Modeling as a Learning Method

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Discovery learning is a good way for students to actively learn about complex subjects. There are some difficulties with the method however (Mayer 2004). According to Mayer the most important problem is the lack of support in true discovery learning. One possible form of support is making the students create a model of the phenomena they are studying. Creating a model helps when learning about those subjects for various reasons. The students can use the model in progress to summarize what they already know about the subject and to see where they still need more information (Penner 2001, Sins et al. 2005). When learners create a model they are forced to think about the interactions between processes and to make them explicit (Penner 2001, Sins et al. 2005), for instance the relations between aerobic and anaerobic combustion. Because the models are physical objects they can be discussed by others (peers and teachers in the classroom), which also encourages reflection and evaluation, two important aspects of learning (Smith et al. 1993). During the modeling the student makes changes to the model, which causes the ideas of the student to change as well (Kuutti 1996).

So we know that creating a physical model helps learners, however it only works well if the created model is of a high quality. Currently there seems to be a lack of published material about what makes a model good and how learners can be taught to make good models. To answer these questions we must first decide what makes a model “good”. For the purposes of this study, a good model is any model that results in acquiring knowledge about the subject matter while creating it (and, hopefully, because of it), and also that the model contains all the important aspects of the subject matter and their relations with each other.

In this study hand drawn models were chosen (as opposed to computer generated models), because pretty much everyone can draw, but using a computer program to create a model would require training. This would only increase the amount of time each subject had to spend concentrating on off-task learning. Computer generated models could be more interactive, but it would require more time and effort from the participants and for the current study the benefits wouldn't be worth the trouble. Also, this method can be used with anyone, not just computer savvy individuals. The quality of the drawing is not judged on how pretty everything looks, but on the processes and relationships between them.

The learning task for the participants of this study was a reasonably complex biological system that could be learned relatively fast. The production of ATP (the fuel for muscle contraction i.a.) in the human body. In short, there are three ways with which ATP is produced. The learners will have to draw a model of what is needed to fuel them, the waste products of each process, the interaction between the processes and the speed of each process. Oxygen is an important part of only one of these processes (aerobic combustion), which might be unexpected for some participants. The most complex part of the production process is the interaction between pyruvic acid (a waste product of anaerobic combustion) and oxygen. If there is no oxygen available, pyruvic acid turns into lactic acid.

If oxygen is available, however, the pyruvic acid is used as fuel (together with the oxygen) for aerobic combustion.

The aim of this study is to discover what the important aspects of a model are for the learning objectives; what parts of the modeling experience are most important for learning. This is done by comparing models of good learners (measured by a written test) to those of bad learners. The models are analyzed, based on which processes and variables are present, and scored accordingly.

Method

Participants

Eighteen first and second year psychology students (6 male, 12 female) as part of the required test subject hours.

Procedure

One subject at a time took part in the experiment. The first phase of the experiment is the introduction, where the participant enters and meets the experimenter who explains the study to them. The participant gets to try out the equipment (touchscreen with pen) with a tutorial and is asked to read the text. The text is about how ATP is produced. There are three processes that are responsible for the production, which the participant is supposed to draw, including the interactions between them.

In the second phase, which begins when the subject is finished reading the text, the experimenter asks them to draw a model of the text. The subjects are allowed to ask questions and they still have access to the text. They are encouraged to draw whatever they feel like drawing, as long as it is about the subject matter.

The third phase starts when the subject is done drawing. The experimenter starts a replay of the drawing phase, in which the entire process (every drawn line, pause etc.) is played again in fast forward. The subject is asked to explain what they did and why they did it. These conversations were recorded.

In the final phase the experimenter put the text away and gave the subjects a quiz, three open questions about the text without time limit. The subjects were allowed to look at their drawing, but not the text. When they indicated they were finished, the experimenter debriefed them and they left.

Materials

The text that was used was 2 pages long, with a third page containing only an example model they could base their own drawing on (see appendix A). The computer program they used to make the drawings (and the experimenters used to make the replays) is a simple "paint" like drawing tool. A simulation was also present which could be used by the participants to create a graph of some of the basic elements of the subject-matter. The physical tool that was used to create the drawings was a Cintiq LCD monitor with a touchscreen pen. This device can be used roughly the same as a pencil and paper, which makes it very intuitive for first time users. Most of the test subjects hadn't used anything like it before, but they got accustomed to it quickly and most of them liked working with it. The quiz at the end of the experiment consisted of 3 open questions.

Measures and tests

As previously mentioned the drawings of the participants were logged, every pen stroke or letter they typed. This was interesting because sometimes people draw something and then change it when they get a better idea. Those moments were recorded as well.

The phase where the subjects explain what they drew was recorded as well. Some of the thought processes about the subject-matter can practically be heard crystallizing during this phase. Making thoughts explicit is also a good way to improve learning.

The quiz at the end of the experiment was used to determine how much understanding about the subject-matter there was after the experiment. The questions were about the basic knowledge elements of the text, but also to measure whether the subject understands how the processes work together to form a whole. This was especially important because the subjects who understand the entire process can be compared to the students who only grasp the smaller parts of the equation. The goal of this experiment, after all, is to see what the best students do differently compared to the others.

Results

Subject	Fuel and Waste (6)	Pyruvic acid process (5)	Reaction rate (1)	Drawing score combined (12)
1	4	5	1	10
2	6	5	1	12
3	6	5	1	12
4	4	5	0	9
5	5	5	1	11
6	6	5	1	12
7	5	0	0	5
8	6	5	1	12
9	6	5	0	11
10	3	0	0	3
11	6	0	1	7
12	6	5	0	11
13	3	0	0	3
14	6	0	1	7
15	6	5	1	12
16	5	5	0	10
17	5	5	1	11
18	4	0	0	4

Table R1: The number in (parentheses) is the maximum amount of points awarded for the item if the subject added everything important about it in their drawing.

Drawn models

The drawings were evaluated on a number of items that should be drawn in a good representation of the text. Each subject earned points for the following items if they were added to their model. 6 different fuel and waste molecules (O2, CO2, H2O, pyruvic acid, lactic acid and glucose), the speed of each reaction and the link between aerobic and anaerobic combustion (named "pyruvic acid process" in the table below). All of these combined made up the total score for the drawing.

There was only 1 subject who didn't draw ADP&ATP and all of them drew the basic model with the three ways to produce ATP, so those data aren't very informative for this study, aside from the fact that everyone at least drew the basics. The fuel and waste results are more interesting, some subjects only drew half of them. The link between aerobic and anaerobic combustion is also an interesting item, most of the subjects who didn't draw the link also had lower scores on the quiz. The speed of the reactions also had a (barely) significant effect on the quiz scores. The combined score for the drawing unsurprisingly has a very significant correlation with the performance on the quiz.

Correlations

		Fuel and Waste	Pyruvic acid process	Reaction rate	Drawing score combined
Quiz Score	Pearson Correlation	.579*	.569*	.471*	.664**
	Sig. (2-tailed)	.012	.014	.049	.003
	N	18	18	18	18

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table R2: Correlations between items of the drawing and scores on the quiz.

Audio

After drawing their model, the subjects were asked to explain what they drew and why. These explanations were recorded and scored for four different kinds of explanation: The subjects explained a process correctly, they explained a process incorrectly, they drew something and then revised it (something relevant about the model, not just a pen stroke they didn't like) and sometimes they explained why they drew something the way they did.

		Audio Process Correct	Audio Process Incorrect	Audio Revising Mistake	Audio Explanation
Quiz Score	Pearson Correlation	.538*	-.674**	-.335	.469
	Sig. (2-tailed)	.026	.003	.188	.057
	N	17	17	17	17

Table R3: Correlations between the audio and the score on the quiz.

Almost every subject explained at least a few of the processes correctly when they talked about their drawing. There is a significant correlation between these explanations and the quiz score, which isn't that surprising as most of the quiz is basically a pen and paper version of explaining how it all works. What is even more interesting is that the incorrect explanations (negatively) correlate even more with the quiz, even though there are only seven of them among all test subjects.

The recorded changes and explanations however aren't significantly correlated with the quiz. It is interesting to note that the audio is not significantly correlated with the drawing, only with the score on the quiz. However the incorrect explanations are (negatively) correlated with the most difficult part of the entire process.

		Audio Process Incorrect
Pyruvic Acid Process	Pearson Correlation	-.515*
	Sig. (2-tailed)	.035
	N	17

		Audio Process Correct	Audio Process Incorrect
Drawing score combined	Pearson Correlation	.396	-.480
	Sig. (2-tailed)	.115	.051
	N	17	17

Tables R4&5: Correlations between the audio and the drawing above, and the incorrect explanations correlated with the link between aerobic and anaerobic combustion below.

Conclusions and discussion

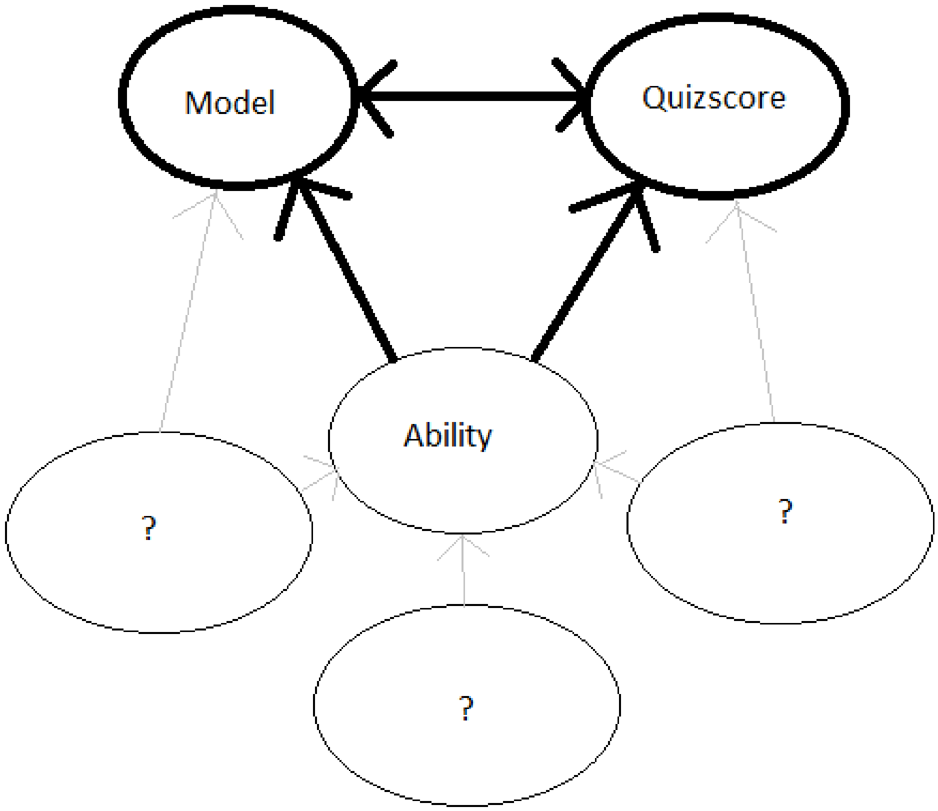
The goal of this study was to get an idea of what parts of drawing a model about a complex subject can help learners learn the subject matter. Looking for differences between the best and worst drawings and comparing those to the actual knowledge the learners have about the subject matter can shed some light on this problem. Considering that the drawings and the quiz scores are quite significantly correlated we can safely assume that drawing a good model will most likely improve knowledge about the subject-matter and vice versa. This could be interesting for learners who aren't good at learning from books alone, but prefer a more hands on approach.

As for the drawing itself, it looks like the most difficult part is also the most important one. Subjects who understood the interaction between the processes scored 2 points higher on the quiz on average than those who didn't, and only some of the subjects who **didn't** draw the interaction scored failing grades on the quiz. Obviously understanding is more important than remembering simple facts, but, unfortunately, it isn't necessary to get a passing grade.

The audio correlates nicely with the score on the quiz, but not with the drawing. This is odd considering that all three are supposed to measure the same thing. The audio portion of this study could definitely be prepared more carefully and with a stricter scoring system. That might explain this discrepancy, or perhaps the learners were a little more nervous when they had to talk. Either way this could use some more research. The finding that the incorrect explanations are correlated to the pyruvic acid process suggests that it is the number one cause for mistakes, further proving that it is the hardest part of the subject matter. Understanding the big picture could also be an important part to research to improve learning.

It is quite possible that another variable (called Ability in the picture below) influences both the drawing score and the quiz score. If so, it could be useful to investigate how to improve this factor, but that is beyond the scope of this study.

Some students may be more motivated or talented to draw models instead of learning from reading a text. They may enjoy being more active with the subject matter. For them this could also be a better way to learn.



Future research possibilities.

In this study the participants were allowed to use their drawing at the test. The rationale was that around 45 minutes wasn't enough time for the participants to learn everything by heart (the names of the processes and fuel/waste products), but they were expected to use them in the test. The solution to let them keep their drawings solved more than the problem, since it showed them most, if not all, of the answers outright, depending on the quality of their drawing. To truly measure learning, it might have been better not to let them keep their drawing, but instead give them a list of the names they have worked with, or even nothing at all.

Special thanks to
Frank Leenaars
for creating the modeling tool and replayer
and
Diana Becker
for the feedback

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Appendix A (The instructional text)

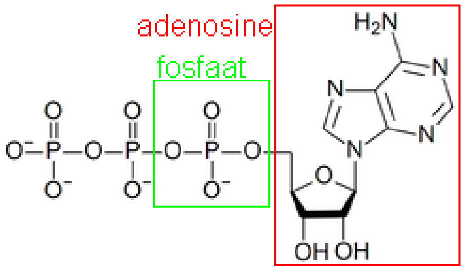
Welkom

Allereerst hartelijk bedankt voor het meedoen aan dit experiment!

Hieronder staat uitgelegd hoe je lichaam energie produceert om te bewegen. Lees de tekst goed door en probeer voor jezelf duidelijk te maken hoe het werkt. Na afloop is het de bedoeling dat je (met de tekst erbij) een model tekent van het hele proces. Je kunt hierbij gebruik maken van het voorbeeld zodat je een idee hebt wat voor tekening je zou kunnen maken. **Je mag ook een tekening maken zonder het voorbeeld te volgen!**

Inleiding verbranding

Bij elke beweging die je doet, activeer je je spieren. Ze trekken zich samen om de beweging te veroorzaken. Je lichaam gebruikt hiervoor chemische energie (energie opgeslagen in moleculen, die vrij komt als ze splitsen). Hoe meer kracht je zet hoe meer energie je verbruikt.
ATP (Adenosine Tri-Fosfaat) is de brandstof die je lichaam gebruikt om spieren samen te trekken. Tijdens dit proces verliest de ATP 1 **fosfaat (PO_4)** molecuul, het wordt dan **ADP (Adenosine Di-Fosfaat)**. De verbruikte ADP en fosfaat worden weer aan elkaar geplakt in een ander deel van de cel, hier is energie voor nodig. Je kunt dat proces vergelijken met het opladen van een lege batterij, maar veel efficiënter.



ATP

Het lichaam heeft 3 manieren om de gebruikte ADP weer om te zetten in ATP.

Creatinefosfaat (CP) is een vrij eenvoudig molecuul, het komt 3-4 keer zo veel voor in het bloed als ATP en kan zijn fosfaat zonder moeite weggeven aan ADP, waardoor het weer ATP wordt. Hier komt geen zuurstof aan te pas. De Creatine die overblijft kan later weer gebruikt worden om Creatinefosfaat te produceren of voor andere processen. Je kunt met de ATP en CP reserves die bij rust in je bloed en cellen opgebouwd worden ongeveer 10-15 seconden maximale spierkracht leveren voor het op is. Deze methode van ATP productie wordt gebruikt als de (an)aërobe productie nog op gang moet komen.

Anaërobe verbranding van glucose start erg snel en heeft geen zuurstof nodig. Het is echter niet erg efficiënt vergeleken met de aërobe verbranding, per glucosemolecuul wordt maar 2 ATP geproduceerd en het wordt omgezet in 2 pyrodruivenzuur moleculen. Dit wordt, als er geen zuurstof aanwezig is, omgezet in melkzuur. Deze methode van ATP productie wordt gebruikt als de aërobe productie nog op gang moet komen of als die het ATP verbruik niet kan bijhouden. Dit kan het geval zijn als je heel veel kracht zet, bijvoorbeeld bij gewichtheffen of sprinten.

Aërobe verbranding start relatief langzaam, het duurt ongeveer 30-45 seconden voor het op gang komt en er is voldoende zuurstof in het bloed bij nodig. Het zet per pyrodruivenzuurmolecuul 19 ADP om in ATP, met als afvalstoffen water (H_2O) en koolstofdioxide (CO_2). De reden dat het lichaam niet uitsluitend deze manier gebruikt is omdat er bij hoge inspanning niet genoeg zuurstof aanwezig is om puur op aërobe verbranding te draaien. Bovendien worden de spieren als ze samentrekken hard waardoor het bloed er moeilijk bij kan komen (en dus ook weinig zuurstof). Deze methode van ATP productie wordt gebruikt als de inspanning lang genoeg duurt om op gang te komen en er genoeg zuurstof beschikbaar is. Aërobe verbranding is een voortzetting op anaërobe verbranding, in combinatie met zuurstof worden de afvalstoffen van anaërobe verbranding (pyrodruivenzuur) niet omgezet in melkzuur maar in koolstofdioxide en water.

De aërobe verbranding gaat na de inspanning nog even door om de reserves weer aan te vullen en de overgebleven pyrodruivenzuur op te maken.

De simulatie

Aan de linkerkant van het scherm kun je je tekening maken. Aan de rechterkant zie je twee grafieken met daaronder een aantal parameters. Je kunt de “gewenste inspanning” instellen om te kijken wat voor invloed dat heeft op de ATP productie. Je kunt het zo vaak resetten als je wilt om de verschillende mogelijkheden te testen. (Je moet eerst resetten en daarna pas de instellingen veranderen, anders reset het programma ook je nieuwe instellingen.)

Gewenste inspanning: Dit is de hoeveelheid inspanning die je levert in procenten. Hoe meer inspanning hoe meer spiervezels (per spier) er actief worden en dus ook hoe meer ATP/s je nodig hebt om het vol te houden.

In de bovenste grafiek kan je zien hoeveel ATP er beschikbaar is in de spieren.
In de onderste tabel verschijnen 3 gekleurde lijnen.
De groene lijn geeft aan hoeveel ATP uit de Creatinefosfaat reserves komt.
De rode lijn doet hetzelfde voor de anaërobe verbranding.
De blauwe lijn voor de aërobe verbranding.
Op de X as staat de tijd weergegeven.

Uitleg taak:
Maak een tekening van de productie en het verbruik van ATP. Zorg ervoor dat je met behulp van je eigen tekening iemand anders kan uitleggen hoe het in elkaar zit. Probeer alle processen uit de tekst in je tekening te verwerken.