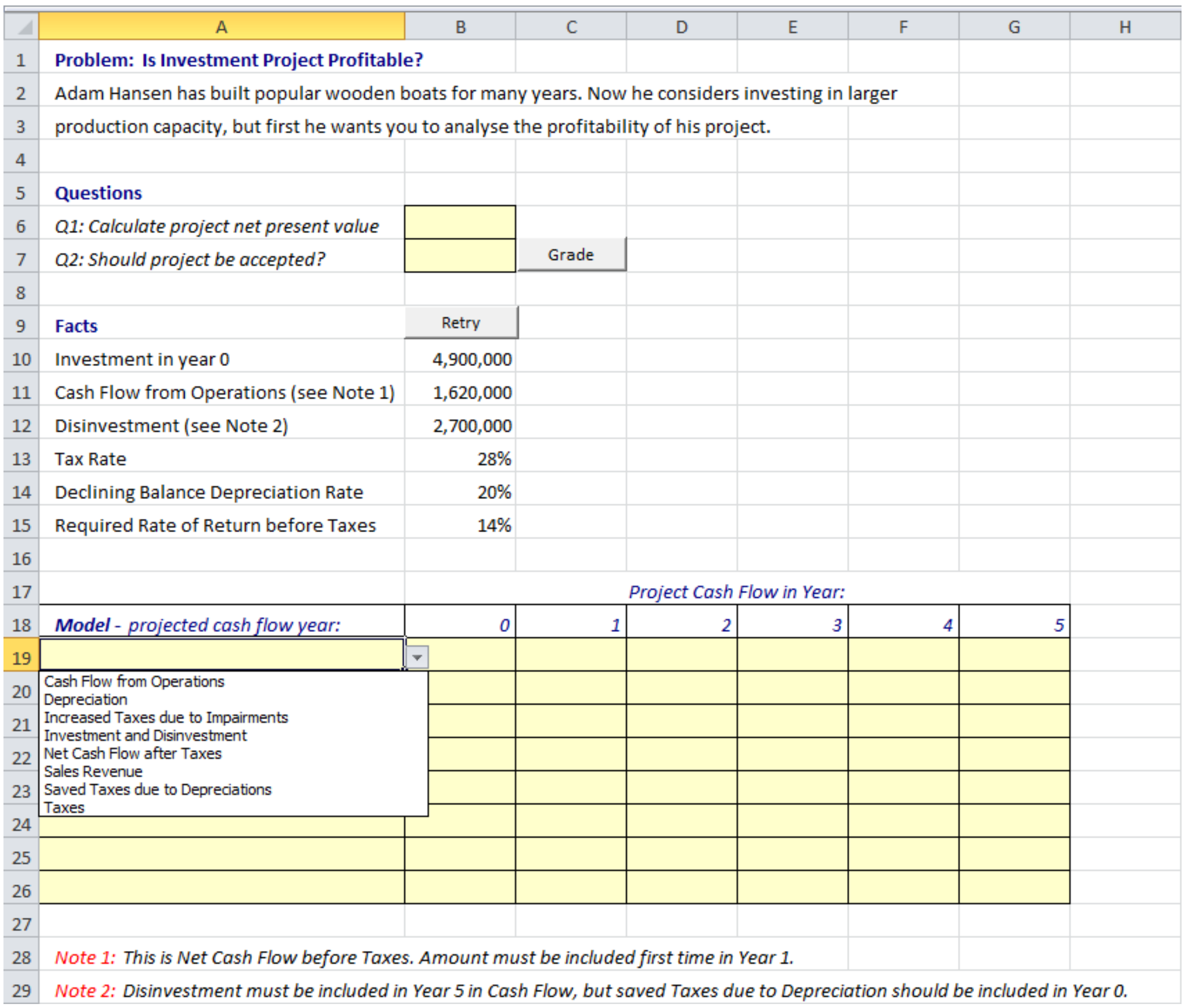
Fig. 3. A Marking worksheet exemplified.

Table 2
The Marking worksheet.

Data generation	Meta data regarding individualized data generation and grading are entered into the upper part of the Marking worksheet. Since Fact ranges are located differently in the Problem/Solution worksheets (b10:b15) and the Marking worksheet (b60:b65), both ranges must be entered. In B60:B65 formulas are generating random facts based on AVG and SD in C60:D65. =ROUND(NORM.INV(RAND(),C60,D60),-5) in B60 e.g., picks a random value from a normal distribution and rounds it to the nearest hundred thousand. The Fact orientation is horizontal when facts are row-wise. When Facts randomization is set to yes, the facts will be placed placed randomly in cells A10:B15 when a student repeats the exercise. The randomized location of facts implies that a student cannot rely on his/her memory when repeating the exercise. Instead, he/she must build the model and formulas from basic principles when retrying (see Fig. 4).
Grading	The model ranges and the model orientation are specified in the Grading specification section. The Calculation ranges and the Decision ranges specifiy the cell addresses for the decision critical calculation, the decision itself and on which cell the decision depends. If the task involves a decision, the professor must enter an IF formula (in B14) that “makes” the investment decision depending on the calculation result (in B6). The IF formula is required for the marking algorithm to correctly handle consecutive errors: =IF(B6>=0,”yes”,”no”). If the NPV in B6 is >=0, “yes” will be shown in B7 when the student’s work is marked. Otherwise, the label “no” will show up. Therefore, a student who has concluded correctly according to his/her individual NPV calculation will earn a full score due to the consistency between his/her conclusion and the calculation result regardless of how wrong the latter may be.
Scoring	The professor scores every production rule in the problem-solving task. A student who achieves 100 points has solved the task completely and correctly. In Fig. 3, the professor weights the production rules in B56:B57 and in H69:H76. In addition to scoring every rule, the professor also can score subsets of the production rules individually. In Fig. 3, this task is accomplished in B69:G76. The score always add up to 100 for a production rule. A negative score indicates that a student is penalized for undertaking a calculation in a cell that should be left blank. In rows 74:75 there are two irrelevant entries in the model (Depreciation and Sales Revenue). As can be seen by the scores in H74:H75, a student can earn 10 points for not including an irrelevant entry in his/her completed model. If a formula contains multiple cell addresses, the professor may decide that a student should be able to earn points for each relevant address included in the formula by setting Address to “yes” or “no.” The addresses are weighted equally. When the marking algorithm scores the cell addresses used correctly in the formulas, a student also earns points if he/she presents a partially correct formula. However, the algorithm does not take into account whether the operators are applied correctly in a formula. The percentage entered into the Sign cells (from 0% to 100%) specifies the score deduction for use of a wrong sign in a formula. If the calculation result is a percentage, the professor specifies how sensitive the marking should be to the number of decimal places entered into the Decimals cells.

5. The Problem worksheet

The Problem worksheet represents a copy of the Solution sheet but without the model, the NPV calculation and the investment decision. A professor can quickly and easily create a Problem worksheet by copying the Solution sheet and renaming it. Finally, he/she can delete the model and calculations in the Problem worksheet. The result is shown in Fig. 4 below, and the procedure is explained in Table 3.



	A	B	C	D	E	F	G
1	**Problem: Is Investment Project Profitable?**						
2	Adam Hansen has built popular wooden boats for many years. Now he considers investing in larger						
3	production capacity, but first he wants you to analyse the profitability of his project.						
4							
5	**Questions**						
6	*Q1: Calculate project net present value*						
7	*Q2: Should project be accepted?*		Grade				
8							
9	**Facts**	Retry					
10	Investment in year 0	4,900,000					
11	Cash Flow from Operations (see Note 1)	1,620,000					
12	Disinvestment (see Note 2)	2,700,000					
13	Tax Rate	28%					
14	Declining Balance Depreciation Rate	20%					
15	Required Rate of Return before Taxes	14%					
16							
17				*Project Cash Flow in Year:*			
18	***Model** - projected cash flow year:*	*0*	*1*	*2*	*3*	*4*	*5*
19							
20							
21							
22							
23							
24							
25							
26							
27							
28	*Note 1: This is Net Cash Flow before Taxes. Amount must be included first time in Year 1.*						
29	*Note 2: Disinvestment must be included in Year 5 in Cash Flow, but saved Taxes due to Depreciation should be included in Year 0.*						

Cash Flow from Operations
Depreciation
Increased Taxes due to Impairments
Investment and Disinvestment
Net Cash Flow after Taxes
Sales Revenue
Saved Taxes due to Depreciations
Taxes

Fig. 4. A Problem worksheet exemplified.

Table 3

The Problem worksheet.

The Problem worksheet This sheet is a copy of the Solution worksheet but without the model, decision critical calculation, and the decision. Therefore, the decision range (B6:B7) and the model range (A19:G24) are empty in the Problem worksheet.
Labels The professor can insert a data validation list of labels (e.g. see A19) not only to simplify the model construction but also to make it possible to mark the model automatically. If a student were free to label the production rules, it would become more challenging for the marking and feedback algorithm to identify the necessary entries. In this way, a student can quickly build the model using the pre-constructed labels. The order of the entries does not impact the grading. A professor can include irrelevant labels as distractors to complicate the model construction. If the text is provided in the validation list, the length of all text is limited to 256 characters.
Feedback If the problem-solving task is formative, the professor will insert Feedback and Retry buttons into this worksheet. When a student clicks the Feedback button, a detailed feedback report is prepared that automatically explains what he/she has achieved and how he/she has failed (see Fig. 5). Moreover, comments are inserted in the cells that contain errors in the Problem worksheet. A student can click the Feedback button at his/her own discretion.
Retry When the problem is intended for formative use, a student can restart his/her work by retrying. The Problem worksheet is emptied, and new facts are randomly inserted.

As shown in Fig. 4, a student must develop a solution based on a professional analysis of the problem-solving task presented. The analysis will uncover what information the student needs to make a decision critical calculation (e.g., NPV). The student must obtain this critical calculation by building a cash flow model using the required data for the calculation. The only hints the student receives for the modeling work are the predefined labels for the model axis (see the data validation list in Fig. 4). A student who solves a similar task manually will generally not receive such assistance. However, recognizing a label requires only a marginally less cognitive effort than remembering it (Anderson & Krathwohl, 2001). The fact that a student can construct a model quickly may motivate him/her to learn through trial and error and to perform more repetitions.

Predefined labels do not only have an educational purpose, they are also a precondition for the VBA algorithm to mark the student's work automatically. It would be a much greater challenge for a marking and feedback algorithm to identify the production rules if a student were able to freely arrange the model axis because different words can describe the same phenomenon. Moreover, the same word can be written in several ways if we take into account the possibility of typing errors.

A professor can include irrelevant labels to complicate the texting of the axis. The student must subsequently evaluate which labels are relevant and should be included in the model and which should not due to irrelevance. The order of the student's selection of entries does not matter.

6. The Feedback worksheet

A computer algorithm can mark a problem-solving task immediately and will treat every student equally. The students must perceive automatic marking as fair or in line with manual marking. If a student has implemented an appropriate production rule, he/she receives a full score (see ranges B6:B7 and H19:H24 in Fig. 3). If the rule is implemented only partially, the scoring is awarded accordingly (see range B19:H24 in Fig. 3). If the rule is not implemented or implemented completely wrong, the student receives no score.

In addition to scoring, the marking and feedback algorithm can also provide formative feedback to a student. The feedback worksheet provides corrective feedback or hints on how the student can develop his/her solution further. For a student to learn from the hints, the information should be presented in a professional and understandable language and not as mysterious data messages (Evans, 2013; Shute, 2008). This aspect is particularly important if a problem-solving task is applied formatively (Hattie & Timperley, 2007; Price, Handley, Millar, O'Donovan 2010). However, a feedback report can also be used summatively (Knight, 2002b). The students do not simply receive marks but also receive a professional explanation for the grade achieved on their assignments, tests, and final examination.

The Feedback worksheet is inserted into the workbook automatically by the marking algorithm. Fig. 5 shows a partial example of a student's work, while Fig. 6 illustrates the corresponding Feedback worksheet.

	A	B	C	D	E	F	G
17			*Project Cash Flow in Year:*				
18	***Model** - projected cash flow year:*	*0*	*1*	*2*	*3*	*4*	*5*
19	*Investment and Disinvestment*	-4 900 000					-2 700 000
20	*Cash Flow from Operations*		1 620 000	1 620 000	1 620 000	1 620 000	1 620 000
21	*Depreciation*		- 440 000	- 440 000	- 440 000	[illegible]	[illegible]
22	*Taxes*		- 453 600	- 453 600	-1 620 000	- 453 600	- 453 600
23	*Saved Taxes due to Depreciations*	912 234					
24	*Increased Taxes due to Impairments*	- 310 980					
25	*Net Cash Flow after Taxes*	-4 298 746	726 400	726 400	- 440 000	726 400	-1 973 600
26							

- Tax Rate is missing.

Fig. 5. A partial solution exemplified.

In the work shown in Fig. 5 (only the student's model is shown), the student has used the wrong sign on the disinvestment in year 5. The tax calculation in year 3 is also wrong because he/she has not taken the tax rate into account. Finally, the student has included Depreciation as a production rule but this is an irrelevant entry (see row 22 in Fig. 5). The worksheet in Fig. 6 provides feedback on the student's work reflected in Fig. 5.

Feedback on Problem: Is Investment Project Profitable?
Total score: 86 %

÷ ***Model: Investment and Disinvestment***
Wrong sign (look at G19).

✓ ***Model: Cash Flow from Operations***

÷ ***Model: Taxes***
Incorrect calculation (look at E22).
- Tax Rate is missing.

✓ ***Model: Saved Taxes due to Depreciations***

✓ ***Model: Increased Taxes due to Impairments***

✗ ***Model: Depreciation is included in your model, but this is wrong!***

✓ ***Model: Sales Revenue is an irrelevant item and not included in your model. This is correct.***

✓ ***Model: Net Cash Flow after Taxes***

✓ ***Q1: Calculate project net present value***

✓ ***Q2: Should project be accepted?***

Fig. 6. A Feedback worksheet exemplified.

The student's total score (86%) is shown in the second line of the report heading. Next, each production rule in the model is commented individually. A checkmark (green) indicates confirmatory feedback, a cross (red) indicates missing or completely wrong implementation of a production rule, and a minus sign (yellow) indicates a partially correct implemented production rule, including corrective feedback. The wrong entries are explained in understandable terminology. The text "Wrong sign in year 5 (see G19)" displays both an error and a hyperlink. Clicking on this hyperlink will bring the student to the cell with the error. To explain the error a comment is inserted in the cell that is wrong. The cross (red) in front of the text "Model: Depreciation is included in your model, but this is wrong!" shows that this entry is completely wrong. Table 4 provides an overview of the typical shortcomings and the formative feedback provided for errors in a student's individual work.

Table 4

Examples of automatic formative feedback.

Quality of the student's work	Examples of formative feedback
Production rule is correct	✓ Investment/disinvestment
Wrong sign on calculation in production rule	÷ Investment/disinvestment Wrong sign in year 5
Calculation missing in production rule	÷ Investment/disinvestment Calculation missing in year 5
Superfluous calculation	÷ Investment/disinvestment It is wrong to include a cash amount in year 2
Variable is missing in formula	÷ Project net present value before taxes Required rate of return missing in calculation
Wrong variable is used in formula	÷ Project net present value before taxes Error in calculation
Wrong operator used	÷ Cash in flow from operations Error in calculation year 1
Production rule missing or completely wrong	× Investment/disinvestment
Irrelevant production rule included in model	× Depreciation included, which is wrong
Investment decision is wrong	× Inconsistent conclusion

7. Marking the students work credibly and fairly

We have described the work required for a professor to create a problem-solving task that is marked automatically and provides feedback both on a student's problem-solving process and his/her problem-solving result. The VBA modules contain generic procedures that mark the student's work and prepare the Feedback sheet. The marking and feedback must be credible for the students to gain confidence in this approach.

However, automatic marking is complicated by the risk of consecutive errors in calculations. A consecutive error is one that occurs early and is propagated through subsequent steps, thus causing errors in subsequent calculations. For this situation, our marking algorithm detects and corrects consecutive errors so that students are not successively penalized for the same error.

In the student's work exemplified in Fig. 5, Tax is calculated incorrectly in year 3 due to missing tax rate. This error propagates to Net Cash Flow after Taxes year 3 because the result of this calculation is dependent on the former. The student's calculation of Net Cash Flow after Taxes is correct based on his/her foundation, and a (green) mark appears in front of this production rule in the feedback report (see Fig. 6). The student's score is not affected by an error that propagates from an error already marked.

The error due to the miscalculated taxes propagates to Net Cash Flow after Taxes in year 3 and spreads further to the project's estimated NPV (see cell B6 in Fig. 2). This error can also have an impact on the final investment decision (see cell B7 in Fig. 2) if it causes the sign to change on the NPV calculation. The error made early in the model propagates and causes at least two consecutive errors and conceivably even three.

If we study the report in Fig. 6, we observe that the student receives a full score for the production rule Net Cash after Taxes because he/she has calculated properly although on a wrong basis. This reasoning also applies to the Depreciation calculations, which are wrongly included in the model (see row 21 Figure 5 and Figure 6), and the disinvestment, which has a wrong sign in year 5 (see cell E22 Figure 5 and Figure 6). The errors in Net Cash Flow after Taxes propagate to the calculated NPV amount (see cell B6 in Fig. 2) and may propagate further to the final investment decision (see cell B7 in Fig. 2).

The marking algorithm “remembers” the student’s errors and makes adjustments continuously as the marking is executed. This approach addresses the consecutive-errors problem and therefore helps to ensure that the student’s work is marked credibly and fairly.

8. Using problem-solving tasks formatively and summative

In a course design, both formative and summative assessment activities should be embedded (Knight, 2002b). Assessments may have a formative purpose that modifies the learner’s thinking or behaviour to improve overall learning (Shute, 2008). Formative assessment is known as ‘assessment for learning.’ Educational research emphasizes the powerful influence on learning through formative feedback and assessment (Black & Wiliam, 2009; Hattie & Timperley, 2007; Shute, 2008). Interactive spreadsheet problem-solving tasks can be used formatively.

When the interactive spreadsheet problems are used formatively, it is vital that the students get constructive feedback promptly. This, may create extra engagement and motivation for practicing. When used formatively, the Problem, Solution, and Marking worksheets are not separated, but submitted to the students in one single workbook including the VBA-code modules (see Table 5).

Table 5

Sequence of events when interactive spreadsheets are used formatively

Individual	Action	Comment
Professor	Prepares an workbook containing problem-solving tasks.	One workbook can contain several problems. For each problem there are three worksheets (viz., Problem, Solution, and Marking).
	The workbook, including all necessary worksheets, is distributed to students via the Faculty's Learning Management system.	The Solution sheet is hidden and the Marking sheet is very hidden meaning it can only be unhidden from the VBA-editor, and not from the user interface.
Student	Completes the Problem worksheets and self-grades them one by one.	If the solution is not correct, the student can use the Feedback worksheet and the Solution worksheet (must first be unhidden) to track and correct errors.

Assessments that certify achievement include a feed-out function since the grades can be treated as a performance indicator for the students. Such assessment is often called 'summative' or 'assessment of learning' (Wiliam, 2011). Interactive spreadsheet problem-solving tasks can be used summative.

Table 6

Sequence of events when interactive spreadsheets are used summative

Individual	Action	Comment
Professor	Prepares workbook– first the Solution worksheet, next the Marking worksheet, and finally the Problem worksheet.	When used summative, there are normally several problems for the students to solve and accordingly matching Solution worksheets and Marking worksheets.
	Only the workbook containing the Problem worksheets is distributed. The corresponding Solution and Marking worksheets are saved in separate workbooks on the professor's hard drive.	A macro generates individual workbooks for each student and splits the individual workbooks into a Problem workbook and corresponding workbooks with the Solution and Marking sheets. Another macro emails only the Problem workbook to the students.
Student	Completes all Problem worksheets in Problem workbook	As specified above, the Solution and Marking worksheets are removed before Problem workbooks are distributed.
	Submits the Problem workbook to faculty	When the students have finished their work, they reply by email and attach their prepared Problem workbooks.
Professor	Merges the submitted Problem workbooks with the corresponding stored Solution and Marking workbooks.	This is done automatically by a macro.
	Scores and grades	Runs grading macro and prepares summary scoring report with grading statistics.
	Provides feedback to students	Using a macro the graded workbooks containing a detailed feedback report are sent by email to students.

The system described in this article supports problem-solving tasks challenging different cognitive processes (see Table 7).

Table 7
Problem-solving tasks challenging different cognitive processes

	Question/Problem Type	Cognitive Processes Challenged
1	Multiple-choice questions	Remembering facts and understanding concepts, but can also challenge higher-order cognitive processes
2	Implementing a single calculation procedure	Applying procedural knowledge
3	Implementing multiple calculation procedures in an established structure	Applying and analysing procedural knowledge
4	Implementing a model, i.e. multiple calculation procedures in a structure established by the student him-/herself	Applying, analysing, evaluating and creating procedural knowledge
5	Goals Seeking problem-solving task	Applying procedural knowledge
6	Solver problem-solving task	Applying and analysing advanced proceduralknowledge
7	Regression problem-solving task	Applying and analysing advanced procedural knowledge

Detailed instructions for implementing the problem-solving tasks formatively and summative are provided in the supplemental Implementation Guide available, on request, from the author.

9. Conclusion

Whether on campus or on-line, teaching undergraduate accounting and business economics subjects often involves large groups of students. For such courses, it is challenging for a professor to provide timely feedback that is tailored and targeted toward improving both the process and the outcome of the students' problem-solving abilities. Educational research, however, emphasizes that formative feedback can engage and motivate students and help them to identify their weaknesses, reflect on their performance, and improve their study skills (Aisbitt & Sangster, 2005; Evans, 2013; Halabi, 2006; Lewis & Sewell, 2008). Moreover, the assessment load on professors is substantial if it includes manual marking and grading of written assignments and examinations.

In this paper, we have described an approach that enables a professor with proficient spreadsheet skills to create problem-solving tasks in basic accounting/business subjects that are marked automatically. To model regression and optimization problem-solving tasks the professor should be familiar with array formulas.

The problem-solving application architecture that is the professors point of departure (see Fig. 1) includes a generic "plug and play" marking and feedback algorithm developed in VBA, the programming language integrated into Microsoft Excel.

The generic model-tracing algorithm that evaluates the student's work provides feedback not only on the problem-solving result but also on the student's problem-solving process. This feedback is delivered via a feedback report, which indicates the steps that will improve the student's solution.

The concept discussed in the article is applied at a University business school in Norway and has been used for several years with approximately 800 hundred students, not only for summative tasks (i.e., mandatory assignments and the final examination) but also as a vital component for providing the students' with formative feedback on their homework. Because homework, assignments and exams are marked automatically, the assessment load on professors is substantially reduced.

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