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Empirical evaluation of a virtual laboratory approach to teach lactate dehydrogenase enzyme kinetics

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HIGHLIGHTS

- We developed & implemented a specially-designed adaptive virtual-laboratory [vLab].
- Laboratory lactate dehydrogenase kinetics were taught to 2nd-year biochem students.
- The vLab was designed using HTML5 and hosted on an adaptive e-learning platform.
- The learning outcomes were on par with that from a conventional classroom tutorial.

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ABSTRACT

Background: Personalised instruction is increasingly recognised as crucial for efficacious learning today. Our seminal work delineates and elaborates on the principles, development and implementation of a specially-designed adaptive, virtual laboratory.

Aims: We strived to teach laboratory skills associated with lactate dehydrogenase (LDH) enzyme kinetics to 2nd-year biochemistry students using our adaptive learning platform. Pertinent specific aims were to:

(1) design/implement a web-based lesson to teach lactate dehydrogenase(LDH) enzyme kinetics to 2nd-year biochemistry students
(2) determine its efficacious in improving students' comprehension of enzyme kinetics
(3) assess their perception of its usefulness/manageability(vLab versus Conventional Tutorial)

Methods: Our tools were designed using HTML5 technology. We hosted the program on an adaptive e-learning platform (AeLP). Provisions were made to interactively impart informed laboratory skills associated with measuring LDH enzyme kinetics. A series of e-learning methods were created. Tutorials were generated for interactive teaching and assessment.

Results: The learning outcomes herein were on par with that from a conventional classroom tutorial. Student feedback showed that the majority of students found the vLab learning experience “valuable”; and the vLab format/interface “well-designed”. However, there were a few technical issues with the 1st roll-out of the platform.

Conclusions: Our pioneering effort resulted in productive learning with the vLab, with parity with that from a conventional tutorial. Our contingent discussion emphasises not only the cornerstone advantages,

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Abbreviations: AeLP, Adaptive e-learning platform; CSS, Cascading Style Sheets; CTML, The Cognitive Theory of Multimedia Learning; HTML 5, Hyper Text Markup Language 5; JS, Java Script; LDH, lactate dehydrogenase; SaaS, Software as a Service; SD, Standard deviation; SDLC, Software development life cycle; UTAS, University of tasmania; vLab, Virtual lab; Vs., Versus; WYSIWYG, What-You-See-Is-What-You-Get.

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but also the shortcomings of the AeLP method utilised. We conclude with an astute analysis of possible extensions and applications of our methodology.

1. Introduction

Over the past couple of decades, biochemistry education has transitioned into a new paradigm, owing to several factors impacting higher education:

(1) Higher education has massified, resulting in a more diverse/large cohort of students with broader foundational skills [1].
(2) Internet and communication technology provide new ways of involving students in higher education [2] – intranational and international; urban and rural.
(3) Many students have cultural, family or part-time work commitments. An increasingly student-centric educational approach (like Learning Management Systems) has provided greater flexibility in course structure and delivery for them.
(4) Funding models have changed emphases by rationalising teaching resources to teach more students with less funding and requiring greater accountability for quality.

Computer-assisted learning, animated biomolecules [3], and simulated experiments [4–6] are no longer restricted to campus-computer use. They are widely disseminated via DVDs/CDs/USBs or the internet. Games [7] and computer-games have been used to actively engage learners in education. Numerous interactive laboratory courses in biochemistry are accessible free online [8]. However, barely a handful of these are genuine 3D-simulations of actual laboratory procedures or biochemical processes.

Virtual worlds and second life [9] offer new ways of garnering foundational skills for biochemical research that provide students with greater control over their study modus operandi. Adaptive e-learning [10] offers personalised education where a student may learn skills and assimilate concepts via a guided journey dynamically commensurate with their knowledge and skill-sets.

Online laboratory simulations can assist students from the outback to familiarise themselves with laboratory procedures before they attend sessions on their enrolled academic campus [4]. When simulations are integrated with other educational activities [11], they greatly accentuate learning. We chose an adaptive approach to deliver lesson-content owing to our awareness of our students' broad range of abilities. Enzyme kinetics is a topic which many students struggle with, an aspect which motivated us to develop an interactive simulation of an enzyme-based assay.

The students chosen for this study were 2nd year undergraduate students enrolled in an introductory biochemistry unit, having limited knowledge of chemistry/mathematics, and least-intending to undertake further study in biochemistry. Our objective of elucidating their comprehension of enzyme kinetics, translated into the following 3 specific aims:

(1) To design and effectuate a web-based lesson to teach basic enzyme kinetics to 2nd-year biochemistry students.
(2) To determine the efficaciousness of that lesson in improving grasp of enzyme kinetics; both content-, and skill-based. The teaching session was designed to:
    (i) conduct simultaneous enzyme catalysed colorimetric reactions using a microplate reader
    (ii) analyse kinetic data to determine the rate of an enzyme catalysed reaction and calculate the kinetic constants, K_m and V_{max}
    (iii) determine two-different types of enzyme inhibition by comparing calculated values of $K_{m(app)}$ and $V_{max(app)}$ in the presence of an inhibitor with the K_m and V_{max} of the uninhibited enzyme.
(3) To assess students' perception of the lesson's usefulness and ease of use

Our study summarises the design, implementation and evaluation of an interactive virtual lab for teaching lactate dehydrogenase (LDH) kinetics. We also describe a few hurdles which we encountered, as would commonly occur whilst utilising a pioneering web-based learning program.

2. Materials and methods

2.1. LDH kinetics experiment and data analyses

The LDH kinetics laboratory experiment designed by Powers *et al* [12], was modified by us for use with a 24-well microplate and the SpectraMax microplate reader. This microplate reader utilises Softmax Pro software version 5.3 (Molecular Devices, Germany). Each 1.2 mL assay run in glycine buffer (0.5 mol/L glycine with 2.5 mmol/L EDTA, pH 9.5) consisted of 0.7 U/mL LDH, 0.22 mol/L hydrazine and 1.2 mmol/L β-NAD$^+$. Across each of the 4 microplate rows, wells had varying concentrations of lactate (5, 25, 55, 75 and 95 mmol/L). An inhibitor (oxalate or oxamate) was added to each well in rows B (10 mmol/L), C (20 mmol/L), and D (30 mmol/L). The kinetic assay performed at 25 °C, was initiated with the addition of β-NAD$^+$. Absorbance (340 nm) was recorded at 20-s intervals for 5 min. Five replicate plates were analysed.

Velocity versus [substrate] Michaelis-Menten plots were constructed using Graph Pad Prism (version 6.02, San Diego California, USA) (Fig. 1). The plots pertaining to the reactions with oxalic acid are depicted in Fig. 1A, and the ones with oxamic acid are depicted in Fig. 1B. Each point represents the mean and SD for 5 replicate kinetic-experiments. The values for V_{max}, $V_{max\ app}$, $K_{m,}$ and $K_{m\ app}$ were calculated by fitting the data to a one-site binding hyperbola. The value of K_m and V_{max} (Supplementary file – Table) were 20.0 ± 5.6 mmol/L (95% CI 8.5–31.4 mmol/L, $r^2 = 0.864$) and 30.1 ± 2.2 μmol/L/min (95% CI 24.1–34.2 μmol/L/min, $r^2 = 0.864$) respectively.

2.2. Development of the virtual lab (vLab) using AeLP

We used the Adaptive eLearning Platform (AeLP) developed by Smart Sparrow™. This is a web-based set of tools for creating, publishing and analysing adaptive eLearning activities [10,13,14]. The AeLP runs as Software as a Service (SaaS), with a platform containing a What-You-See-Is-What-You-Get (WYSIWYG) author component. The Software development life cycle (SDLC) is the conventional depiction of the software development/management process targeting a specific objective. It consists of a series of phases. Our SDLC consisted of: