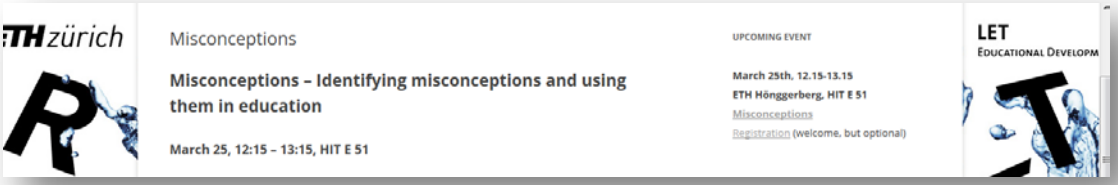


Conceptual understanding in biology: insights into the misconceptions maintained by students

Project review

Authors:
Annie Champagne Queloz*, Katja Köhler, Elsbeth Stern, Markus Aebi, Michael W. Klymkowsky, Ernst Hafen
* Contact: champagne@imsb.biol.ethz.ch

Why did we start this project?

We were interested to know what was the biological "authentic" conceptual understanding of students at the end of the Maturität diploma and during their studies at university. According to previous research, mostly done in the US, students often held important misconceptions concerning basic knowledge in biology, even after some years at university. We investigate that problematic issue in Switzerland with "Maturitätsschüler" in their last year of gymnasium and students at ETH Zürich and at Universität Zürich. The diagnostic of students' knowledge will be useful to adapt the teaching according to the learning needs of students.

The objectives

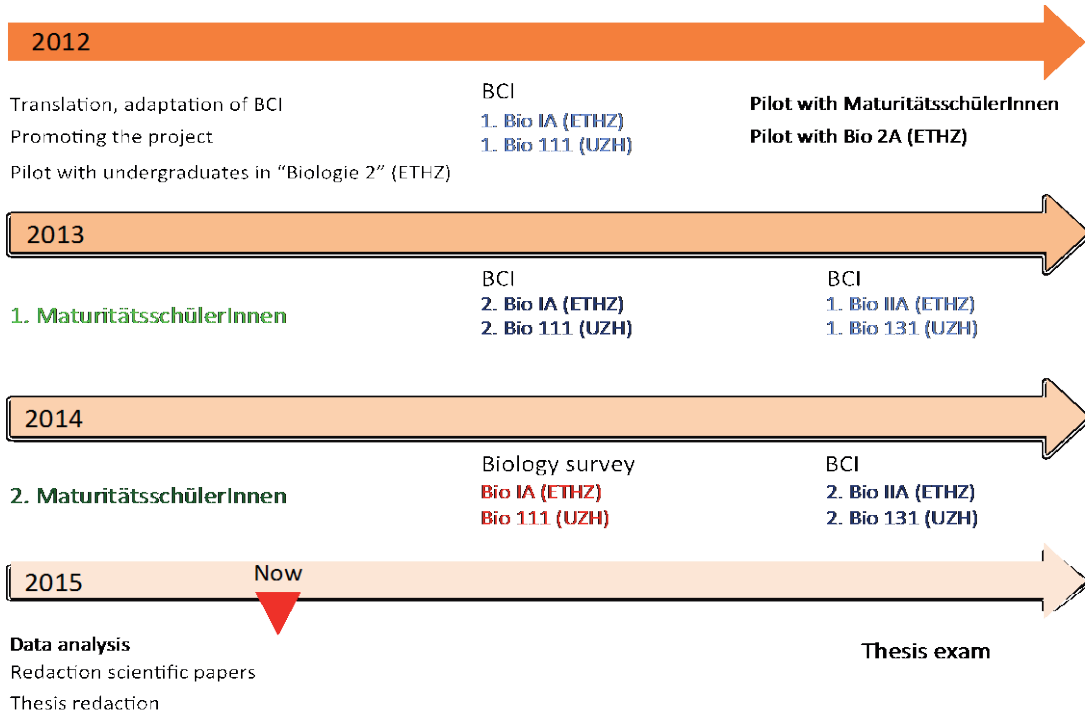
- Identification of misconceptions in biology held by Maturitätsschüler entering ETH that need to be addressed in undergraduate teaching
- Assessment of basic conceptual knowledge in biology of Maturitätsschüler
- Evaluation of the learning needs of students and of teaching needs to help students to improve their understanding.
- Adaptation to the current biology curriculum at ETHZ to promote a deeper conceptual understanding.

The diagnostic tool and the methodology

An adapted and translated version of the Biological Conceptual Instrument (BCI). Klymkowsky et al. 2010. http://arxiv.org/abs/1012.4501
24 multiple-choice questions

25 minutes in class and on paper
Administrated to:
1) The "Maturitätsschüler" in their last year of gymnasium, in different German cantons.
2) Cohort of students in their first- and second-year at university in obligatory biology lectures at ETHZ and UZH.

Project worthwhile
Doctorate thesis. 3-4 years. 60%.



What does the BCI look like?
Here are some questions.

<u>Question 1</u>
Topic: Evolution
It is often the case that a structure (such as a functional eye) is lost during the course of evolution. This is because ...

A. It is no longer actively used.
B. Mutations accumulate that disrupt its function
C. It interferes with other traits and functions.
D. The cost to maintain it is not justified by the benefits it brings

Explanations:

- The question evaluates if students held a common Lamarckian thinking, i.e. animals' needs will determine how an organ would it use or not use and then, whether it is conserved or not over time (Kampourakis & Zogza, 2006).
- The results demonstrate that some students are confused with the use/not use and the selection of a structure or a trait.
- The costs and benefits determine whether a structure is retained or not. The best answer is D.
- The Lamarckian model still influences one third of students in their understanding about evolution at the end of the gymnasium.

Question 2

Topic: Energetics and molecular interactions

Once two molecules bind to one another, how could they come back apart again?

A. A chemical reaction must change the structure of one of the molecules.
B. Collisions with other molecules could knock them apart.
C. The complex will need to be degraded.
D. They would have to bind to yet another molecule.

Explanations:

- The majority of students (second-year undergraduates) think that, once two molecules bind to one another, a chemical reaction must change the structure of one of the molecules to come back apart again (answer 1).
- Even if it is true in some cases, random collisions between molecules are much more often responsible for their dissociation than an active mechanism (Alberts et al., 2007). The best answer is B.
- The students don't really recognize the effect of randomness involved in many biological processes like diffusion or molecular interactions.

Question 3

Topic: Drift and diffusion (randomness)

Sexual reproduction leads to genetic drift because ...

A. there is randomness associated with finding a mate.
B. not all alleles are passed from parent to offspring.
C. it is associated with an increase in mutation rate.
D. it produces new combinations of alleles.

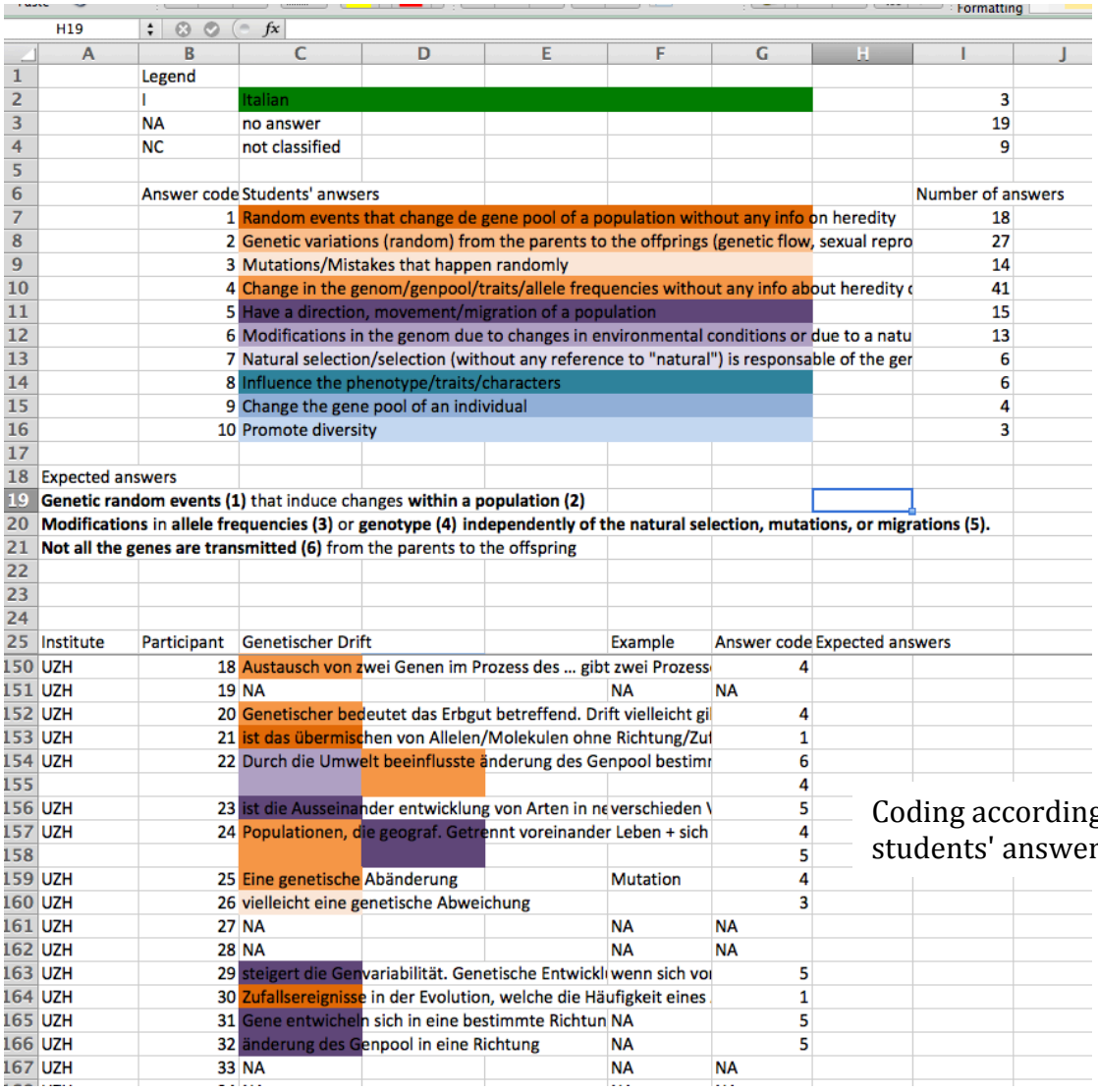
Explanations:

- For this question, all answers can be true, but answer 2 is the best answer.
- It will have not genetic drift if all alleles are passed from parents to offspring.

- The concept of randomness underlying genetic drift was quite hard even when students were in their second year at university.

Biological Concepts Survey (ongoing)

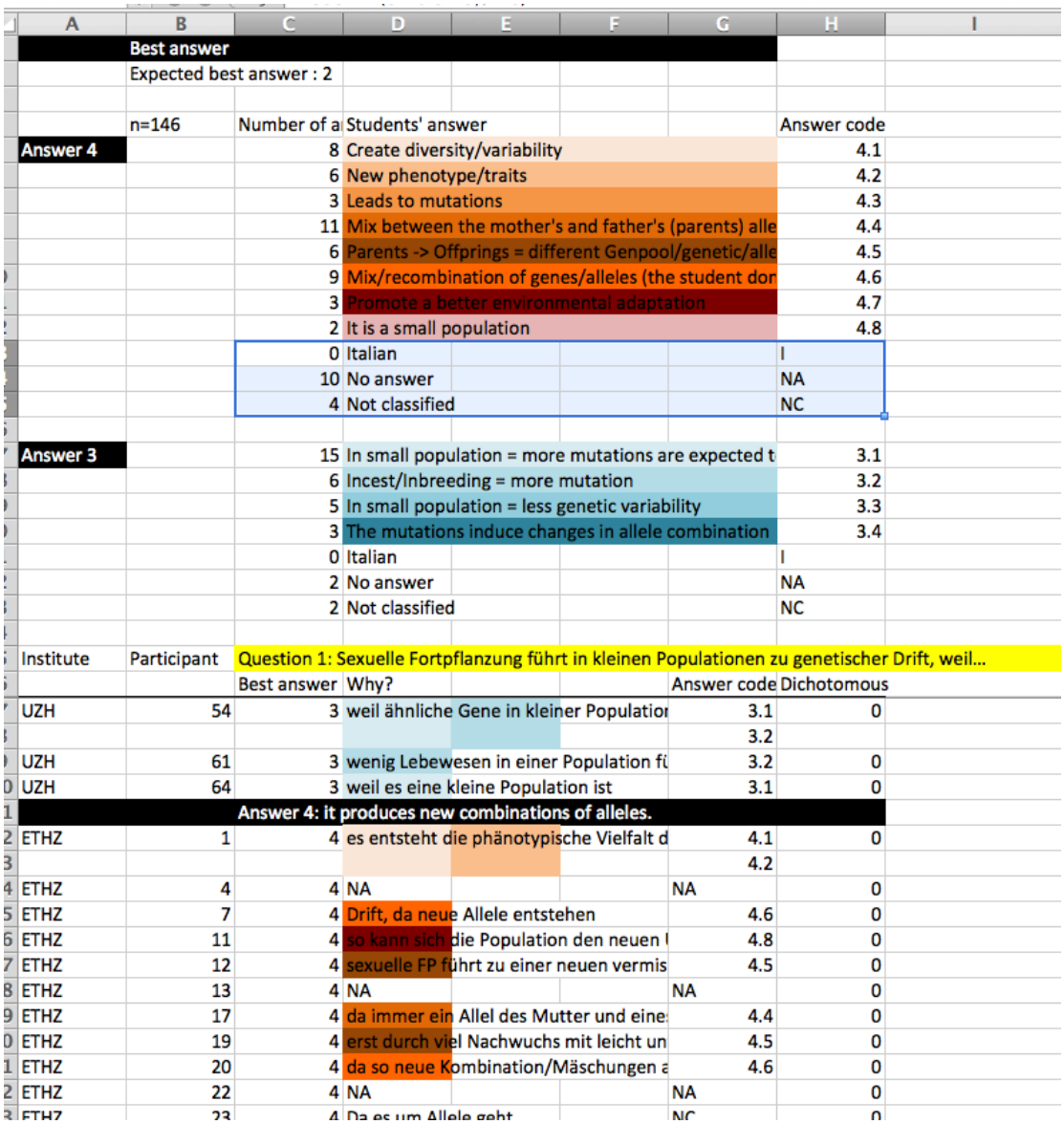
Multiple-choice questions have limits. On some BCI questions, the results are ambiguous. We would like to deepen those by asking students to explain their thinking. A survey was distributed to undergraduates in their first biology lecture at ETHZ and UZH in September 2014. The survey is divided into three sections. In the first part, students define simple common expressions taught in biology lectures. In the second part, we show some of the ambiguous BCI questions. We ask the students to select a best answer and one wrong answer and then to explain their choices. In the third part, the students have to explain simple biological processes and how randomness can be involved. All student answers are coded and grouped according to students' common thinking. Here are examples of the answer coding:



1		Legend								
2		I	Italian						3	
3		NA	no answer						19	
4		NC	not classified						9	
5										
6		Answer code	Students' anwsers						Number of answers	
7		1	Random events that change de gene pool of a population without any info					on heredity	18	
8		2	Genetic variations (random) from the parents to the offprings (genetic flow,					sexual repro	27	
9		3	Mutations/Mistakes that happen randomly						14	
10		4	Change in the genom/genpool/traits/allele frequencies without any info about					heredity	41	
11		5	Have a direction, movement/migration of a population						15	
12		6	Modifications in the genom due to changes in environmental conditions or					due to a natu	13	
13		7	Natural selection/selection (without any reference to "natural") is responsable					of the ger	6	
14		8	Influence the phenotype/traits/characters						6	
15		9	Change the gene pool of an individual						4	
16		10	Promote diversity						3	
17										
18	Expected answers									
19	**Genetic random events (1)** that induce changes **within a population (2)**									
20	**Modifications** in **allele frequencies (3)** or **genotype (4) independently of the natural selection, mutations, or migrations (5).**									
21	**Not all the genes are transmitted (6)** from the parents to the offspring									
22										
23										
24										
25	Institute	Participant	Genetischer Drift				Example	Answer code	Expected answers	
150	UZH	18	Austausch von zwei Genen im Prozess des ...				gibt zwei Prozess	4		
151	UZH	19	NA				NA	NA		
152	UZH	20	Genetischer bedeutet das Erbgut betreffend. Drift vielleicht gi					4		
153	UZH	21	ist das übermischen von Allelen/Molekulen ohne Richtung/Zu					1		
154	UZH	22	Durch die Umwelt beeinflusste änderung des Genpool bestim					6		
155								4		
156	UZH	23	ist die Ausseinander entwicklung von Arten in ne				verschieden V	5		
157	UZH	24	Populationen, die geograf. Getrennt voreinander				Leben + sich	4		
158								5		
159	UZH	25	Eine genetische Abänderung				Mutation	4		
160	UZH	26	vielleicht eine genetische Abweichung					3		
161	UZH	27	NA				NA	NA		
162	UZH	28	NA				NA	NA		
163	UZH	29	steigert die Genvariabilität. Genetische Entwickl				wenn sich vo	5		
164	UZH	30	Zufallsereignisse in der Evolution, welche die Häufigkeit eines					1		
165	UZH	31	Gene entwickeln sich in eine bestimmte Richtun				NA	5		
166	UZH	32	änderung des Genpool in eine Richtung				NA	5		
167	UZH	33	NA				NA	NA		

Coding according to students' answers

Students' answers



		Best answer						
		Expected best answer : 2						
		n=146	Number of a	Students' answer			Answer code	
Answer 4			8	Create diversity/variability			4.1	
			6	New phenotype/traits			4.2	
			3	Leads to mutations			4.3	
			11	Mix between the mother's and father's (parents) alle			4.4	
			6	Parents -> Offprings = different Genpool/genetic/alle			4.5	
			9	Mix/recombination of genes/alleles (the student dor			4.6	
			3	Promote a better environmental adaptation			4.7	
			2	It is a small population			4.8	
			0	Italian			I	
			10	No answer			NA	
			4	Not classified			NC	
Answer 3			15	In small population = more mutations are expected t			3.1	
			6	Incest/Inbreeding = more mutation			3.2	
			5	In small population = less genetic variability			3.3	
			3	The mutations induce changes in allele combination			3.4	
			0	Italian			I	
			2	No answer			NA	
			2	Not classified			NC	
	Institute	Participant	Question 1: Sexuelle Fortpflanzung führt in kleinen Populationen zu genetischer Drift, weil...					
			Best answer	Why?		Answer code	Dichotomous	
	UZH	54	3	weil ähnliche Gene in kleiner Populatio		3.1	0	
						3.2		
	UZH	61	3	wenig Lebewesen in einer Population fü		3.2	0	
	UZH	64	3	weil es eine kleine Population ist		3.1	0	
	Answer 4: it produces new combinations of alleles.							
	ETHZ	1	4	es entsteht die phänotypische Vielfalt d		4.1	0	
						4.2		
	ETHZ	4	4	NA		NA	0	
	ETHZ	7	4	Drift, da neue Allele entstehen		4.6	0	
	ETHZ	11	4	so kann sich die Population den neuen		4.8	0	
	ETHZ	12	4	sexuelle FP führt zu einer neuen vermis		4.5	0	
	ETHZ	13	4	NA		NA	0	
	ETHZ	17	4	da immer ein Allel des Mutter und eine		4.4	0	
	ETHZ	19	4	erst durch viel Nachwuchs mit leicht un		4.5	0	
	ETHZ	20	4	da so neue Kombination/Mäschungen a		4.6	0	
	ETHZ	22	4	NA		NA	0	
	ETHZ	23	4	Da es um Allele geht		NC	0	

In this example, the majority of students have selected a wrong answer as the best answer. Their explanations would give us some indication on the clarity of the question and the students' thinking. The analysis of students' answers is ongoing.

Additional information about misconceptions in biology and some collections of questions available online

- Bioliteracy. University of Colorado, Boulder. http://bioliteracy.colorado.edu
- Understanding evolution. University Berkeley. http://evolution.berkeley.edu
- American Association for the Advancement of Science. http://assessment.aaas.org
- European Commission. Europeans and Biotechnology in 2010. http://ec.europa.eu/research/swafs/pdf/pub_archive/europeans-biotechnology-in-2010_en.pdf
- BBC. http://www.bbc.co.uk/education
- Nature Education. http://www.nature.com/nature_education