Supplemental Material

CBE—Life Sciences Education

Fiedler *et al.*

Supplemental Materials

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Supplement 1: The Randomness and Probability test in the context of Evolution (RaProEvo)

*Note: * = right answer; contact author for guide of free-response items*

E01 (Source: cf. Fenner, 2013)

You observe the following situation. In the South Pole, a male penguin with normally thick plumage and a female penguin with very thick plumage generate an offspring. This one also has very thick plumage. **How can this be explained with the theory of evolution?**

- □ Because it is very cold at the South Pole, the offspring's body had to receive the thickest plumage that the parental genetic pool had to offer.
- □ *The offspring was lucky. It could also have got less thick plumage.
- □ The plumage grew stronger, because otherwise the offspring would have frozen to death.

E02 (Source: cf. Fenner, 2013)

The litter of a cheetah includes two offspring: one with an advantageous mutation and one without this mutation. **What can you say about survival of the two offspring?**

- □ The offspring with the advantageous mutation will survive.
- □ The offspring without the advantageous mutation will survive.
- □ *Both offspring may either survive or die.

E03 (Source: cf. Robson and Burns, 2011)

Milkweed leaves are toxic to most insects, but a subspecies of beetle has been found that can eat milkweed leaves with no ill effects. **Which of the following do you think best explains the evolution of some beetles' ability to eat milkweed leaves without getting sick, even though eating milkweed leaves kills other, closely-related beetles?**

- □ Eating milkweed makes beetles produce an enzyme that destroys milkweed toxins, so that the more milkweed the beetles eat, the less it bothers them.
- □ *A few beetles just happened to make an enzyme that destroys milkweed toxins. When beetles eat milkweed leaves, only those that happen to make this enzyme are able to survive.
- □ Beetles become immune to milkweed toxin the more milkweed leaves they eat. Then, when the beetles reproduce, they pass their immunity to milkweed toxin on to their offspring.

E04 (Source: EvoVis project)

There is a pack of 17 grey and 13 brown wolves. The wolves hunt and run along a canyon. Suddenly, some stones fall and hit one of the wolves, which then falls down the canyon.

Mark the probable color of the wolf that fell:

- □ Grey.
- □ Brown.
- □ *Grey or brown.

E05 (Source: cf. Campbell *et al.*, 2006)

Explain why the statement "Evolution through natural selection is a *random process.*" is wrong.

E06 (Source: EvoVis project)

The human eye is composed, like a camera, of many parts, all of which are needed for the eye to work. **Which of the following statements about the eye do you find most credible?**

- □ If you remove one part of the eye it will stop functioning. Therefore, the eye cannot have evolved through a gradual process. It must have appeared in one step as a functioning unit.
- □ *Since small improvements are often favored by natural selection, the eye probably evolved gradually.
- □ The probability that such a complex organ as the eye can evolve by mere chance is so small there must be some thought behind it.
- □ Since animals need to see in order to find food they have evolved eyes.
- □ The eye has evolved solely by chance.

E07 (Source: cf. Campbell and Reece, 2011)

Every person is genetically unique. **Mark the answer that best explains the most common cause of this uniqueness according to the theory of evolution:**

- □ Random mutations that have occurred in previous generation.
- □ *New combinations of alleles during sexual reproduction.
- □ Genetic drift associated with small populations.
- □ Geographical variability within the population.
- □ Environmental influences.

E08 (Source: EvoVis project)

The gender of a child depends on whether the sperm involved in his or her conception carries the father's X- or Y-chromosome. Assume that there are equal proportions of sperm carrying these chromosomes, and by chance just one fuses with the female gamete (ovum, carrying an X chromosome from the mother), resulting in the conception of either a girl (XX) or a boy (XY).

a. Given the information above, mark the statement that appropriately describes the likelihood of conception of a girl or a boy:

- □ A girl is more likely to be conceived than a boy.
- □ A boy is more likely to be conceived than a girl.
- □ *Girls and boys are equally likely to be conceived.

b. Respond to the statement "You can be sure to get at least one girl if you give birth to three children."

E09 (Source: EvoVis project)

More sheep than people live in New Zealand. A hundred sheep stand in a pasture with no shelter: 68 with a mutation that is advantageous for their survival and 32 without this mutation. Suddenly, there is a flash of lightning. **Mark which sheep could be hit by the flash:**

- □ A sheep with the advantageous mutation for its survival.
- □ A sheep without the advantageous mutation for its survival.
- □ *A sheep either with or without the advantageous mutation for its survival.

E10 (Source: cf. Fenner, 2013)

In former times, half of the foxes in Northern Europe had white fur, while the other half had brown fur. Today, nearly all foxes have white fur. **How can this change be explained by the theory of evolution?**

- □ *Foxes with lighter fur could hunt prey more easily, produce more offspring, and pass on their genetic basis for fur color to more descendants.
- □ The foxes wanted to improve their adaptation to the surrounding landscape by enhancing their camouflage.
- □ The foxes recognized that they needed white fur for their survival.

E11 (Source: EvoVis project)

In an experiment four populations of white lab mice are observed. Sometimes a mutation occurs that changes their white fur to brown. **Mark which of the statements best describes what you can tell about changes in the populations after <u>one generation</u>:**

- □ The mutation will occur in every population, so brown mice will appear in all four populations.
- □ The mutation will occur and brown mice will appear in two of the four populations.
- □ *It is impossible to tell whether or not the mutation will occur in the populations.
- □ No mutation will appear in any of these populations, because they are lab mice and do not mutate.

E12 (Source: cf. Bowling *et al.*, 2008)

Mutations in DNA occur in the genomes of all organisms, including humans. **Why are mutations most important according to the theory of evolution?**

- □ Mutations allow the production of new genes in individuals.
- □ Mutations allow the production of new enzymes in individuals.
- □ Mutations are sources of new cells for individuals.
- □ *Mutations are sources of genetic variation for future generations.
- □ Mutations allow the production of new chromosomes for future generations.

E13 (Source: EvoVis project)

In a very dry area a sudden violent storm leads to flooding of the whole area. **Mark the statement that best describes which animals and plants survive this catastrophic event according to the theory of evolution:**

- □ Only individuals with potentially advantageous genetic combinations for the new surroundings can survive the catastrophe, all others die.
- □ *Individuals both with and without potentially advantageous genetic combinations may survive the catastrophe.
- □ All individuals will survive, because the flood is only a brief event so it will not affect their survival.

E14 (Source: cf. Klymkowsky *et al.*, 2010)

Why is a catastrophic global event regarded as a random phenomenon?

- □ Because undesirable genes are removed.
- □ Because new genes originate.
- □ *Because only some species survive the event.
- □ Because there are only brief effects, which disappear over time.

E15 (Source: EvoVis project)

Explain the meaning of the statement “Mutations are random”.

E16 (Source: EvoVis project)

The following information is given:

Species	**Bodyweight**	**Generation time***
Mouse	14 g	2 months
Wolf	40 kg	2 years
Viper	200 g	5 years
Elephant	5000 kg	14 years

* The average time between birth and reproductive maturity in a given population or taxon.

Mark which of the four species can adapt most readily through natural selection to sudden, drastic environmental changes:

- □ *Mouse
- □ Wolf
- □ Viper
- □ Elephant

E17 (Source: cf. Campbell *et al.*, 2006)

A large part of variability in the fur coloring and pattern in every generation of wild mustangs is probably due to…

- □ … mutations that occurred in the previous generation.
- □ *… recombination of alleles.
- □ … genetic drift associated with small populations.
- □ … geographical variability within the population.
- □ … environmental influences.

E18 (Source: EvoVis project)

Assume that two identical populations of laboratory mice are placed in two different habitats (G and W). Allele 1 is more advantageous in habitat G than in habitat W, while allele 2 is equally advantageous in both habitats (G and W). **Mark what will happen in your opinion to the frequency of allele 1 <u>after 100 generations</u> in both populations:**

- □ *It will become higher in the population living in habitat G than in the population living in habitat W.
- □ It will become higher in the population living in habitat W than in the population living in habitat G.
- □ It will rise in both the population living in habitat G and the population living in habitat W.

E19 (Source: cf. Green, 1982; EvoVis project)

a. Match each of the four notions with one of the five statements (A-E). Note, you can match statements with more than one notion:

<u>Statements</u>

A: Cannot happen.

B: Cannot happen very often.

C: Happens rather often.

D: Happens almost always.

E: Always happens.

<u>Notions</u>

a. very likely	*D
b. unlikely	*B
c. likely	*C or D
d. not very likely	*B

b. Now, match the three biological examples with one of the five statements (A-E). Again, you can match statements with more than one notion:

<u>Biological examples</u>

The descendants of sexually reproducing organisms are genetically identical to their parents.	*A
A bottleneck reduces the genetic variability of a population.	*C or D
Non-resident species that are introduced into an environment in which the climatic conditions differ from those in their original environment can spread and bring local species close to extinction.	*B

Supplement 2: The Randomness and Probability test in the context of Mathematics (RaProMath)

*Note: * = right answer; contact author for guide of free-response items*

M01 (Source: cf. Garfield, 2003)

Two containers (A and B) are filled with the following numbers of red and blue marbles:

Containers	Red	Blue
A	6	4
B	60	40

Each container is shaken vigorously. **Which container offers the highest chance of pulling out a blue marble?**

- □ Container A.
- □ Container B.
- □ *There are equal chances of getting a blue marble from container A and container B.

M02 (Source: cf. Green, 1982)

In an experiment 12 coins are tossed together in the air and land on a table. It is possible that one of the following results may occur:

Result 1: Two heads and 10 tails

Result 2: Five heads and seven tails

Result 3: Six heads and six tails

Result 4: Seven heads and five tails

On which result do you bet <u>within a single round</u>? Explain your answer:

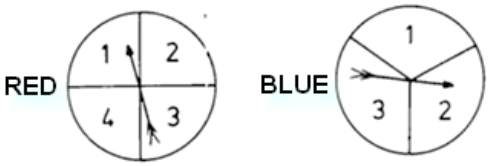
M03 (Source: cf. Green, 1982)

A small, round disc is red on one side and green on the other. The disc is thrown in the air with the red side upwards, turns several times and lands on a table. **Mark the right statement:**

- □ Only the red side will be facing upwards
- □ Only the green side will be facing upwards.
- □ *Either the red or green side will be facing upwards.

M04 (Source: cf. Green, 1982)

In the following diagram you see two wheels of fortune (red and blue) with their arrows at rest. You can spin the arrow of either wheel, and win $50 if it lands on a three.



Which wheel should you choose to maximize your chance to win?

- □ The red wheel.
- □ *The blue wheel.
- □ The chance is equally high with both discs.

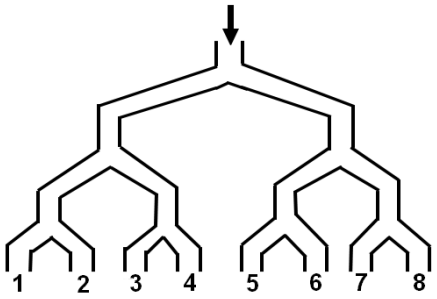
M05 (Source: EvoVis project)

Anna and Moritz are gambling by throwing a dice six times. Anna receives $2 from Moritz if a 5 or 6 comes up, while Anna has to pay Moritz $1 if a 1, 2, 3, or 4 comes up. **Mark if the chance of profit is:**

- □ Higher for Anna than for Moritz.
- □ Higher for Moritz than for Anna.
- □ *Equally high for Anna and Moritz.
- □ Impossible to judge.

M06 (Source: cf. Green, 1982)

A marble is dropped into an apparatus with forked channels, illustrated below.



Mark where the marble will come out:

- □ Channel 1 or 8.
- □ Channel 3, 4, 5 or 6.
- □ Channel 1, 3, 5 or 7.
- □ *Channel 1, 2, 3, 4, 5, 6, 7 or 8.
- □ Channel 1, 2, 7 or 8.

M07 (Source: Garfield, 2003)

When two dice are simultaneously thrown it is possible that one of the following two results occurs:

Result 1: A 5 and a 6 are obtained.

Result 2: A 5 is obtained twice.

Select the response that you agree with the most:

- □ *There is more chance of obtaining result 1.
- □ There is more chance of obtaining result 2.
- □ The chances of obtaining each of these results are equal.

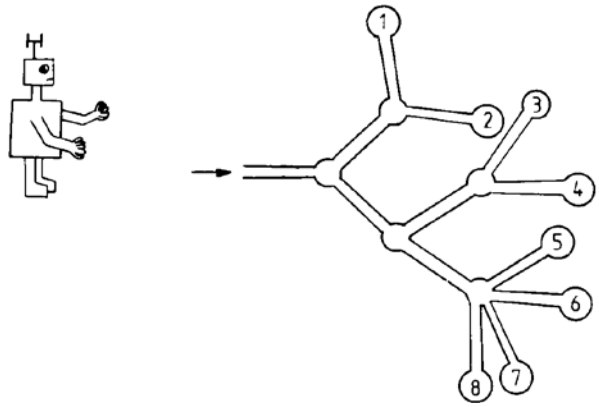
M08 (Source: Green, 1982)

A mathematics class has 13 boys and 16 girls in it. Each pupil's name is written on a slip of paper. All the slips are put in a hat. The teacher picks out one slip without looking. **Thick the correct sentence:**

- □ The name is more likely to be a boy than a girl.
- □ *The name is more likely to be a girl than a boy.
- □ It is just as likely to be a girl as a boy.

M09 (Source: cf. Green, 1982)

A robot is put in a maze and begins to explore it. At every junction the robot must choose a path, and at the end of every path there is a trap (see picture).

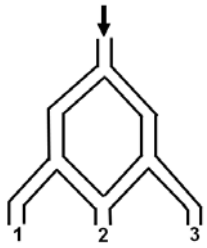


Mark the trap (or traps) where the robot is most likely to be trapped:

- □ *Trap 1 □ *Trap 2 □ Trap 3 □ Trap 4
- □ Trap 4 □ Trap 5 □ Trap 6 □ Trap 8

M10 (Source: cf. Green, 1982)

A marble is dropped into an apparatus with forked channels, illustrated below.



Mark where the marble will come out:

- □ Channel 1.
- □ Channel 2 or 3.
- □ Channel 1 or 3.
- □ *Channel 1, 2 or 3.
- □ Channel 2.
- □ Channel 3.
- □ Channel 1 or 2.

M11 (Source: cf. Garfield, 2003)

Five sides of a faire cube are black and the other is white. The cube is thrown six times and the following results are possible:

Result 1: A black side will come up in five throws and the white side in one throw.

Result 2: A black side will come up in all six throws.

Choose the correct statement:

- □ *Result 1 is more likely than result 2.
- □ Result 2 is more likely than result 1.
- □ Results 1 and 2 are equally likely.

M12 (Source: cf. Jones *et al.*, 1997)

A container is filled with five green, three red and two blue marbles then vigorously shaken. A red marble is blindly pulled out and then put back into the container. The container is shaken again. Then another marble is pulled out. **Choose the correct statement**:

- □ *The marble pulled out is most likely to be green.
- □ The marble pulled out is most likely to be red.
- □ The marble pulled out is most likely to be blue.
- □ The marble pulled out is equally likely to be green, red or blue.

M13 (Source: cf. Garfield, 2003)

If three faire dice are thrown simultaneously, one of the following results may occur:

Result 1: Three 5s may come up

Result 2: Two 5s and a 3 may come up

Result 3: A 5, 3 and 6 may come up

Choose the answer you agree with most strongly:

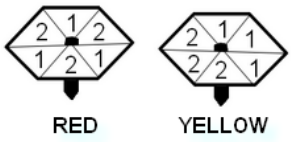
- □ Result 1 has the highest chance.
- □ Result 2 has the highest chance.
- □ *Result 3 has the highest chance.
- □ The chance of all three results is equally high.

M14 (Source: cf. *Jones et al.*, 1997)

A container is filled with five green, three red and two yellow marbles then vigorously shaken. One of the marbles is blindly pulled out and examined. It is green. The marble is put back into the container, which is shaken again then another marble is pulled out. **What is this marble's color? Explain your answer:**

M15 (Source: cf. Green, 1982)

Segments of two symmetrical six-sided spinning tops (one red and one yellow) are marked with the numbers 1 and 2, as illustrated below. You win $50 if one of them lands resting on the side of a segment marked with a 2.



Which spinning top provides the best chance of winning?'

- □ The red one.
- □ The yellow one.
- □ *The chances are equally high with both spinning tops.

M16 (Source: EvoVis project)

If a fair coin is tossed, the likelihood of getting 'tails' (i.e. the reverse side facing up) is ½. In three consecutive throws the result is 'tails'. **Which of the four statements applies for the next throw?**

- □ 'Heads' (the obverse side facing up) is most likely
- □ 'Tails' is most likely.
- □ *'Heads' and 'tails' are equally likely.
- □ More information is needed to answer the question.

M17 (Source: EvoVis project)

When throwing a faire dice a number between 1 and 6 will face upwards. When is the result of the next throw predictable?

- □ After 100 throws.
- □ After 10,000 throws.
- □ *The result is never predictable.
- □ After 500 throws.
- □ After 50,000 throws.

M18 (Source: cf. Green, 1982)

Two containers (A and B) are filled with the following numbers of red and blue marbles:

Containers	Red	Blue
A	12	4
B	20	10

Each container is shaken vigorously. You want to pull out a blue marble. **Which statement is correct?**

- □ There is a higher chance of pulling a blue ball from container A than from container B.
- □ *There is a higher chance of pulling a blue ball from container B than from container A
- □ There are equal chances of pulling a blue ball from container A and container B.

M19 (Source: Garfield, 2003)

Half of all newborns are girls and half are boys. Hospital A records an average of 50 births a day. Hospital B records an average of 10 births a day. **On a particular day, which hospital is more likely to record 80% or more female births?**

- □ Hospital A (with 50 births a day).
- □ *Hospital B (with 10 births a day).
- □ The two hospitals are equally likely to record such an event.

M20 (Source: cf. Herget *et al.*, 2009)

You have five white, five black and five grey marbles. **Describe how a container has to be filled so that the likelihood of pulling out a white marble is 3/10:**

M21 (Source: cf. Weber and Mathea, 2008)

In a roulette wheel there are 17 segments with numbers from 1 to 17. You win if you spin and the ball lands in a segment with an even number, and lose otherwise. **Mark the correct statement:**

- □ *You are more likely to lose than to win.
- □ You are more likely to win than to lose.
- □ Winning and losing are equally likely.

M22 (Source: cf. Jones *et al.*, 1997)

A container is filled with five green, three red and two yellow marbles and vigorously shaken. One of the marbles is blindly pulled out and examined. It is red. The marble <u>is not put back into</u> the container. The container is shaken again and another marble is pulled out. **Mark the correct statement:**

- □ *The marble pulled out is most likely to be green.
- □ The marble pulled out is most likely to be red.
- □ The marble pulled out is most likely to be yellow.
- □ The marble pulled out is equally likely to be green, red or yellow.

M23 (Source: EvoVis project)

Many adults study lottery statistics every week to forecast the next round's winning numbers. The following pictures show lottery coupons with three sets of forecasts.

1	2	3	4	5	~~6~~	7
8	~~9~~	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	~~25~~	26	27	28
~~29~~	30	31	32	33	~~34~~	35
36	37	38	~~39~~	40	41	42
43	44	45	46	47	48	49

Lottery coupon A

1	2	3	4	5	6	7
~~8~~	9	10	11	12	13	14
15	16	17	~~18~~	19	20	21
22	23	24	25	~~26~~	~~27~~	~~28~~
29	30	31	32	33	34	35
36	37	38	39	40	41	42
43	44	45	46	47	48	~~49~~

Lottery coupon B

1	2	3	4	5	~~6~~	~~7~~
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	~~28~~
~~29~~	30	31	32	33	~~34~~	35
36	37	38	39	40	41	42
~~43~~	44	45	46	47	48	49

Lottery coupon C

Which of these lottery coupons could win?

□ Lottery coupon A □ Lottery coupon B □ Lottery coupon C

□ Lottery coupon A and C □ *Lottery coupon A, B, or C

M24 (Source: cf. Garfield, 2003)

When you throw a coin five times possible sequences of 'heads' (H, obverse side facing up) and 'tails' (T, reverse side facing up) include the following:

Sequence 1: H H H T T

Sequence 2: T H H T H

Sequence 3: H T H H H

Sequence 4: H T H T H

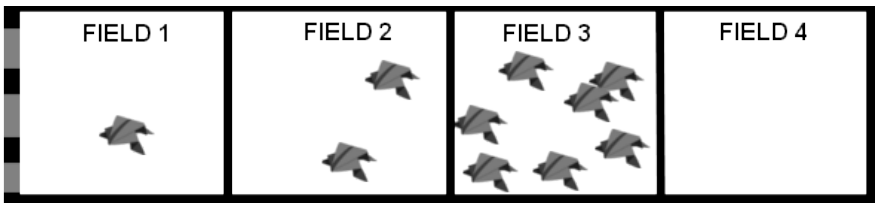
Which of these sequences is most likely?

□ Sequence 1 □ Sequence 2 □ Sequence 3

□ Sequence 4 □ *Sequence 1, 2, 3 or 4

M25 (Source: cf. Eichler and Vogel, 2012)

Class 4B records the lengths of 10 paper frogs' jumps and which of four zones they land in, as illustrated below.



Where could an eleventh frog land?

□ Field 1 □ Field 2 □ Field 3 □ Field 4 □ *Field 1, 2, 3 or 4

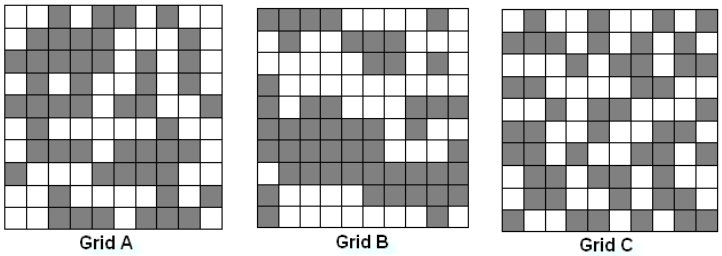
M26 (Source: EvoVis project)

In an experiment, the life span of 10,000 light bulbs was examined; 80% lasted longer than 100 hours, while 5% stopped working within 20.4 hours. **Mark how long a freshly installed light bulb will probably last:**

- □ More than 100 hours.
- □ At most 20.4 hours.
- □ Between 20.4 and 100 hours.
- □ *The life span of the light bulb cannot be predicted.

M27 (Source: cf. Falk and Konold, 1997)

The following diagram shows three 10x10 grids, each with 50 white and 50 grey squares.

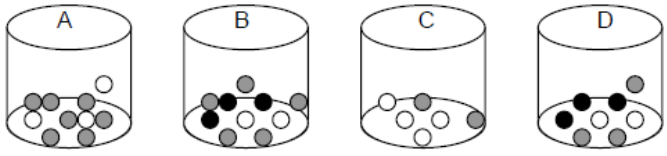


Mark which of the grids may have originated from random placement of white and grey squares:

□ Grid A □ Grid B □ Grid C □ Grid A and C □ *Grid A, B and C

M28 (Source: cf. Herget *et al.*, 2009)

Four containers are placed on a table, each containing different numbers of uniformly sized marbles, with varying proportions of colors, as shown in the following picture. If you pull out a white marble, you will win.



Which container provides the best chance of winning?

- □ Container A.
- □ Container B.
- □ *Container C.
- □ Container D.

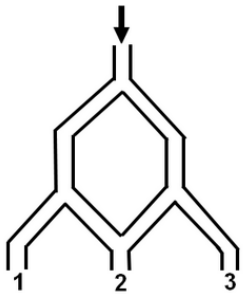
M29 (Source: EvoVis project)

A coin is tossed five times and every time it lands with the head facing upwards. **Mark the correct sentence:**

- □ Next time the coin will land with the head facing upwards.
- □ Next time the coin will land with the tail (reverse side) facing upwards.
- □ *Next time the coin will land with either the head or tail facing upward.

M30 (Source: cf. Green, 1982)

Numerous marbles are dropped into an apparatus with forked channels, illustrated below.



With which statement do you agree most strongly?

- □ The same numbers of marbles will come out from channels 1, 2 and 3.
- □ *Twice as many marbles will come out from channel 2 than from channel 1 or 3.
- □ Half of the marbles will come out from channel 1, while the other half will come out from channel 3.

M31 (Source: cf. Green, 1982)

To find out whether a thumb tack (drawing pin) more often lands on its back  or side  , a seminar leader empties a pack of 100 on a table. 68 fall on their back, and 32 on their side. The experiment is repeated another three times by the seminar leader. The results are:

1. Back, 64; side, 36.
2. Back, 70; side, 30.
3. Back, 66; side, 34.

If the seminar leader carried out the experiment once more, the following results would be possible:

Result 1. Back, 36; side, 64.
Result 2. Back, 63; side, 37.
Result 3. Back, 50; side, 50.
Result 4. Back, 85; side, 16.

Which of the results is most likely?

□ Result 1 □ *Result 2 □ Result 3 □ Result 4 □ Result 1, 2, 3 and 4

M32 (Source: cf. Weber and Mathea, 2008)

Three hunters (Adam, Ben and Chris) shoot at a duck simultaneously. **Decide for each of the following cases whether or not the duck has a chance to survive:**

	Duck has a chance to survive	Duck has no chance to survive
Adam, Ben and Chris have hit rates of 30%, 50% and 20%, respectively.	□*	□
Adam, Ben and Chris have hit rates of 40%, 50% and 30%, respectively.	□*	□
All three hunters have a hit rate of 20%	□*	□

M33 (Source: cf. Green, 1982)

A container is filled with unknown numbers of green, red and yellow marbles. You blindly pull out a marble and record the color. Then the marble is put back into the container and the container is vigorously shaken. You repeat the process four times, and every time the marble is red. **If another marble is taken what color will it be?**

□ Red. □ Green. □ Yellow.

□ *Red, green or yellow. □ Green or yellow.

Supplement 3. Academic self-concept items (Adapted from Braun *et al.*, 2008)

1. I can see the connections and inconsistencies in …
2. I can give an overview of the topic of …
3. I can clearly present complicated issues of …
4. Now I see myself in the position to process a typical question of …
5. I can work out the contradictions and similarities of learning content (e.g., contradictions between different models or methods) of the subject area of …

Table S1. Compulsory modules (genetics, evolution, ecology, molecular biology, and cell biology) of six universities that sets of our participants attended, with brief synopses of subject matter

University	Students	Bachelor's program 1st year	2nd year	3rd year
Europa-Universität Flensburg	preservice biology teachers	-------	***Evolution and Functional Morphology (3 or 5. Sem.)*** (1) Evolutionary theories and mechanisms of evolution, (2) phylogeny of life including theories about genesis of life, and (3) biomechanical knowledge about structure and function of selected bodies of vertebrates. *Ecology (4. Sem.)* (1) Basics of ecology	***Evolution and Functional Morphology (3. or 5. Sem.)*** content see left
Technical University of Munich	biology majors	*Genetics (2. Sem.)* (1) Structure of genes and genomes, (2) gene expression (transcription and translation), (3) passing on of genetic information, (4) genetic recombination in eukaryotes and bacteria, (5) recombinant DNA and genetic technology, (6) genomic, (7) mutation and genetic analyses of complex biological processes, and (8) regulation of gene expression. *Cell Biology (2. Sem.)* no content required	*Ecology (4. Sem.)* (1) Abiotic factors, (2) population and sexuality, (3) communication systems, (4) population in time and space, (5) population dynamics, (6) growth models, (7) intra and inter specific concurrence, (8) zoogeography, (9) ecosystems of the world, (10), global change, and (11) invasive species.	***Evolution, Biodiversity and Biogeography (6. Sem.)*** (1) Basics of evolution, (2) population and speciation, (3) evolution of plants, (4) evolution of animals, (5) biodiversity, extinction and climate change, (6) genetic diversity, (7) sexual selection, (8) basics of biogeography, (9) plant geography, (10) symbiosis, and (11) animal geography.
Universität Hamburg	biology majors	*Genetics and Molecular Biology (2. Sem.)* (1) Classical and formal genetics (Mendelian inheritance, population genetics), (2) cytogenetics, (3) human genetics, (4) structure and function of nucleic acid (replication, transcription, translation, mutation, recombination), (5) gene regulation, (6) developmental genetics, and (7) methods of molecular biology and genetic technology.	*Genetics and Molecular Biology (3. Sem.)* content see left *Ecology (4. Sem.)* (1) Function, principles and methods of ecology, (2) recording and investigation of species in their environment, and (3) abiotical factors.	-------

(Continued)

Table S1. Continued

University	Students	Bachelor's program 1st year	2nd year	3rd year
Universität Hildesheim	biology majors / preservice biology teachers	-------	*Students have to choose two of three compulsory subjects; two of them are Ecology and Evolution/Behavioral ecology (4.-6. Sem.)* *Ecology* (1) Autecology, (2) population ecology and synecology, (3) aspects of material and energy flows in ecosystems, (4) selected ecosystems, (5) methods of ecological recording and investigation. ***Evolution and Behavioral Ecology*** (1) Central theories, concepts and methods of ethology, (2) methods and analyses of behavioral observations, (3) central theories and concepts of evolutionary biology, and (4) evolution of selected organisms.	
Carl von Ossietzky Universität Oldenburg	biology majors	*Microbiology and Cell Biology (2. Sem.)* (1) Molecules of life, (2) energy and enzymes, (3) central metabolism, (4) breathing, (5) photosynthesis, (6) anaerobic metabolism, (7) chemolithotrophy, (8) prokaryotic and eukaryotic cell structures, (9) microbial diversity, (10) importance of microorganisms for human beings, plants, animals, biotechnology and earth system, (11) signal transmission and communication between cells, (12) meiosis, mitosis, Mendelian inheritance, and chromosomal and molecular basis of inheritance, (13) replication, transcription, translation, (14) genomic organization, and (15) mutation and repair.	*Genetics (3. Sem.)* (1) General and molecular genetics, (2) mechanisms of mutation, recombination, DNA repair, and regulation of transcription, (3) quantitative experiments with prokaryotes and eukaryotes, and (4) human genome project and personalized medicine.	-------
	preservice biology teachers	*Microbiology and Cell Biology (2. Sem.)* content see above	-------	-------

(Continued)

Table S1. Continued

University	Students	Bachelor's program 1st year	2nd year	3rd year
Christian-Albrechts-Universität zu Kiel	biology majors	*Basics of Zoology and Cell Biology (1. Sem.)* (1) Blueprint of representatives of the important large animal groups, (2) functional units of animal organism, (3) basic knowledge of construction and function of the animal cell, and (4) evolution of animal body structures.	*Ecology (3. Sem.)* (1) Influence of environmental factors: radiation, temperature, humidity/water availability, (2) energy balance of animals and plants, (3) resistance and acclimatization, (4) host parasite and predator-prey interactions, competition, and gender conflicts, and (5) mechanisms of evolution in populations *Cell Biology Animal (3. Sem.)* (1) Simple cell biology and molecular biology techniques, (2) experimental handling and phenomenological observation of different cell types and invertebrate organisms under different experimental conditions and under adequate control, and (3) technics: light microscopy, fluorescence microscopy, polymerase chain reaction. *Cell Biology Plant (4. Sem.)* (1) Fluorescence- and electron microscopy of plant cell, (2) protein biochemical methods: electrophoresis, density gradient centrifugation, and (3) in situ hybridization *Genetics and Microbiology (4. Sem.)* (1) Classical genetics, (2) cytogenetics, (3) human genetics, (4) molecular genetics (DNA, RNA, genomes, replication, transcription, translation, gene regulation, epigenetics), (5) recombination, (6) mutation, (7) gene technology, (8) development, (9) basics of microbiological methods (microscopy, enrichment, cultivation), (10) morphological and physiological differentiation of microorganisms (Gram-staining, antibiotics), and (11) genetic exchange between microorganisms.	
	preservice biology teachers	*Basics of Zoology and Cell Biology (1. Sem.)* content see above	*Ecology (3. Sem.)* content see above *Cell Biology Animal (4. Sem. or Plants 5. Sem.)* content see above	*Cell Biology Plant (5. Sem. or Animals 4. Sem.)* content see above *Genetics and Microbiology (6. Sem.)* content see above

Table S2. Item parameter estimates for RaProEvo test

Item	Discrimination (a)	Difficulty (b_1)
ovE01	0.54	0.523
ovE02	0.21	-0.567
ovE03	0.40	-0.727
ovE07	0.23	-1.366
ovE11	0.38	-1.118
ovE12	0.42	-0.420
ovE15	0.51	2.012
ovE17	0.40	0.003
adE04	0.19	-0.643
adE09	0.19	-1.366
rpE07	0.23	-1.366
rpE13	0.38	0.952
rpE16	0.35	-2.128
nsE06	0.35	-0.049
nsE10	0.33	-1.236
nsE16	0.35	-2.128
nsE18	0.33	0.208
peE08a	0.44	-0.641
peE08b	0.44	-0.223
peE19a	0.35	1.502
peE19b	0.34	3.291

Note. The first two letters stand for: *ov* origin of variation, *ad* accidental death (single events), *rp* random phenomena, *ns* process of natural selection, and *ps* probability of events. *E* represents the content of evolutionary theory, while *01* to *19* indicates the item number in the RaProEvo test and the last letter stands for *a* item 1 and *b* item 2 within a similar item task.

Table S3. Item parameter estimates for RaProMath test

Item	Discrimination (a)	Difficulty (b_1)
seM02	0.37	2.378
seM03	0.17	-2.923
seM06	0.35	-1.447
seM10	0.21	1.322
seM14	0.21	2.600
seM25	0.38	0.988
seM29	0.31	-1.954
seM33	0.37	-0.808
rpM17	0.11	-1.757
rpM23	0.42	-1.442
rpM26	0.41	1.191
rpM27	0.29	-0.310
prM01	0.41	-0.988
prM04	0.17	-2.922
prM08	0.23	-1.593
prM12	0.38	-0.648
prM15	0.44	-0.725
prM16	0.26	-1.087
prM18	0.31	-0.504
prM20	0.51	0.987
prM21	0.33	-0.806
prM22	0.40	-1.311
prM28	0.26	-2.908
peM05	0.34	1.741
peM07	0.25	3.105
peM09	0.29	2.102
peM11	0.20	0.159
peM13	0.22	2.717
peM24	0.40	-0.436
peM32	0.61	0.115
srM19	0.15	2.678
srM30	0.37	-0.505
srM31	0.28	0.737

Note. The first two letters stand for: *se* single events, *rp* random phenomena, *pr* probability as ratio, *pe* probability of events, and *sr* sample reasoning. *M* represents the content of mathematics, while *01* to *40* indicates the original item number.

References

Bowling BV, Acra EE, Wang L, Myers MF, Dean GE, Markle GC, Moskalik CL, Huether CA (2008). Development and evaluation of a genetics literacy assessment instrument for undergraduates. Genetics *178*, 15-22.

Braun E, Gusy B, Leidner B, Hannover B (2008). Das Berliner Evaluationsinstrument für selbsteingeschätzte, studentische Kompetenzen (BEvaKomp) [The Berlin Evaluationsinstrument for selfapproximated, student competence]. Diagnostica *54*, 30-42.

Campbell NA, Reece JB (2011). Campbell Biologie - Gymnasiale Oberstufe, Übungsbuch [Campbell biology – Secondary level, workbook]. München, Germany: Pearson Schule.

Campbell NA, Reece JB, Markl J (2006). Biologie [Biology]. München, Germany: Pearson Studium.

Eichler A, Vogel M (2012). Basic modelling of uncertainty: Young students' mental models. ZDM Mathmatics Education *44*, 841-854.

Falk R, Konold C (1997). Making sense of randomness: Implicit encoding as a basis for judgment. Psychol Rev *104*, 301-318.

Fenner A (2013). Schülervorstellungen zur Evolutionstheorie: Konzeption und Evaluation von Unterricht zur Anpassung durch Selektion [Students conceptions about the theory of evolution: Design and evaluation of a teaching sequence about adaption through selection] (Doctoral dissertation, Institute of Biology Didactics). Retrieved from http://geb.uni-giessen.de/geb/volltexte/2013/9250/ (accessed 01 March 2017)

Garfield JB (2003). Assessing statistical reasoning. Statistics Education Research Journal *2*, 22-38.

Green D (1982). Probability concepts in 11-16 year old pupils. Report of research sponsored by the Social Science Research Council. Loughborough, England: CAMET, University of Technology.

Herget W, Kösters E, Merziger P (2009). Stochastisches Denken – Lehren und Lernen [Stochastic thinking – Teaching and learning]. Retrieved from http://disk.mathematik.uni-halle.de/lehrerseite/Stochastik_Reader_mit_Aufgaben_und_Loesungen_0909.pdf (accessed 01 March 2017)

Jones GA, Langrall CW, Thornton CA, Mogill AT (1997). A framework for assessing and nurturing young children's thinking in probability. Educational Studies in Mathematics *32*, 101-125.

Klymkowsky MW, Underwood SM, Garvin-Doxas RK (2010). Biological Concepts Instrument (BCI): A diagnostic tool for revealing student thinking. arXiv preprint arXiv:1012.4501.

Robson RL, Burns S (2011). Gain in student understanding of the role of random variation in evolution following teaching intervention based on Luria-Delbruck experiment. J Microbiol Biol Educ *12*, 3-7.

Weber F, Mathea B (2008). SINUS-TRANSFER: Zufällige Erscheinungen - Hinweise zur Umsetzung der Leitidee Daten und Zufall im rheinland-pfälzischen Rahmenlehrplan Mathematik [SINUS-TRANSFER: Random phenomena – Tips for implementation of the central idea data and coincidence of the curriculum mathematics in Rhineland-Palatinate]. Mainz, Germany: Ministerium für Bildung, Wissenschaft, Jugend und Kultur.

Module manuals:

Carl von Ossietzky Universität Oldenburg (2016). Veranstaltungsverzeichnis - Campusmanagementsystem Stud.IP [online lecture course schedule – campus management system Stud.IP]. Retrieved from https://elearning.uni-oldenburg.de/plugins.php/veranstaltungsverzeichnis/verzeichnis/module (accessed 01 March 2017)

Christian-Albrechts-Universität zu Kiel (2016). Studieninformationsblatt Biologie [Study information sheet of biology]. Retrieved from https://www.studium.uni-kiel.de/de/studienangebot/studienfaecher/biologie-ba (accessed 01 March 2017)

Europa-Universität Flensburg (2015). Modulkatalog Biologie, B.A., Bildungswissenschaften [Module manual biology, bachelor of arts, educational sciences] Retrieved from https://www.uni-flensburg.de/fileadmin/content/portale/studium_und_lehre/dokumente/po-studiengaenge/bachelor-of-arts/bildungswissenschaften/2015/modulkataloge/mk-babw-po2015-biologie.pdf (accessed 01 March 2017)

Technical University of Munich (2013). Modulhandbuch [Module manual]. Retrieved from http://sf-

biowiss.wzw.tum.de/fileadmin/Dokumente/BIO/ModulhandbuchMSc/Modulhandbuch_Bio_MSc_FPSO2007_13.11.13.pdf (accessed 01 March 2017)

Universität Hamburg (2016). Modulhandbuch Bachelorstudiengang Biologie [module manual of bachelor's program biology]. Retrieved from https://www.biologie.uni-hamburg.de/studium/bachelor/bachelor-biologie.html (accessed 01 March 2017)

Universität Hildesheim (2014). Studien- und Prüfungsornungen [Study and examination regulations]. Retrieved from https://www.uni-hildesheim.de/studium/studienangebot/studienangebot/ordnungen2faecherbachelor/ (accessed 01 March 2017)