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Accommodating the difference in students' prior knowledge of cell growth kinetics

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Abstract This paper describes the development and benefits of an adaptive digital module on cell growth to tackle the problem of educating a heterogeneous group of students at the beginning of an undergraduate course on process engineering. Aim of the digital module is to provide students with the minimal level of knowledge on cell growth kinetics they need to comprehend the content knowledge of the subsequent lectures and pass the exam. The module was organised to offer the subject matter in a differentiated manner, so that students could follow different learning paths. Two student groups were investigated, one consisting of students who had received their prior education abroad and one of students that had not. Exam scores, questionnaires, and logged user data of the two student groups were analysed to discover whether the digital module had the intended effect. The results indicate that students did indeed follow different learning paths. Also, the differences in exam scores between the two student groups that was present before the introduction of the digital module was found to have decreased afterwards. In general, students appreciated the use of the material regardless of their prior education. We therefore conclude that the use of adaptive digital learning material is a possible way to solve the problem of differences in prior education of students entering a course.

Keywords: adaptive digital learning material, bioreactor design, biotechnology, education, intelligent tutoring system, intelligent Web-based educational system

INTRODUCTION

The various university exchange programs have led to more differentiation in levels of student knowledge at the beginning of a course. For a teacher it is not desirable to teach concepts which are not known to some students whereas other students do know these concepts and are bored and not motivated. To tackle the problem of these different levels of prior knowledge it is preferred to use learning material that presents the theory to the student in a differentiated way. One way to accomplish differentiation is by using digital learning material. Digital learning material is often called e-learning and is increasingly being used in university education (Wallace, 2003; Tham and Werner, 2005). Digital learning material capable to offer theory in a differentiated way to students is called adaptive digital learning material. Adaptive digital learning material can be of help to teach a heterogeneous group of students by adapting to the knowledge level of individual students (Brusilovsky, 2001; Knutov et al. 2009). Many groups have focused on the development of adaptive digital learning materials (Melis et al. 2001; Gogoulou et al. 2007; Kortemeyer et al. 2008; Keleş et al. 2009; Suebnukarn, 2009). The systems to create the digital learning material are categorised by Brusilovsky and Peylo (2003). Systems that allow access using the Internet are called adaptive and intelligent Web-based educational systems and systems used to let the user actively practise with concepts are called intelligent tutoring systems. These terms overlap and the system investigated in this paper belongs to both categories; the term intelligent tutoring system is chosen to identify the system.

Digital learning material can adapt to the student by collecting information about the student and then to build a user model (Chin, 2001), also called student model (Tsiriga and Virvou, 2004; Martins et al. 2008) or learner model (Akhras and Self, 2002; Shute and Towle, 2003). We interpret the user model as a model of the user based on the information that the system has acquired. This information can be static, *i.e.*, it does not change during the learning activity (*e.g.*, the user's gender, preference for video or audio) or dynamic, *i.e*., the information changes during the learning activity (*e.g.*, the user's knowledge level).

The collaboration between Wageningen University, The Netherlands and China Agricultural University involved the inflow of undergraduate students from China in biotechnology and food technology programs at Wageningen University. The exchange students followed the first part of the study program in China and came to the Netherlands to continue in the second year of the regular undergraduate program. So, from the second year onwards regular and exchange students followed the study program together, which meant that a heterogeneous group of students thus had to be educated in the second and third year of the study program. Instructors experienced problems when giving their lectures because of the differences in the levels of students' prior knowledge. The possibility to use adaptive digital learning material was seized, and an adaptive digital module (ADM) to teach cell growth kinetics was developed for use in a course on process engineering. This paper describes the development and advantages of using this ADM at the beginning of the course to tackle the problem of educating a heterogeneous group of students in an undergraduate course on process engineering.

The intelligent tutoring system

The intelligent tutoring system, called Proteus, was used to make the adaptive digital module was developed by Sessink et al. (2007). It was designed to contain exercises with which students can earn credit points to achieve predefined learning goals. Figure 1 shows an overview of the flow of actions in the tutoring system.

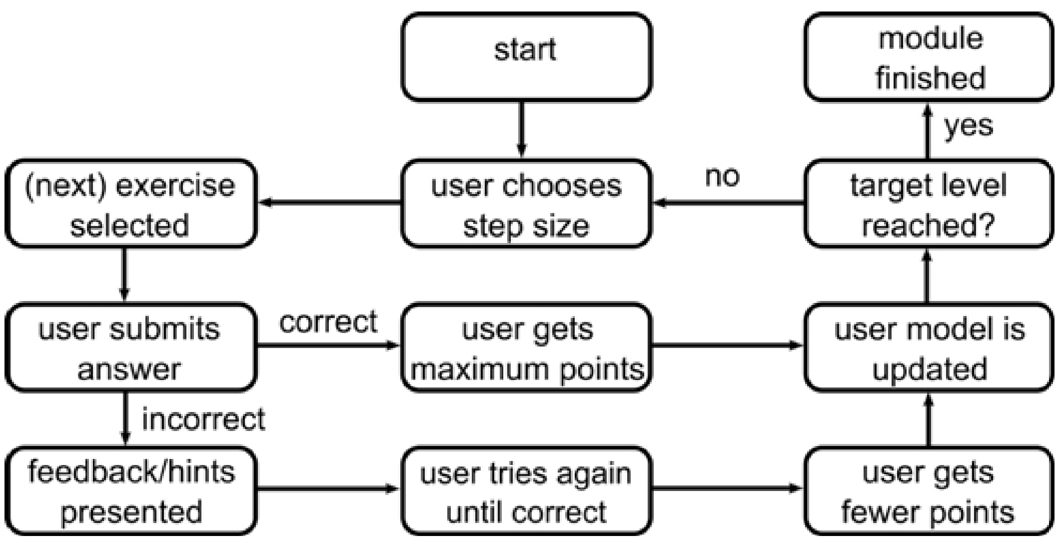

Fig. 1 The flow model of the intelligent tutoring system.

A student starts the ADM and chooses a step size to go through the module: small, medium, or big. The system selects an exercise with the required step size and the student submits an answer. If the answer is correct, the maximum number of credit points assigned to the exercise is added to the corresponding learning goal(s) in the student's user model. If the answer is incorrect, the system presents hints and the student has to try again until the right answer is given. The number of points added in the user model depends on the number of tries the student needs and can also be negative.

Next, the system checks whether the preset minimum number of points for each learning goal is reached. If so, the student has finished the module. If not, the cycle starts again. The selection for the next exercise is based on the user model and the chosen step size, causing a variation in the number of exercises students need to finish the module.

Thus, two parameters contribute to the adaptive feature of the digital module. One is system-driven, namely the distribution of credit points after incorrect answers and the selection of the next exercise. The other is student-driven, namely the choice of step size for the next exercise. The use of these two parameters makes the system adaptive and allows for differentiated learning paths.

Content of the digital module

In order to teach the basic knowledge needed for bioreactor design, which is part of the course on process engineering, an ADM called 'Introduction to cell growth kinetics' was designed. The module was made using the intelligent tutoring system Proteus, which was described in detail in the previous section. By doing the module students learn to set up a general mass balance over a general bioreactor, and from that to derive the basic equations for batch and continuous stirred tank reactor. They learn the concepts of specific growth rate μ, Monod (K_s, μ_{max}), biomass yield coefficient y_{xs}, maintenance coefficient m_s, and by specifying mass (substrate, biomass) and units (kg, m, s, etc.), learn to derive the equations needed to calculate desired reactor volumes, residence times, conversions, etc. Thus, the module provides knowledge and understanding by means of basic bioreactor applications.

The exercises, including feedback, a digital library, and annotated credits for the exercises, were written by a researcher in the field of biotechnology education. The feedback is adaptive and consists of 'answer until correct' and 'elaborated' types of feedback (Vasilyeva et al. 2007). After use by the students the content was improved in several revision cycles. The module contains different kinds of exercises, such as multiple choice questions, calculation exercises, and exercises to design an equation (Figure 2).

The material is freely available for use in educational settings to teach the basics of cell growth kinetics[1].

Preliminary results from the ADM on cell growth kinetics have already been presented (van Seters et al. 2008), and offer promising perspectives for the use of this material to teach heterogeneous groups of students. Students found the use of the ADM challenging, useful, and were generally positive about the module, regardless of their background. In the study described here the opinion of the students about the use of the module was analysed.

Aim of this study

This paper reports on data that are part of a larger research project focusing on the learning process of students with different levels of prior knowledge using adaptive digital learning material. The aim of this study was to discover if the ADM on cell growth kinetics at the beginning of the course could give students with different prior education the same basic level of knowledge needed to comprehend the subsequent lectures and pass the exam. The three subsequent research questions were:

1. Do students with different levels of prior education perform equally well on the topic of cell growth kinetics after introduction of the ADM?

2. Do students appreciate using the ADM to gain knowledge about cell growth kinetics?

3. Do students follow different learning paths to finish the ADM?

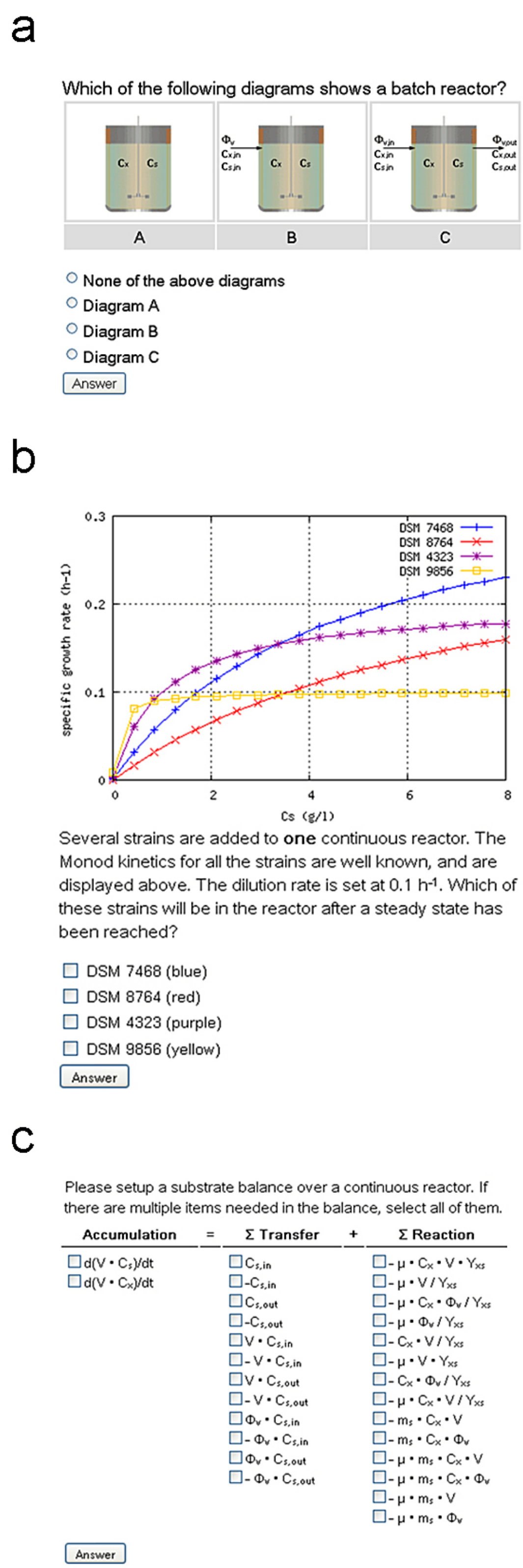

Fig. 2 Screenshots from the ADM ‘Introduction to cell growth kinetics’ showing examples of different types of exercises: a) multiple choice, b) equation design, and c) calculation.

MATERIALS AND METHODS

Participants

Participants in this study were regular and exchange students in the second year of the biotechnology or food technology programs at Wageningen University, The Netherlands. At the time of the experiment all students were following a course 'Introduction to process engineering'. The exchange students had followed a two-year preparation program in China, which of course differed from the first-year program that the regular students followed. The study covered three successive years (cohorts). The numbers of students that participated in the study per cohort is given up in Table 1.

Context of the experiment

The students from cohort 1 followed the course 'Introduction to process engineering' without the ADM. This course consisted of lectures in which the instructor explains the subject matter, and seminars in which the student practise the subject matter by making exercises. The students from cohorts 2 and 3 followed the course with the ADM added, which was introduced by the instructor during the first lecture on bioreactor design. The students worked on the module during the subsequent seminar of two hours. The instructor and several assistants were available to help students with the module. The students were allowed to finish the module at home if necessary. At the end of the course the students' knowledge was tested during an exam, containing one exercise on the subject taught by means of the ADM.

Data collection

The data that were needed to answer the three research questions were collected from exam scores from all students, and the user data and responses to a questionnaire logged from the students of cohorts 2 and 3. The exam scores were obtained from the exercise in the end-of-course exam that dealt with the subject taught in the ADM. The user data contain the answers students submitted to the exercises in the ADM. From the user data it is possible to deduce how many exercises an individual student needed to make to finish the module.

To enhance learning it is important that students are motivated by the materials they use. To discover if students appreciated the ADM on cell growth kinetics, we asked them to fill in a questionnaire after finishing the module. This questionnaire consisted of open-ended and Likert-scale items. The items from the questionnaire analysed in the study were '*This module is useful*', '*This module is fun*', '*This module challenged me*' and '*This module is motivating*'. Student could indicate on a five-point scale in how far they agreed with the statements.

In addition, the course instructor was interviewed to give his opinion about the ADM.

Data analysis

The data were filtered to include only the students relevant for this study: those who used and finished the module, and took the exam for the first time. The number of exercises that students needed to finish the module was calculated.

The data from the two student groups were compared in order to find differences between them using the parametric independent *t*-test or the non-parametric Mann-Whitney test. The statistical analysis

Table 1. Overview of the number of students [that were] analysed in the study.

Cohort	Regular group	Exchange group
1	54	12
2	22	37
3	38	23

was conducted using Statistical Package for the Social Sciences (SPSS) for Windows (release 17.0.3.2007). A significance level of $p < .05$ was used.

RESULTS

Analysis of the exam scores

The differences in scores to the module-related question of the exam between the two student groups were measured using both parametric and non-parametric tests (Table 2). The non-parametric Mann-Whitney test compares medians (Mdn) instead of means (M), but to allow for better comparison of the cohorts only means are presented here. The results from Table 2 show that before introduction of the ADM the difference in mean exam scores for the module-related question between the two student groups is large (cohort 1). After introduction of the ADM the differences are smaller (cohort 3) or even absent (cohort 2).

Table 2. Comparison of exam scores.

Cohort	ADM?	Mean score		Difference	Significant?[a]
		Regular group	Exchange group		
1	No	4.0 (N=54)	0.8 (N=12)	3.2	Yes
2	Yes	4.8 (N=22)	5.4 (N=37)	0.6	No
3	Yes	5.0 (N=38)	3.6 (N=23)	1.4	Yes

[a] $p < 0.05$.

Analysis of the questionnaire

Four Likert-scale items on appreciation were included in the questionnaire, and the answers to these items were combined into one indicator of appreciation by averaging them. The results are given in Table 3.

The appreciation mean indicates that all student groups appreciated the use of the module (M = 3.6-3.9). Statistical tests showed that there is no significant difference in appreciation between regular and exchange students ($p > 0.05$).

In an open ended question the students were asked to write down their opinion on the module. The responses illustrate the positive opinion of the students on the module. Students wrote, for example: *'The module can help me to learn and understand the equations better than before', 'At first I thought it would be very very hard for me to finish it, because I didn't get enough information from the instructor. However when I started it I found I could get most information from the digital library and it seems more interesting and challenging to find the right answer and get a high grade. I really like the module!', 'The explanation at the end of the exercise why the answer was correct is very clear'* and ***'****the hints are important and clear enough to give me some information when I made mistakes'*.

Table 3. Means of the responses to Likert-scale questions in the questionnaire.

	Cohort 2		Cohort 3	
	Regular	Exchange	Regular	Exchange
This module is useful	4.4	4.0	4.2	4.7
This module is fun	3.1	3.6	2.7	3.1
This module challenged me	3.8	3.8	3.9	4.1
This module is motivating	3.4	3.8	3.6	4.1
Appreciation mean	3.7	3.8	3.6	3.9

Students also encountered problems using the module. They found the scoring system inconsistent and unclear: '*I think the penalty for a wrong answer could use some adjustment*' and '*the negative points you get when you make mistakes should be changed*'. They also indicated that more information was needed to find the right answer: '*I want to know more about the explanation of the questions*' and '*I do think there could be more explanation in the library or more extensive hints*'.

Analysis of the logged user data

The adaptivity of the module is determined in two ways: first, by the selection of exercises by the system according to the performance of the individual student as recorded in the user model; and second, by the students' choices of small, medium and big steps. As a result, the number of exercises students need to finish the module can vary. The comparison of the two student groups in cohorts 2 and 3 shows no difference between both groups ($p > 0.05$). However, the number of exercises needed to finish the module varies a lot within the groups (Table 4).

Table 4. Mean and range of the number of exercises needed to finish the module.

	Cohort 2		Cohort 3	
	Mean	Range	Mean	Range
Regular group	49.8 (SD=12.0)	23-69	54.5 (SD=14.8)	27-86
Exchange group	52.1 (SD=12.7)	26-82	54.6 (SD=15.5)	27-82

Teaching experiences

The course instructor experienced problems when teaching the two student groups first without the module (cohort 1). He received many questions about basic concepts during the lecture and seminar. The explanation of these basic concepts took too much of the time that was in fact reserved to deal with more complex concepts. After the introduction of the ADM the problems were to a large extent solved. Since the students work with the digital module before attending lectures about the complex concepts, they understand these lectures much better. The questions that the instructor received in the seminar were more advanced. In his opinion, the module helped students to understand basic concepts, and basic mistakes they made were often covered in the feedback on the exercises.

DISCUSSION

The use of adaptive digital learning material is one way to overcome the problem of differences in levels of prior knowledge between students entering a course. Our study indicates that the ADM on cell growth kinetics at the beginning of the course did give students of varying levels of prior education the basic level of knowledge needed to follow the subsequent lectures and pass the exam. Furthermore, the students liked using this learning material, which increased their motivation.

The system that we describe in this paper, Proteus, collects dynamic data and on the basis of these data adapts the learning activity to the student. Most adaptive systems described so far only collect static user data (Henze and Nejdl, 1999; Melis et al. 2001; Brusilovsky and Cooper, 2002), so that we believe that using Proteus is innovative in this respect.

Unexpectedly, we did not find a difference between the regular and exchange students in the average number of exercises needed to finish the module. However, there is a large within-group variety in the number of exercises needed to finish the module. Thus, it seems that the adaptive feature of the module is exploited by all students, and not only if their prior education differed, as with the two student groups investigated in this study. A possible explanation for this finding is that of course students' knowledge does not only depend on their earlier education. Some students remember the theory from previous courses better than other ones; students differ in the capacities they have to learn certain concepts; finally, students differ in the step sizes they choose. Students who opt to take small steps will do more exercises than those who take big steps. Taking this into account we can state that it is not only the differences in prior knowledge and capacity to learn, but also the personal preference of students to take small or big steps that lead to a difference in the number of exercises they need to finish the module. These findings suggest an advantage of using adaptive digital material allowing for differentiated learning paths for remedial purposes in general. The ADM is therefore still used in the course, even though the exchange program with the China Agricultural University has ended.

Another important reason to continue using this ADM on cell growth kinetics and even initiate the development of adaptive modules on other topics is the students' appreciation of the material. The results from the open-ended and Likert-scale questions show that students are very positive about using this material.

The responses to the questionnaires also gave good suggestions for improvements, and we already implemented some of these. For example, the presentation of the scoring system has been changed to conform to students' expectations, and the feedback to incorrect answers has been expanded. The improvements will be evaluated the next time this ADM is used.

The combination of the different learning paths followed by students, the decrease in variation in exam scores, and the instructor's observations lead us to the conclusion that an ADM can be used to give students with different levels of prior education the same basic level of knowledge on cell growth kinetics so that they are be able to follow the subsequent lectures and pass the exam.

Although designed to fit the context of the course 'Introduction to Process Engineering' the ADM can easily be used in other courses or at other universities since it is web-based. This has already been done at the University of Technology in Graz, Austria. Furthermore, the intelligent tutoring system can contain other content as well, thus providing plenty of possibilities for creating new adaptive learning modules.

CONCLUDING REMARKS

Our study shows that the ADM on cell growth kinetics at the beginning of the course did give students of varying levels of prior education the basic level of knowledge needed to follow the subsequent lectures and pass the exam. We also report a positive attitude of the students when using the ADM.

The ADM described in this paper allows for self-regulated learning by letting students choose the level of the exercises. At the end, all students have to achieve the pre-defined learning objectives to be able to finish the ADM.

We therefore advise educators who are confronted with students that have different prior knowledge to start their course with learning materials that offer the required knowledge in a differentiated manner. The freely available system described in this paper, called PROTEUS, facilitates such a smooth implementation since it only requires Internet access and an Internet browser to function. This system allow teachers to integrate questions and resources, which they think are suitable for the concepts they want to teach in an ADM. The number and kind of questions can easily be adapted. But, teachers have to take great care when designing the exercises since the learning effectiveness of the material relies heavily on the quality of the exercises. In addition, good ICT arrangements have to be made to ensure a bug-free implementation of the digital learning material.

Further research in science education is needed to address the question, what the exact role of self-regulated learning is when using ADM. It is interesting to investigate in more detail the impact of the step-size that students choose to go through the module. It is for example known that the learning strategy of students is also related to their gender. In addition, the prior knowledge of the students and the learning effect of the ADM can be directly investigated by adding a pre- and post-test to the ADM. We also suggest research about the use of ADM as a replacement for tutorials during the whole course.

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[1] A demo version is available at http://pkedu.fbt.wur.nl/webman7/demos/intro_growth.html. Please contact the corresponding author before using the material.

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