Development and Evaluation of an Adaptive Digital Module on Enzyme Kinetics

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Abstract: An adaptive module on basic enzyme kinetics was developed for first- and second-year university students. The module offers more assignments to students who have less knowledge of the theory than to more advanced students. The aim of the research was to investigate what influence students' backgrounds have on their use and appreciation of this module. Both freshmen and second-year students showed a large variation in the number of assignments they needed to perform in order to finish the module, indicating that the module's adaptive feature was exploited by all the students. Findings indicated that the prior knowledge was of influence of students' motivation and perception of difficulty of the module.

Introduction

Teaching enzyme kinetics to undergraduate science students at universities in the Netherlands presents challenges. For instance, students have varying levels of prior knowledge of enzyme kinetics, since they participate

in different programmes. One can tackle this problem by using learning material that presents the theory differentiated to the individual students' knowledge level. A way to accomplish differentiation is to use adaptive digital learning material. Such material can be of help in teaching a heterogeneous group of students by adapting to the level of the individual students (Brusilovsky, 1996). In addition to the variation in prior knowledge, some teachers note that their students consider the subject of enzyme kinetics old-fashioned or too mathematical, and are therefore not very motivated to study it. To increase students' motivation, one can get them to practice with the theory (Dickinson, 1995). Digital learning material can stimulate students by presenting them with assignments and providing feedback to their answers (Diederen, 2005). Therefore, an adaptive digital module on enzyme kinetics was developed, using a content management system called *Proteus* that was developed by Sessink and colleagues (Sessink, et al., 2007).

Digital learning material that adapts to the student can do so by collecting information about the student that is then used to build a user model as described by Brusilovsky (Brusilovsky, 1996). We interpret the user model as a model of the user that is based on the information that the system acquires. This information can be static – for example, the gender of the user and his or her preference for video or audio – or dynamic, namely the data concerning the user's actual usage of the system. The adaptive systems described so far collect static user data (Al-Dujaily, 2007), while the system described in this paper (*Proteus*) collects dynamic data and continuously adapts to the student on the basis of these data.

Proteus is a digital tutoring system that is designed to contain assignments that are organized into pools. The assignments in a pool and the feedback accompanying these assignments can be created by the teacher or another expert in the field. The teacher assigns marks to the assignments in order to distinguish between the difficult and the easier ones. *Proteus* is adaptive by selecting the assignments that are presented to a student based the answers that student gave to other assignments. A student has to gain a certain number of marks for predefined learning objectives. By successfully finishing an assignment, the student receives marks for the learning objective(s) involved in that assignment. If a student fails an assignment, he or she receives fewer marks for these learning objectives – and can even lose marks after several incorrect tries. The student has to keep trying until he or she gives the correct answer, at which point the adaptive system selects the most appropriate subsequent assignment. This selection is based on, for example, the learning objectives for which the student still needs to gain marks. The module is completed when the student has obtained the preset minimum number of marks for each learning objective. Thus, the number of assignments and the amount of time that students need to finish the module vary. We call the information that is obtained about students through their use of the module *indirect student input*.

Proteus also acquires *direct student input* in order to select the next assignment. Students can determine the difficulty of the assignments they get by choosing a difficult, medium or an easy assignment (small, medium or big step), thereby providing direct input to the assignment selection criteria. This is useful when, for example, a student feels that he or she already knows a lot about a specific topic and hence would like to be given difficult (big step) assignments in order to be challenged and remain motivated. This self-control of students is also reported to increase their motivation to learn (Laurillard, 1987).

This paper describes the development, use and evaluation of an adaptive digital module for enzyme kinetics in order to investigate the suitability of an adaptive module on basic enzyme kinetics for use by students of varying levels, namely freshmen and second-year students.

Material and Methods

Development

The adaptive digital module was constructed using the *Proteus* system. The assignments were developed by scientists in the field of enzyme kinetics in cooperation with the teachers who would be implementing the module in their courses. Different types of assignments were designed, such as multiple choice questions, multiple option questions, drag and drop assignments, and open questions. The scientists devised most of the assignments. The teachers' main task was to indicate how many marks should be allotted to each assignment.

The digital module contains ninety assignments that are related to four categories of learning objectives; one assignment can contribute to one or more categories. The categories are: basic concepts of Michaelis–Menten kinetics (43 assignments), kinetics of inhibition of enzymes (38 assignments), linearization of Michaelis–Menten kinetics curves (23 assignments) and units used in Michaelis–Menten kinetics (11 assignments).

After the first use of the module by Group A, 23 assignments were adapted or extended in order to improve the module. These improvements mainly concerned the feedback for assignments that require the performance of calculations.

Experimental Setting

The module was used in a classroom setting at two universities in the Netherlands. All students worked individually but were allowed to confer with their peers. A teacher or assistant was available during the sessions to answer any questions. The students were allowed to finish the module at home, if such was necessary. An exam comprising one question related to the module was taken after the course had been completed.

Group A comprised BSc students who were at the end of their second year. The module was introduced after four 45-minute lectures on enzyme kinetics. The module was scheduled as a computer practical, and the students started working with the module during this practical. The students could spend three hours on the module during the practical.

Group B comprised BSc students who were at the beginning of their first year (freshmen). These students could spend 45 minutes on the module during the practical.

Data Collection and Analysis

Several sets of data were collected in order to answer the following three questions: 1) Are the two adaptivity modes employed and appreciated by the students? 2) Do the students consider the module appropriately extensive? 3) Does the material motivate the students?

Data on the students' perceptions were obtained by means of a questionnaire that consisted of items in three categories, namely efficiency, motivation and use of the module. The responses were given on a five-item Likert scale (Likert, 1932). Some demographic data and information about the study details of the students were also gathered by means of the questionnaire. The questionnaire was improved after the first use, and thus varies between Groups A and B. In addition, the students' actions during the module were logged. The learning outcome of the module was measured by including one question about the topic in the final exam of the course of which the module formed a part. The exam was designed and given by the teacher of the course.

The responses to the questionnaires given by both groups, the tracking data and the exam results of the students were analysed by procedures described by Field (Field, 2009) using SPSS for Windows version 15.

Results and Discussion

Respondents

Group A comprised 37 BSc students, of whom 13 finished the module and 18 completed the questionnaire. A schematic representation of the participants is shown in fig. 2a.

In Group B, only 17 of the 237 students who started the module finished it and 25 completed the questionnaire. Twelve students who completed the questionnaire had not finished the module. This is schematically represented in fig. 2b.

A B

Figure 2: Euler diagrams of the participants in the experiment indicating the number of students who finished the module ('Module'), completed the questionnaire ('Questionnaire' or 'Quest.') and took the exam ('Exam') for Group A (a) and Group B (b)

Of the students in Group A who finished the questionnaire, 14 followed the biotechnology programme, 3 the biology programme and 1 the molecular life sciences programme. All students in Group B followed the life sciences programme. Since Group B comprised freshmen, these students were asked to indicate which pre-university study they had finished. Of the students in Group B who completed the questionnaire, 5 followed the technical specialization at secondary school (Nature and Technology) and 20 followed the medical specialization (Nature and Health). Since the division of the students according to their study programmes in this case results in at least one category with a very low number of students, the analysis of the results uses only the division into Group A and Group B.

Are the two adaptivity modes employed and appreciated by the students?

Indirect student input: The number of assignments that the students needed to perform in order to finish the module varied from 26 to 87. This indicates not only that the module was adaptive, but also that this feature was indeed employed by the students. In contrast, the adaptivity of the module would not have been used had all students needed to perform more or less the same number of assignments for each learning objective. The students in Group A needed on average to perform 51 assignments in order to finish the module, while the students in Group B needed to perform an average of 57 assignments. This was to be expected, since the students in Group B were assumed to have less prior knowledge than those in Group A. Similarly, the average amount of time that students reported to have spent on the module is 5.72 hours in Group A and 6.4 hours in Group B. This difference was also to be expected, considering that Group A comprised second-year students and Group B freshmen.

Direct student input: The students could choose the level of their next assignment. An open question asking the students about their perception of the difference between small step and big step assignments was included in the questionnaire for Group B and has provided insight into the use of the direct student input. While 40 per cent of the students mentioned that there was a difference in the level/complexity they experienced or in the number of marks, 33 per cent did not experience much difference. The answers to the questionnaire items about the direct student input indicate that the students used the opportunity to choose the level of the next assignment and did not just take the same step every time. The questionnaire also revealed that the students used the big steps more at the end of the module than at the beginning, which can be explained by the increase in their knowledge of enzyme kinetics during the module (table 1).

Item (1=Disagree 5=Agree)	Response mean
I always used the small steps	2.2
I avoided choosing the big steps	2.2
At the end of the module, I used more big steps than small steps	3.2

Table 1: Questionnaire responses of Group B to direct student input items

Do the students consider the module appropriately extensive?

The digital module is intended to serve the needs of individual students with varying levels of prior knowledge. The aim is to provide sufficient information to students who lack experience of enzyme kinetics, while being sufficiently challenging to those who are already familiar with some of the concepts. According to the questionnaire responses, the module did not contain too many assignments and the students learned many new things (table 2a). There was no difference between the students in Group A and those in Group B regarding the number of questions ($P=0.47$). The students in Group A agreed more ($P=0.22$) with the statement about learning new things than the students in Group B. The students in Group A also rated their own knowledge higher ($P=0.05$) than the students in Group B (table 2b). This indicates that the students in Group B did not already have all the knowledge. Nevertheless, they agreed less with the statement about learning new things. This might be because they had understood less of the module. This supposition is supported by the fact that the students in Group B considered the module to be more difficult ($P<0.001$) than the students in Group A (table 2c), which is a result of the difference in years (i.e. first or second year at university).

Item	Response mean	
	Group A	Group B
a. Number of assignments (1=Disagree 5=Agree)		
I received too many questions on the same topic	2.7	2.8
I have learned many new things about enzyme kinetics using this module	3.8	3.2
b. Reaching the learning goals (1=Poor 5=Good)		
My understanding of Michaelis–Menten kinetics at this moment is:	3.5	3.1
My understanding of Lineweaver–Burk plots at this moment is:	3.7	3.3
My understanding of enzyme inhibition at this moment is:	3.5	3.3
My understanding of the units used in enzyme kinetics at this moment is:	3.3	2.7
Average self-rated knowledge score	3.5	3.1
c. Level of the module (1=Easy 5=Hard)		
The questions were:	3.4	4.4

Table 2: Questionnaire responses to efficiency items

The aim of this module is to teach enzyme kinetics to students with heterogeneous backgrounds. The learning goals were assessed by including an exam question related to the module. The exam questions were designed by the teacher and were not identical for both groups. The marks scored on this question by students who had finished the module were compared with those of the students who had not finished it (table 3). The marks that were obtained for this exam are presented on a scale of 1-10, which is the usual way of presenting marks in the Netherlands. A comparison between the students in Group A who finished the module ($P=0.25$) and those who used the module but did not finish it, reveals no differences between the exam marks for the kinetics part and the total exam mark ($P=0.19$). The students who did not use the module had a lower mark for the module part compared to the total exam mark ($P<0.05$). These students also had a lower ($P<0.05$) mark for the module part than students who finished the module, although the total exam mark does not show a difference ($P=0.46$). These two observations indicate a positive effect of the module on the learning outcome. This positive effect is not present in Group B (all P-values>0.05).

	Group A			Group B		
	n	Module part	Total exam	n	Module part	Total exam
Module finished	12	6.8	6.2	17	6.8	6.9
Module not finished	12	3.9	4.6	216	7.1	6.7
Module not used	11	3.6	5.4	4	6.5	6.1

Table 3: Exam results

Item	Response mean	
	Group A	Group B
a. Opinion of the module (1=Disagree 5=Agree)		
I liked working with this module	3.4	2.1
This module challenged me	3.9	3.3
This module was useful	4.2	3.0
This module motivated me	3.4	2.8
Average motivation score	3.7	2.6
b. Intrinsic motivation (1=Disagree 5=Agree)		
I find enzyme kinetics an interesting subject	2.9	2.0

Table 4: Questionnaire responses to motivation items

Does the material motivate the students?

The students' motivation was measured with the questionnaire; their responses to the motivation items are summed up in table 4. Group A was clearly more motivated ($P<0.001$) than Group B. This difference might be explained by the level of the module: the students in Group B found the module more difficult than those in Group A. The students in Group B were asked to self-rate their prior knowledge of enzyme kinetics. Their responses

indicate that they had little prior knowledge (a mean of 1.7 on a 1-5 scale, ranging from 'little' to 'extensive'). The students in Group B also indicated less interest (P=0.02) in the subject of enzyme kinetics than Group A.

General Discussion and Conclusion

Both of the system's adaptation modes – namely the direct and the indirect student input mode – were employed by the students. However, only 7 per cent of the freshman group finished the module. This may have been because of the difficulty of the module and the limited amount of time that the students could spend on the module while under supervision. In addition, most (89 per cent) of the freshmen did not complete the questionnaire. The response rate could be increased by stimulating students to finish the module, for example by adding extra credits to the exam mark if they finish the module. This strategy is already successfully employed by a teacher who uses another *Proteus* module on cell growth kinetics.

The module on enzyme kinetics is appropriately extensive, but seems to be too difficult for freshmen. It is therefore concluded that second-year students can better deal with the module and that if it is to be suitable for freshmen courses, it must be adapted by, for example, including in it more basic-level assignments.

Although the second-year students were motivated by the module, the freshmen were not. Adapting the module to an appropriate level for freshmen could result in increasing their motivation.

In general, this study should be repeated with larger student groups in order to obtain more reliable data upon which more solid conclusions can be drawn.

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