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Catalyzing the Understanding of Enzyme Kinetics: A Consistent Application of Constructive Alignment and Its Evaluation

ABSTRACT/ZUSAMMENFASSUNG

In this study, the principles of constructive alignment were applied to an introductory lecture offered every year for bachelor students in the Faculty of Biosciences at Heidelberg University. The introductory lecture is part of a course that consists of the lecture followed by a practical laboratory session on the topic of enzyme kinetics. This course sequence is repeatedly taught over five weeks to 25-40 students each week. The motivation to use this course as a didactical experiment stemmed from the observations I made in previous years that (1) only a fraction of the students actively participated during the lecture and (2) a significant portion of the students did not grasp key concepts. Hence, I started this project by asking myself how I could design my teaching in a way that would engage the most students in active learning and would help them understand what I wanted to convey. To achieve this goal, I decided to apply the concept of constructive alignment by John Biggs. To do so, I redesigned the introductory lecture to first introduce learning objectives (LOs) and then broke down the lecture in blocks that covered each LO and were followed by a dedicated teaching-learning activity (TLA). In this report, I present the design and outcomes of the re-designed lecture and discuss successes, limitations, and potential improvements.

Keywords: bioscience – enzyme kinetics – lecture – Constructive Alignment – learning objectives – teaching learning activities

In dieser Untersuchung wurden die Prinzipien des Constructive Alignment auf eine Einführungsvorlesung, die jährlich für Bachelorstudierende der Fakultät für Biowissenschaften der Universität Heidelberg angeboten wird, angewendet. Diese Einführungsvorlesung ist Teil eines Kurses, der aus der Vorlesung und einer darauffolgenden praktischen Laborsitzung zum Thema Enzymkinetik besteht. Diese Kurssequenz wird wöchentlich über fünf Wochen hinweg wiederholt und an Gruppen von 25-40 Studierende unterrichtet. Die Motivation, diesen Kurs als didaktisches Experiment zu nutzen, wurde durch zwei Beobachtungen gespeist, die ich in meiner Lehre in diesem Kontext über die letzten Jahre gemacht hatte: (1) Nur ein kleiner Teil der Studierenden partizipierte aktiv an der Vorlesung und (2) ein signifikanter Teil der Studierenden schien die Schlüsselkonzepte nicht zu verstehen. Daher begann dieses Lehrprojekt mit der Frage, wie sich die eigene Lehre insoweit konzipieren ließe, dass der Großteil der Studierenden zum aktiven Lernen angeregt werden könnte und dass sie das Gelehrte auch verstehen könnten. Um diese Ziele zu erreichen, entschied ich mich, das Konzept des Constructive Alignment von John Biggs umzusetzen. Dies bedeutet, dass ich die Einführungsvorlesung so umgestaltet

habe, dass zunächst die Lernziele vorgestellt wurden und dann die Vorlesung in einzelne Blöcke unterteilt wurde, die die jeweiligen Lernziele abdeckten. Diese Blöcke wurden durch abgestimmte Lehr-Lernaktivitäten abgerundet. Im vorliegenden Beitrag werden das Lehrdesign und die Ergebnisse der umgestalteten Vorlesung präsentiert. Dabei werden Erfolge, Grenzen und das Potential zur Weiterentwicklung diskutiert.

Schlagworte: Biowissenschaften – Enzymkinetik – Vorlesung – Constructive Alignment – Lernziele – Lehr-Lernaktivitäten

Introduction

The class I used for this project is a practical course that is part of a foundational course series offered to students enrolled in the B.A. program in Biosciences at Heidelberg University. The series covers several basic biochemical methods. The module I taught, "Enzyme Kinetics Using the Protease Trypsin as an Example", consists of a one-hour introductory lecture followed by a four-hour practical lab in which experiments are performed. Before the course, students receive a script with the necessary theoretical background and a detailed protocol of the experimental work to be performed. Students are expected to read the script before coming to the introductory lecture. Altogether, ca. 180 students dispatched in five groups of 25 to 40 participants took part in the course. Each group started the module on a different day, organized as follows: in the morning, the whole group attended the introductory one-hour lecture, and in the afternoon lab, pairs of students were dispatched in three subgroups, each supervised by a different person. In this particular year, I taught the introductory lecture and supervised the experimental work of the first three groups. I also designed questions for the final exam. For organizational reasons, another teacher took over the two remaining groups.

The aim of the introductory lecture is to refresh key thermodynamic and kinetic concepts of chemical reactions and to explain what enzymes do. In addition, to prepare for the practical work in the afternoon lab, typical parameters used to characterize an enzyme as well as two types of enzyme inhibitors are explained. During the practical section, students perform experiments aimed at determining the enzymatic parameters introduced in the morning. In addition, they have to identify the mode of action of two enzyme inhibitors. The next day is free of class and meant for students to write a report on the experimental work and to answer four questions about the key concepts introduced during the lecture. At the end of the series, students must take a written multiple-choice exam that covers the five methods addressed in the series.

Five years earlier, when I first agreed to teach this course, I was provided with a presentation for the introductory lecture that had been designed by a colleague. No special recommendation on how the teaching should be performed or what the students were supposed to achieve accompanied it. With limited prior teaching experience, I modified the

presentation in order to simplify the conveyed message and to illustrate key concepts with concrete examples. Already at that time, I wanted to promote active participation to stimulate the learning process of the students. To achieve this, I would ask questions during the lecture and would wait for individual students to answer them. Over the years, I observed that only a few students were actively participating in the lecture (usually three or four students would volunteer answers) and a visible fraction of students always looked passive, with some close to falling asleep. Furthermore, the students' answers to the four questions of the written report as well as to the questions of the final written exam showed that year after year key concepts (particularly two of them) were not grasped by a significant portion of the students. Reflecting on the knowledge I gained from didactic courses I attended at Heidelberg University, I realized that, when teaching, I positioned myself as an expert who tried to transmit facts and examples. This clearly put a focus on teaching rather than on students constructing their own learning. With the tools and concepts I had learned during my didactic training at Heidelberg University, I decided to address the following questions with this project:

- How can I ensure almost all the students actively participate in my lecture?
- How can I ensure all students grasp the key concepts I want to convey?

To achieve these goals, and following the considerations of Ference Marton and Roger Säljö on deep and surface approaches to learning (MARTON & SÄLJÖ 1976b, MARTON & SÄLJÖ 1976a), I proposed to completely redesign the lecture series by experimenting with a student-centred approach to learning and testing the concept of constructive alignment as described by John Biggs (BIGGS 2014). In their seminal work "On Qualitative Differences in Learning", Marton and Säljö (1976) advocate for differentiating between how much is learned from what is learned. The former is associated with surface-level learning (focused on memorizing) whereas the latter is associated with deep-level learning (focused on understanding content). This distinction is supported by a series of experiments in which groups of students had to read chapters of books or journal articles and were then asked questions aimed at testing if the message conveyed by the texts had been understood. Different levels of outcomes (ways of comprehending the texts), ranging from no comprehension at all to comprehension of the true intentional content of the texts, correlated with the students' descriptions of the way they tried to learn during the task. Those who had focused on memorizing were the ones who performed poorly whereas those who had focused on understanding the content were the ones who performed best on the test. Moreover, students who adopted a deep approach to learning tended to retain what they had learned for a longer time. An important aspect of the work of Marton and Säljö is that surface- and deep-level learning are not intrinsic abilities of the students but can be induced, for example by making the expectations or learning objectives explicit or by the expected form of the final exam. This implies that a main consideration when teaching should be influencing how students construct their knowledge. The concept of

"constructive alignment" (summarized in BIGGS 2014) exactly addresses this by providing a "technology of teaching" (BIGGS 1999) that funnels students into deeper approaches to learning. When preparing a lecture, a key concept of constructive alignment is to first define what skills students are expected to gain and what tasks they are supposed to do with the knowledge they will have learned. Once this is defined, corresponding learning objectives (LOs) should be phrased in a way that can be tested and measured. Instructors should then design courses that address each of the LOs by using teaching-learning activities (TLAs). The design of a dedicated TLA for each LO is an essential part of constructive alignment as each TLA serves the goal of engaging the students in performing a problem-solving task that corresponds to the skills the students are expected to gain. In that way, students explicitly engage in deeper learning approaches. Another essential aspect of constructive alignment is the design of the assessment tasks (ATs) used in the final exams: these should also be aligned to the LOs by precisely testing the skills students were supposed to gain during the course. This is why LOs should be formulated in a measurable way and clearly presented to the students at the beginning of the course. Research tends to show that a constructive alignment approach leads to improvement in student learning and better student evaluations – though at the cost of a higher workload for both students and teachers (summarized in BIGGS 2014).

Based on this research, the fundamental question driving my project was: will a constructive alignment approach address the two challenges I encountered in my teaching (getting most students to actively participate and ensuring most of them would grasp key concepts)?

Lecture Design

Overall, the purpose of the introductory lecture is to explain what enzymes do in a chemical reaction and what parameters are usually used to characterize their mode of action. These parameters are experimentally determined during the lab sections. The lecture first reviews thermodynamic and kinetic concepts that students should already know. The Michaelis-Menton equation, which was designed to describe the kinetics of an enzyme-catalyzed chemical reaction, is then introduced as well as the parameters than can be deduced from the equation. Finally, two different types of enzyme inhibitions are presented.

Learning objectives

The first step in designing the lecture was the definition of LOs that comply with the SMART (Specific, Measurable, Achievable, Reasonable, Time-Bound) principle. The following LOs were chosen:

After the introductory lecture, you should be able to…

- define the terms enthalpy, entropy, Gibb's free energy
- explain the difference between free energy and standard free energy
- predict if a chemical reaction runs spontaneously or not
- define the term activation energy of a reaction
- describe the role of enzymes in chemical reactions
- list parameters that are used to describe an enzyme activity
- explain the difference between competitive and non-competitive enzyme inhibition

After the introductory lecture and the lab, you should be able to…

- design an experiment to measure enzymatic activity parameters
- calculate the parameters from the experimental data
- design an experiment to determine if an inhibitor is competitive or non-competitive

As during the lab session students are specifically asked to perform the tasks outlined in the last three LOs, I will focus for the rest of this article on the implementation of the introductory lecture.

Building blocks for the sandwich concept

To ensure the attention of the students is kept during the whole lecture and to ease the alignment of LOs with TLAs, I applied the "sandwich concept", in which the lecture is broken down into blocks of 10–12 min. explanations, directly followed by 1–2 min. TLAs (KNOLL 2007). The LOs for the introductory lecture fall into three main categories that I have used as the main building blocks of the redesigned lecture, as follows:

Block	LOs
Thermodynamic Concepts	– Define the terms enthalpy, entropy, Gibb's free energy – **Explain the difference between free energy and standard free energy** – Predict if a chemical reaction runs spontaneously or not

Kinetic Aspects + Enzymes	– Define the term activation energy of a reaction – Describe the role of enzymes in chemical reactions – List parameters that are used to describe an enzyme activity
Inhibitors	– **Explain the difference between competitive and non-competitive enzyme inhibition**

Teaching-Learning Activities

Indicated in bold in the table above are the two LOs which, from my experience with this lecture, are the most problematic for students. Therefore, I designed two dedicated TLAs to make the students construct their own understanding of the two concepts.

TLA 1: Difference between free energy and standard free energy

The value of the change of free energy (ΔG) in a chemical reaction allows us to predict if this reaction can occur spontaneously after mixing the reagents together (in that case $\Delta G < 0$). This value depends on the standard free energy of the chemicals involved in the reaction and on the concentration of these chemicals. By contrast, the value of the change of the standard free energy (ΔG0) is an intrinsic property of the chemicals used in a chemical reaction and corresponds to the value of the change of the free energy that would be obtained if all the reagents were used in the so-called standard conditions (concentration of 1M for each of the reagent, temperature of 25°C and pressure of 1 bar), which is usually a hypothetical state. The value of the change of the standard free energy, ΔG0, is important, as it is directly correlated to the equilibrium constant of a chemical reaction (which is an important, and experimentally accessible, parameter of any reaction), and it is needed to calculate the change in free energy, ΔG. Due to the similar nomenclature of the two values (ΔG vs ΔG0), students often confuse free and standard free energy and wrongly use the latter to predict if a reaction can be spontaneous.

To stimulate students to understand the meaning and application of ΔG and ΔG0, rather than to try to memorize their definitions, a TLA was designed in the form of a classical problem-solving exercise performed in a buzz group format (Figure 1).

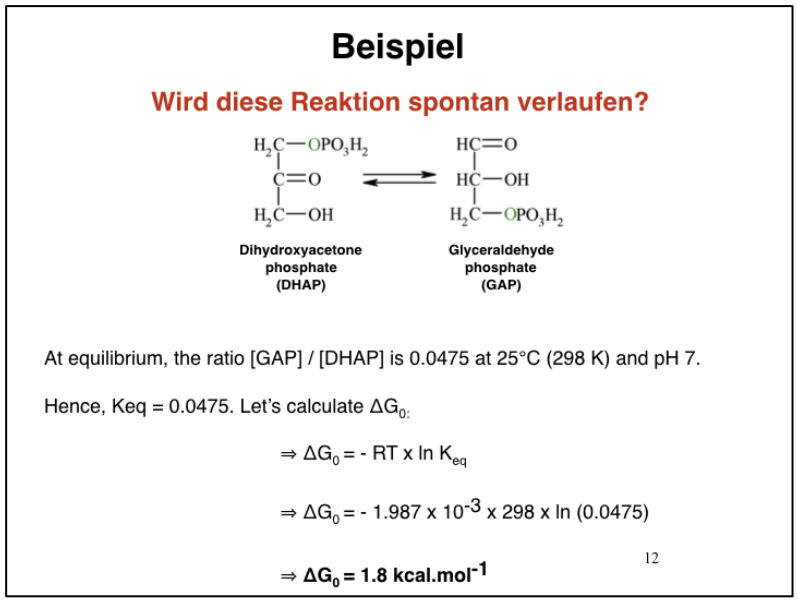


Figure 1
TLA 1: Difference between free energy and standard free energy. Problem-solving task

In this TLA, students are presented with a simple chemical reaction with the calculated value of the ratio of concentration product over concentration adduct of the respective chemicals at equilibrium. This information is used to calculate the equilibrium constant of the reaction, which itself is used to calculate the corresponding ΔG0 of the reaction. In the example, ΔG0 > 0. Students are then asked if the reaction is predicted to run spontaneously. They are given one minute to discuss the answer to the question in pairs with their neighbors (buzz groups). The information provided is not actually sufficient for answering the question and the correct answer should be "I don't know" - because it is not the value of ΔG0 that determines if a reaction is spontaneous, but the one of ΔG. To calculate ΔG, one would need to know the concentration of the chemicals used in the reaction. After the one minute is over, students vote on the right answer (spontaneous, non-spontaneous, I don't know) and I ask those who voted for "I don't know" why they chose this answer. I then provide the missing concentrations as well as the calculation of the actual ΔG (Figure 2). In this example, a negative value of ΔG is found, which indicates a spontaneous reaction.

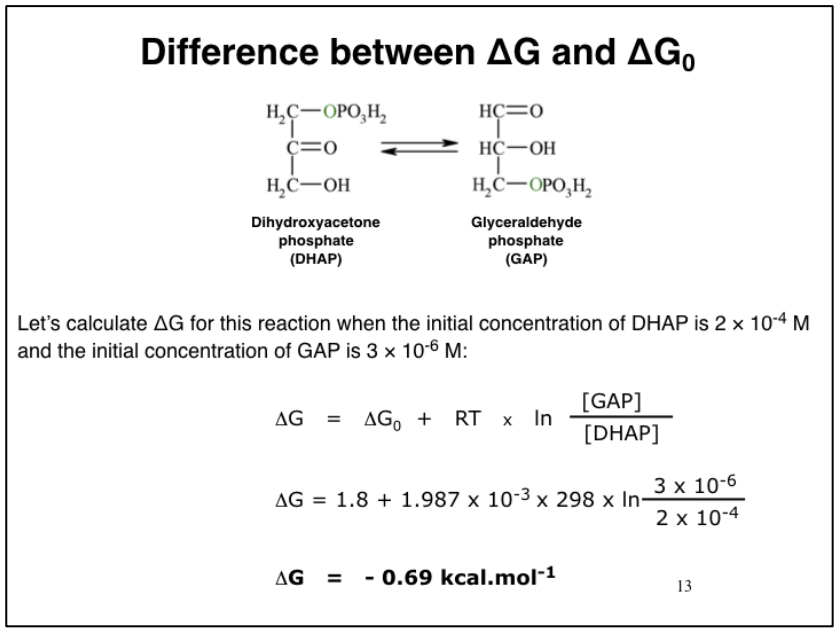


Figure 2
TLA 1: Difference between free energy and standard free energy. Solution to problem.

TLA 2: Difference between competitive and non-competitive inhibition
Enzymes accelerate the speed of chemical reactions by binding to their substrate (the adduct of the reaction) and thereafter stabilizing a reaction intermediate (an intermediate chemical entity) that is needed in order to get the final product of the reaction. The part of the enzyme that binds and stabilizes the reaction intermediate is the "active center". Chemicals that can inhibit the activity of an enzyme can do so through different mechanisms. One class of inhibitors is called competitive inhibitors. These bind directly to the active center of the enzyme, thereby blocking binding to the actual substrate. A second class of inhibitors are the non-competitive inhibitors that bind to the enzyme, but not at the site of the active center. The non-competitive inhibitors do not block binding of enzymes to their substrates but instead deform the overall structure of the enzyme, thereby rendering the active center unable to stabilize reaction intermediates. A practical outcome of the two modes of inhibitions is that competitive inhibitors decrease the affinity of an enzyme to its substrate but not the maximal speed achievable by the reaction whereas a non-competitive inhibitor does not alter the affinity of an enzyme to its substrate but considerably reduces the maximal speed achievable by the reaction. The exact difference between the two classes of inhibition and the practical consequences on the enzymatic parameters (affinity and maximum speed) is often not clear for students.

A TLA I designed, called "the beauty chair", had students relate the different concepts of inhibition to an imaged example that helped them remember the logic behind the two mechanisms and their different outcomes on enzyme kinetics. "The beauty chair" represents a game in which a student plays the substrate who tries to sit on a chair (the enzyme). Sitting on the chair has the effect of rendering the student more beautiful (the accelerated chemical reaction). The game is complicated by the instructor (the inhibitor), who can interfere with this process in two ways. In the first case, the instructor also tries to sit on the chair and hence competes for the same spot as the student: sitting on the chair will be more difficult, but once seated, the student still gets more beautiful. In the second case, the instructor does not compete for sitting on the chair, but just touches it on the side; this removes its magic. In that case, sitting on the chair is still as easy for the students, but they will not get more beautiful by doing so. Students are then asked if the competitive inhibition affects more the speed of the reaction (getting more beautiful) or the affinity of the enzyme for its substrate (how easy it is to sit on the chair). They are given one minute to discuss the answer in buzz groups. Then they are asked the same question for the non-competitive inhibition. After implementing the beauty chair, I observed that, in contrast to previous years, the answers to the questions were obvious to all students.

TLA 3: Definition of the enzyme activity

Finally, to have a break between Block 2 (usually understood very well by the students) and Block 3, and to illustrate a practical application of one of the introduced enzymatic parameters, I designed a third TLA: it asks students to discuss in buzz groups how the enzyme activity is defined on the packaging of commercial lactose intolerance tablets. The very same calculation has to be performed later in the afternoon, this time using the experimental data gathered by the students.

Activation of previous knowledge and of the attention of the students

Directly after introducing myself and the subject of the lecture, and before presenting the LOs, I planned a short activation activity with a triple goal: re-activate the students' previous knowledge, illustrate the importance and relevance of the subject, and indicate that participation of the audience would be expected. To do so, after being told the subject of the lecture (enzyme kinetics), students were asked if they thought this was an important subject and why, and if they knew of practical uses of enzymes (e.g. as in washing powders or as in treatment against lactose intolerance). Then I presented three well-known drugs and their targets, which are all natural enzymes found in human cells. Hence, the three drugs act as enzyme inhibitors, which stresses the need to understand how enzymes work and how inhibitors inactivate them.

Quality control

The evaluation of the lecture series was based on the Evasys system, but focused on the whole series and not on the specific modules. To get faster feedback focused on the effectiveness of the re-designed lecture, I opted for a final one-minute paper in which students were asked the following two open questions:

- The most important thing I learned today is….
- But what is still unclear is….

Answers to the one-minute papers are quick to evaluate even with relatively large-sized groups and give a good overview of the main points that were grasped by the students and what might need to be improved for the next sessions (STEAD 2005).

Another possibility of quality control was to recapitulate the concepts covered in the introductory lecture during the afternoon lab sections. This is particularly well suited as the experiments performed in the lab are a direct illustration of how to determine the different parameters explained in the morning. In the short introduction to the experimental lab, students were asked to relate each experiment to the concepts they had encountered in the morning, and after each wave of experimental results, the data were again related to the theoretical introduction.

Implementation

Altogether, the lecture was structured as follows:

Time (in min.)	Step
1	Title and presentation
3	Activation
2	Learning objectives
15	Block 1: thermodynamics of a chemical reaction – enthalpy – entropy

	– Gibb's free energy and the spontaneity of a reaction – Gibb's standard free energy
3	TLA 1: Difference between Gibb's free energy and Gibb's standard free energy (buzz group)
17	Block 2: kinetics of a chemical reaction and enzymes – activation energy – enzymes as catalysts that lower the activation energy – enzymes as reaction and substrate specific -> example of Trypsin (studied in the afternoon) • reaction catalyzed • active center – enzymatic parameters • the Michaelis-Menton equation • K_M and V_{max} • experimental determination (as will be done in the afternoon) • definition of the enzyme activity
3	TLA 2: Enzyme activity from commercial lactose intolerance tablets (buzz group)
4	Block 3_1: enzyme inhibitors – competitive inhibition vs non-competitive inhibition
6	TLA 3: The beauty chair (game + buzz groups)
2	Block 3_2: consequence of enzyme inhibitors on enzymatic parameters

	– influence of competitive inhibitors on K_M and V_{max} – influence of non-competitive inhibitors on K_M and V_{max}
2	Brief overview of the experimental work in the afternoon
2	One-minute paper

Questions for protocol and final exam

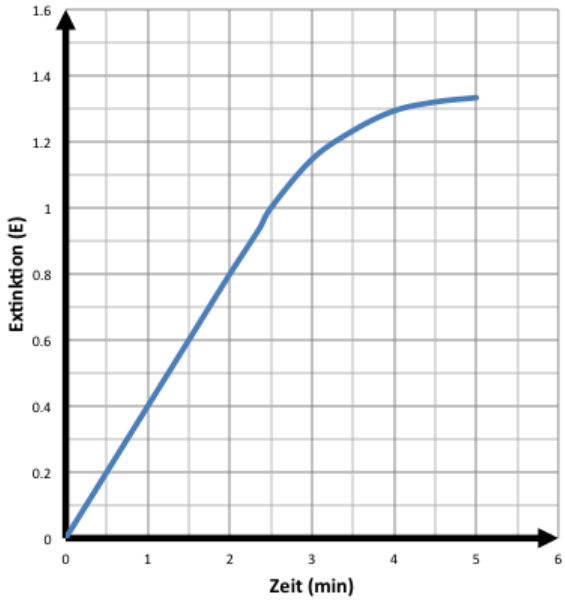
A first assessment task for this course is the report the students have to write about their experimental work. To assess if some of the LOs have been attained, the students must also include the answers to four open questions:

a) Please explain the difference between substrate and reaction specificity on the basis of the protease trypsin.
b) Please explain the meaning of the thermodynamics value ΔG0 for the equilibrium of a reaction.
c) Why is the Michaelis constant KM related to the affinity of a substrate for its enzyme?
d) What is the relation between the activation energy and the speed of a chemical reaction? Compare the activation energy in the absence or the presence of an enzyme and explain why enzymes accelerate chemical reactions.

Please note that the questions cover topics that are not directly addressed by the experimental work (like, for example, the two types of inhibitors).

For the final exam, LOs are assessed within the constraints of the multiple-choice question format. I designed the following eight questions; four for the initial exam and four for a potential makeup exam (in German, correct answer in red):

1. Sie haben die Extinktionszunahme in einer Küvette (Schichtdicke 1 cm) mit 100 µl Trypsin, 175 µl BAPNA und 725 µl EGME-Puffer bei 405 nm über die Zeit verfolgt und aus den Werten folgenden Grafen erstellt:



Der Extinktionskoeffizient für p-Nitroanilin bei 405 nm ist 9,6 mM-1cm-1.
Welcher Wert entspricht am ehesten der Volumenaktivität der verwendeten Trypsin-Lösung (1 Unit (1 U) = 1 µmol Substratumsatz / min)?

(A) 0, 42 U/ml
(B) 38.4 U/ml
(C) 420 U/ml
(D) 3840 U/ml
(E) 1,25 U/ml

⇨ Evaluated LO: Calculate the parameters from the experimental data

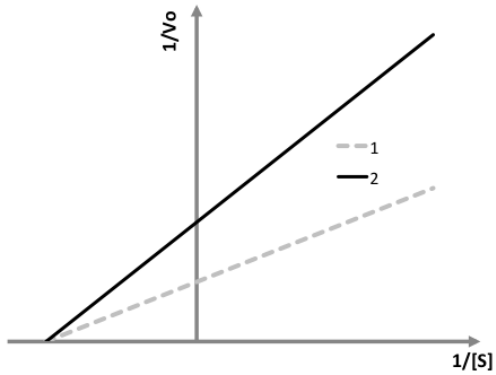
2. Welche Aussage zu Enzymen trifft nicht zu?

(A) Die Geschwindigkeit einer enzymkatalysierten Reaktion ist am größten bei Substratsättigung.
(B) Der K_M -Wert eines Enzyms hängt u.a. vom Substrat ab.
(C) Der K_M -Wert eines Enzyms hängt u.a. von der Enzymkonzentration ab.
(D) Enzyme erhöhen die Reaktionsgeschwindigkeit meist um viele Größenordnungen.
(E) Enzyme erniedrigen die Aktivierungsenergie einer Reaktion im Vergleich zur unkatalysierten Reaktion.

⇨ Evaluated LO: List parameters that are used to describe an enzyme activity, and LO: Describe the role of enzymes in chemical reactions

3. Die Michaelis-Menten Gleichung laut $V_0 = V_{max} \frac{[S]}{[S]+KM}$

Die Abbildung zeigt die Aktivität eines Enzyms ohne (1) und mit (2) einem Hemmstoff in der Auftragung nach Lineweaver-Burke.



Welche Aussage zu dieser Abbildung trifft zu?

(A) Eine starke Erhöhung der Substratkonzentration kann die Wirkung des Hemmstoffs aufheben.
(B) Der Hemmstoff blockiert das aktive Zentrum des Enzyms irreversibel.
(C) Der Hemmstoff verringert Vmax.
(D) Es handelt sich um eine kompetitive Hemmung.
(E) In Anwesenheit des Hemmstoffs wird ein größerer K_M -Wert gemessen.

⇨ Evaluated LO: Explain the difference between competitive and non-competitive enzyme inhibition

4. Welche Aussage zu Inhibitoren trifft zu?

(A) In einer kompetitiven Inhibition verändert sich Vmax, K_M nicht.
(B) In einer kompetitiven Inhibition verändert sich K_M, Vmax nicht.
(C) In einer nicht-kompetitiven Inhibition kann das Substrat den Inhibitor binden.
(D) In einer nicht-kompetitiven Inhibition ändern sich K_M und Vmax.
(E) Alle Aussagen sind falsch.

⇨ Evaluated LO: Explain the difference between competitive and non-competitive enzyme inhibition

5. Welche Aussage zu Trypsin trifft nicht zu?

(A) Trypsin ist selbst ein Protein und kann daher seinen eigenen Abbau beschleunigen.
(B) Trypsin-Aktivität ist temperaturabhängig.
(C) Trypsin beschleunigt die Hydrolyse der Peptidbindung.
(D) Trypsin-Aktivität ist pH-abhängig.

(E) Trypsin kann auch andere chemische Reaktionen (z.B. eine Oxydation) beschleunigen. Die einzige Voraussetzung ist, dass das Substrat eine Peptidbindung enthält.

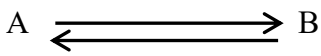
⇨ Evaluated LO: Describe the role of enzymes in chemical reactions

6. Welche Aussage zum Übergangszustand trifft nicht zu?

(A) Seine freie Energie ist höher als die des Substrats.
(B) Je höher seine freie Energie ist, desto langsamer ist die chemische Reaktion.
(C) Die Differenz zwischen der freien Energie des Übergangszustands und der des Substrats definiert die Aktivierungsenergie.
(D) Enzyme stabilisieren den Übergangszustand.
(E) Alle treffen zu.

⇨ Evaluated LO: Define the term activation energy of a reaction

7. Wir wollen die folgende Reaktion durchführen (T = 25°C, P = 1 atm):



$\Delta G0$ für diese Reaktion ist $\Delta G0 = 15\ kJ.mol^{-1}$

Wird die Reaktion spontan verlaufen?

(A) Ja.
(B) Nein.
(C) Die Antwort ist abhängig von den Konzentrationen von A und B, die eingesetzt werden.
(D) Ja, aber nur in Anwesenheit eines Enzyms.
(E) Ja, aber nur in Abwesenheit eines Enzyms.

⇨ Evaluated LO: Explain the difference between free energy and standard free energy, and LO: Predict if a chemical reaction runs spontaneously or not

8. Welche Aussage zu Enzymen trifft zu?
Ein hoher K_M -Wert für ein Enzym zeigt...

(A) eine größere maximale Geschwindigkeit der enzymkatalysierten Reaktion.
(B) eine niedrige Affinität des Substrats zum Enzym.
(C) einen positiven ΔG-Wert.
(D) a, b und c treffen zu.
(E) a, b und c treffen nicht zu.

⇨ Evaluated LO: List parameters that are used to describe an enzyme activity

Results

I taught the re-designed class three times. In between each group, I made small adjustments to take into account the outcome of the one-minute papers. Moreover, for one of the sessions, I had the opportunity to combine the lecture with a classroom observation by a colleague as part of a didactic course offered by Heidelberg University. The goal of the observation was to have an external observer who would give general and specific feedback on the lecture. For the specific feedback, I asked my colleague to pay attention to the participation of the students and to the course of the TLAs.

Impressions during the lectures

My goal during the implementation of the lecture was to pay attention to the active participation of students. The activation slide, stressing the importance of studying enzymes, seemed to be efficient in catching the initial attention of the whole audience as many students participated in this initial discussion. However, the most striking observation, especially in comparison with the very same lecture I gave the years before, was the effect of the TLAs and the use of buzz groups. For every TLA, virtually all the students were focused on the proposed activity. Moreover, with the format of the buzz group, every single person in the audience was forced to engage in solving the questions from the TLAs. It did not matter whether all the students could solve the questions correctly or not; more critical was that they tried to apply the newly introduced concepts to concrete problems. The form of the TLA (a classical problem-solving activity for TLA1, and a game-based explanation for TLA2) did not seem to influence how committed the students were in the buzz group; they appeared to react equally well. But the game-based approach made it easier for me to illustrate a conceptual difference between two kinds of chemical entity. My expectation (without evidence at that point) is that the game-based approach might make it more likely for students to remember the concept the TLA illustrates for a longer time. The third TLA (calculate an enzyme parameter from the packaging of commercial tablets), which I had originally planned more or less solely as a break between two lecture blocks, was actually very useful for having the students relate to a real-life application of enzymes (tablets for lactose-intolerant people) and to the practical use of the parameters to characterize them (to ensure there is no batch-to-batch variability in the activity of lactase tablets bought by lactose-intolerant people).

Altogether, the constructive alignment approach with the use of TLAs was a full success in addressing my first challenge: getting the whole audience to actively participate in the lecture.

Feedback from my classroom observer

My classroom observer praised the LOs (which he thought were presented clearly at the beginning of the lecture) and the activation phase (which he found offered information that allowed the students to relate past knowledge to real-world information). He also observed that the TLAs and buzz groups let students assess important points and relate the theoretical knowledge presented in the lecture to the experimental work of the lab section.

He also had two important suggestions for improvement:

- I should remind the students how the concepts exposed in Block 1 (general concepts of thermodynamics) fit in the subjects presented in Block 2 (on enzymes) with the goal to reinforce what they learned
- I should make use of the blackboard to clarify more complex questions (e.g. how the Michaelis-Menten equation is derived)

Outcome of the one-minute papers and aligned ATs

A very important part of the lecture was the final one-minute paper in which students were asked to identify what they thought was the most important point they had learnt during the lecture and what was still not clear. Whereas 25 students out of 40 in the first group wrote a one-minute paper, most students wrote the paper in the other two groups (26 out of 32 and 20 out of 22 respectively). For the present paper, I have compiled the results in bar graphs listing all the points raised by the students who sometimes gave more than one answer to each question. When asked what the most important thing they learnt was, about two thirds of students from Group 1 stated the difference between ΔG and $\Delta G0$ and one third stated the inhibitors (Figure 4). This is a satisfying result as these were the two usual problematic concepts that students have difficulties grasping. When looking at what they found still unclear (Figure 5), almost 30% mentioned diverse aspects of the Michaelis-Menten equation and more than 15% enzyme inhibitors. This is interesting because my classroom observer, who participated in the first session, had recommended I spend some time at the blackboard to explain more complex concepts such as the Michaelis-Menten equation.

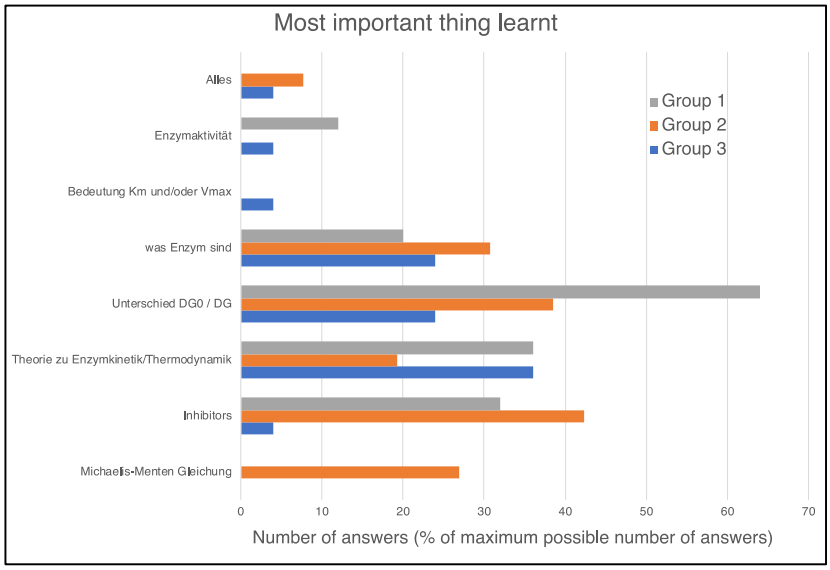


Figure 4
One-minute paper: most important things learned

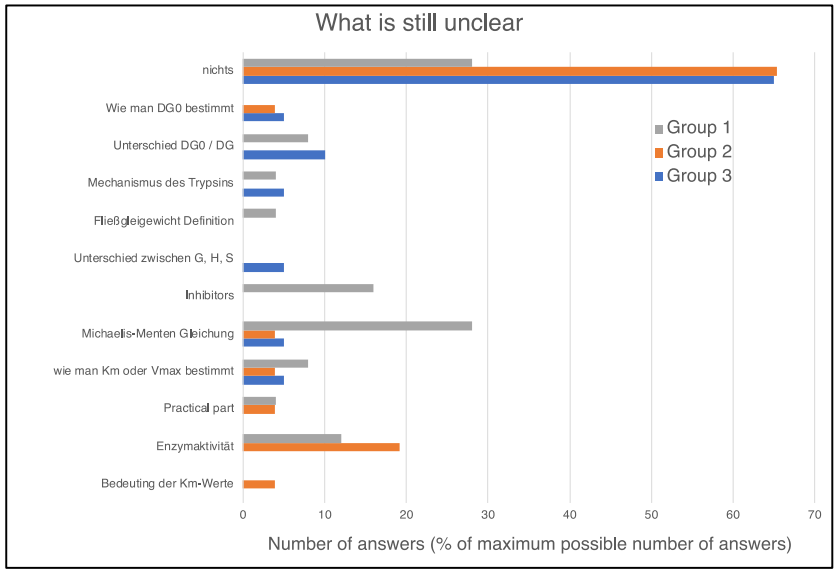


Figure 5
One-minute paper: what is still unclear

Thanks to this first feedback, I decided to spend more time explaining the Michaelis-Menten equation to the next group and to provide more time for the TLA focused on the inhibitors. This had a better than expected outcome with about two-thirds of Group 2 and 3 students stating that nothing was unclear after the lecture (Figure 5). Moreover, apart from the concept of enzyme activity for Group 2, which was consequently given more time for Group 3, there was no specific point that caused problems to a significant number of students. When asked what the most important thing they learnt was, 25% of the students of Group 2 answered the Michaelis-Menten equation. This remarkably illustrates that taking into account the feedback of a simple one-minute paper can help to identify a muddy point and significantly improve how it is understood by the next groups of students. Overall, Group 2 and 3 students did not identify a single point that was the most important in the lecture but cast their votes on diverse aspects with some students even stating that "everything was clear". Yet, one can still see that some students of Group 3 did not understand well the difference between ΔG and $\Delta G0$, stressing that there is no magic formula in teaching and that a seemingly good concept must constantly be adapted and undergo further experimentations.

Evaluation of the aligned ATs (the four questions of the written reports) was very good for all the groups, with an overwhelming majority giving correct answers to all four questions. This is in stark contrast to previous years when students had difficulties to correctly define $\Delta G0$. The improvement can be explained most probably by the TLA of the introductory lecture and by further discussions between students and between students and the instructors during the lab section.

Discussion

Overall success of the constructive alignment approach

One prerequisite of the constructive alignment approach is the definition of clear and measurable LOs. I found that directly thinking about learning outcomes before starting to think about exact content makes it much easier to design and structure a lecture. With the LOs and the resulting structure at hand, it is quite clear how many and which TLAs should be inserted. From my experience with this project, I can only encourage the use of well-designed TLAs. Compared to previous years, there was a tremendous improvement in the capacity of the students to grasp the concepts that were repeatedly misunderstood in the past. From the number of students involved, one can safely exclude the possibility that I by chance dealt with more gifted students this year. The reason for the observed performance improvement must thus have come from the way the lecture was given. The most striking difference between the previous lectures and the new ones were the introduction of LOs and

TLAs, especially the two TLAs dedicated to the two main concepts that had been difficult for the students in the past.

Another powerful tool that decisively contributed to the success of this project was the final one-minute paper. It is actually quite striking how such a simple exercise can provide so much information on how a lecture has been received and which aspects require attention for the next sessions. In my case, this helped improve my lectures for the next groups (as evidenced by the outcome of the next one-minute papers), but the one-minute paper could also be used to prepare the start of the next session of a more classical lecture series with a recap slide addressing the muddy points of the previous lecture. All in all, with its minimal preparation, implementation, and evaluation time, even for large groups of students, the one-minute paper seems to be a must at the end of virtually any lecture.

Chances and challenges

This project shows the opportunities afforded by a constructive alignment approach. Trying to have virtually all students actively participate in my lectures has been a long-standing challenge for me. The use of buzz groups during the TLAs has proven to be extremely effective in achieving that goal. From my perspective, all students were actively engaged and this was confirmed by my classroom observer. Judging from the outcome of the one minute-papers, my discussions with the students while supervising the lab session, and the answers to the four questions of the written protocol, the students grasped the content and concepts of the lecture much better this year than during the previous years. I attribute this change to an effective shift from teaching to learning as the raw content of the lecture was virtually the same, but the way it was presented to the students changed: clear LOs, TLAs to stimulate the students to construct their own knowledge, and their relation to planned ATs.

Naturally, the approach comes with its drawbacks and is by no means a magic recipe. While I found that structuring the lecture and defining which LOs should be accompanied by TLAs was quite straightforward, lots of time needs to be invested in the design of adequate TLAs. They need to illustrate a certain concept, be challenging enough that the students need to think about the concept to solve them within the proposed activity and at the same time not be too long so that they can still fit within the time frame of the lecture. One additional important aspect is that a lecture should evolve according to the feedback of the students. The evaluation of the one minute-papers showed that when I addressed a muddy point from a previous group, other aspects became more problematic for some students of the next group. Giving lectures multiple time over the years would certainly contribute to find an equilibrium there. However, there will never be a perfect lecture that can be applied to any group of students and one must be ready to continuously adapt one's teaching. In the format of the present lecture, I was fortunate that I could meet the students again during the afternoon lab session. This gave me the opportunity to address the muddy

points of the one minute-papers with them. However, I could only do this with the subgroup of students I was supervising during the practical session. Moreover, in a more usual lecture format, I would not have this opportunity. A more useful way of handling the one minute-papers would have been to have a post-teaching communication with students on an online platform. This would have allowed me to address open questions when they were still fresh. The last challenge is to find like-minded colleagues when applying the approach. This is usually not such a problem when one teacher is responsible for one subject within a larger series, as every teacher can align their teaching with their ATs for their own subject. In my case, I encountered the problem of two teachers dealing with the same lecture (I took over the first three, a colleague the last two), which unfortunately resulted in ATs in the final exam that were not fully aligned with my lecture. This was, as far as I can say, mostly due to a tradition of not thoroughly discussing teaching between colleagues. This is something that would benefit from change in the future. In that sense, the effort to establish a scholarship of teaching and learning at Heidelberg University (KLÖBER 2020) seems to be a very promising way forward.

Conclusion

Altogether, the re-design of my lecture according to the constructive alignment principle has been a clear success not only for me but also for students who unknowingly took part in this experiment. My overarching question, "Can I design my teaching in a way that most students are engaged in active learning and clearly understand what I want to convey?", can be answered positively: one can be successful by defining clear and measurable LOs, creating well-designed TLAs in a format that induces the participation of all, and being transparent with what will be expected during the ATs.

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