4.1 Case study 1 (CS1 Poland)

Concept focus	Construction of legorgs and measurement of "fitness" as a model for natural selection
Inquiry skills	Planning investigations Forming coherent arguments
Scientific reasoning and literacy	Scientific reasoning (data entry, drawing conclusions) Scientific literacy (understand how the model legorgs relate to evolution; analysis of data and presentation of scientific results)
Assessment methods	Classroom dialogue Teacher observation Worksheets Other assessment items (pre/post test)
Student group	**Grade:** lower second level **Age:** 15 years **Group composition:** mixed ability and gender; 29 students, groups of 4-6 students **Prior experience with inquiry:** Students had no prior experience; the teacher has rarely used IBSE

In this implementation at lower second level, a creative solution was found to use of English resources – a class was dedicated to translation, which also allowed for introduction of the topic. *Scientific literacy* was the key skill assessed, looking at students' analysis of data, numerical and statistical interpretation and ability to transfer the model system (legorgs) to real-world understanding of natural selection. Assessment methods include teacher observation in-class and a pre/post test.

(i) How was the learning sequence adapted?

Implementation of the **Natural selection** inquiry and assessment unit required four successive lessons (45 minutes each). The first lesson was devoted to adapting the original method to the school's course on evolution. After a short introduction to the unit topics by the teacher (natural selection and Darwinian theory of evolution), the class was divided randomly into groups of 4-6 students. The groups were then preliminarily interviewed (by means of a written test) to verify student's knowledge on such conceptions as: natural selection, genetic drift and fitness. Afterwards, the students themselves compiled an experiment project based on the training materials provided online (videos on http://www.jcd.biology.sdu.dk). However, this presented an additional issue, as all of the materials were in English. In this lesson, groups of students translated the experiment instructions based on the original instruction films from English to Polish. This was an innovative approach, stimulating a task-oriented integration of all members of the groups; at the same time it was a kind of interdisciplinary education, as the considerable part of the biology lesson has been conducted in a foreign language.

During the following lessons the experiments were carried out according to the plans prepared. The students modelled the natural selection of the gene set using "organisms" built of Lego® blocks. The last lesson was assigned for collection, analysis and evaluation of the results obtained by particular groups. Due to the limited time available for implementation of this unit, the experiment was shortened to one or, rarely, two generations of legorgs. Due to the limited availability of Lego® blocks (they are not at disposal in the school's equipment store and the students were older than the usual age for block playing) the number of individuals per population was limited to five (some groups constructed only four or even three legorgs). At the end of the inquiry activity, the teacher carried out a post-implementation test to evaluate students' understanding of natural selection.

(ii) Which skills were to be assessed?

The teacher identified the inquiry skills of *planning investigations* and carrying out an investigation as key skills for assessment. In addition, *scientific reasoning* (data collection) and *scientific literacy* (analysis of data, numerical and statistical interpretation, transfer of model system (legorgs) to real-world understanding of natural selection) were assessed, with considerable weighting placed on the students' *scientific literacy* (50% of marks for this unit were for this skill).

(iii) Criteria for judging assessment data

Planning investigations

The teacher assessed students' ability to adapt the method for the use of legorgs as a model of natural selection using a three-rubric (Table 1), for which a six points level was defined, as is usually used in the Polish education system.

Table 1: Teacher rubric for assessment of planning investigations

Inquiry skill	2 points level	4 points level	6 points level
Adapting the methodology	Student can present the consecutive steps of the natural selection simulation, but without details	Student can create an action plan of the natural selection simulation with legorgs, with some guidance from the teacher	Student can elaborate an instruction for the experiment based on the English language instruction films, with a properly detailed description of the consecutive phases, without help from others

Carrying out the experiment (scientific reasoning and scientific literacy)

There were two aspects identified for assessment as part of the overall skill of carrying out an investigation, namely *scientific reasoning* and *scientific literacy*.

To assess students' *scientific reasoning* capabilities the teacher looked for adequate data collection and precise grouping of data. Students' performance in this area was evaluated using a three-level rubric, as shown in Table 2.

Table 2: Teacher rubric for assessment of carrying out an investigation (scientific reasoning)

Inquiry skill	2 points level	4 points level	6 points level
Carrying out an investigation	Group performs measurements, but not always consistently	Group performs measurements using the same methods sensibly and consistently throughout the experiment.	Group performs measurements consistently throughout the experiment and can discuss the degree of their reliability and precision.

Scientific literacy was evaluated by reviewing how students analysed their data, in particular through use of numerical and statistical methods to obtain well-documented results. The teacher used an observation sheet for evaluation of students' ability to analyse their data (Table 3).

Table 3: Observation sheet for assessment of students' skill in analysing data

Students' actions	Yes	No	Points
1. Students discuss the experimental layout and data collection method.	X		1
2. The leader forces his/her solutions upon other group members.		X	1
3. Students collect data systematically.	X		1
4. The first generation table (illustrating legorgs gene configuration and their fitness) is laid out properly.	X		1
5. Students fill in adequately the data into the first generation table.	X		2
6. The first generation first gene pool table is laid out properly.	X		1
7. Students fill in adequately the data into the first generation first gene pool table.	X		2
8. The first generation 2nd to 5th gene pool tables are laid out properly.	X		2
9. Students fill in adequately the data into the first generation 2nd to 5th gene pool tables.	X		2
10. Students collect and analyse data for following generations analogically to the first one.	X		*
11. A graphical representation of results is created.	X		2
** up to 5 bonus points to be earned for active students for this task*	**Total**		**15 pts.**

Forming coherent arguments (making conclusions based on scientific evidence)

Based on the experiment carried out, the students should conclude that directional (various types of selection) and random (as genetic drift) processes acting on casual phenotypic variability (conditioned by the genetic one) result in changes in allele frequency in populations, and thus in micro-evolutional changes.

The teacher assigned a total of three points for a correctly formulated conclusion, which considered the dependence between natural selection, genetic drift and evolution. For an incomplete conclusion – either considering only the random processes (genetic drift) or only natural selection or identifying the correlation between the results obtained and real evolutionary processes – the teacher awarded one point per feature mentioned.

(iv) Evidence collected

Teacher opinion

1. Physical simulation of the adaptation as a result of the natural selection, based on legorg "evolution" is a very attractive experience, but not adjusted to the Polish school conditions.
2. Several lesson units must be devoted to carrying out the task, so it seems it is most reasonable to be realised during a block of lessons, optional workshops, scientific sessions or scientific camps. Week-long breaks between the lessons (imposed by the school timetable) put the students out of rhythm, allowed them to lose concentration, made the task boring and generally were disadvantageous in terms of the inquiry.
3. The unit is not easily realised in lower second level (*gymnasium*), due to poorer conceptual background knowledge and mathematical skills of the students than in upper second level school (*lycees*). As a result, the students are less likely to draw the correct conclusions from the experiment.
4. At the beginning, the experiment gained considerable interest from the students, but as the inquiry progressed, only a few of the most success-oriented students remained engaged while

their colleagues started to build other constructions of Lego® blocks. Tiresome mathematical calculations added to this effect.

5. It seems that it is reasonable to introduce the experiment in higher secondary school, to interest the students, but the complete, complex version of the task will not be feasible given the current Polish school reality.

The maximum number of points to be earned was 30 (*planning investigations*: 6, carrying out the investigation – *scientific reasoning*: 6, carrying out the investigation – *scientific literacy*: 15 and *forming coherent arguments*: 3). The overall grade for each group in each skill was assigned a mark, according to the following mark levels: 0-8 (unsatisfactory), 9-14 (mediocre), 15-22 (satisfactory), 23-26 (good), 27-30 (very good), as summarised in Table 4. In reality, although the skills were evaluated in four discrete areas, each student was given a single final mark, being more or less a mean of the individual skill marks (8 groups were awarded with "good" and 3 groups with "satisfactory" mark). These final marks, however, were lower than the student's expectations.

Table 4: Results of assessment for all groups

Assessed skill Mark	a) Planning an Investigation	b) Carrying out an experiment – scientific reasoning	c) Carrying out an experiment – scientific literacy	d) Forming coherent arguments (drawing conclusions)
Very good	11	0	2	0
Good	0	11	4	0
Satisfactory	0	0	4	1
Mediocre	0	0	1	1
Unsatisfactory	0	0	0	9
Mean	**5.0 (very good)**	**4.0 (good)**	**3.6 (satisfactory)**	**1.3 (unsatisfactory)**

Sample student artefacts

Some examples of student responses to demonstrate their comprehension of the topic under investigation are provided. The teacher evaluation of the responses is also noted.

Example 1: Group I

Natural selection – a natural process, picking out positive characteristics, promoting survival in the changing environment, with concurrent exclusion of not fit individuals.
Fitness - change of the organism's features by influence of external factors, aiming at survivability increase.
Genetic drift – limiting of the genetic variability as a result of reduction of the fertile individuals, because of this, the risk of falling ill with genetic diseases rises, conditioned by the recessive genes and inheritance of the genetic diseases.

Teacher evaluation: ***The students explain the notions correctly.***

Example 2: Group II

Natural selection – preference of characteristics that are demanded by the environment
Fitness – change of alleles (A and a) that condition e.g. colour because of…
Genetic drift – number of various genotypes, if it is too few

Teacher evaluation: ***The students possess the elementary knowledge on the notions from the evolutionism domain, but define some of them in an enigmatic way.***

Example 3: Group III

Natural selection = natural choice
Fitness – adaptation of a given organism to the living conditions in particular environment
Genetic drift – process, that consists in random frequency of occurrence of a given allele in a population, that is not a result of mutation, migration nor natural selection.

Teacher evaluation: ***The students explain the notions correctly, however in the case of the natural selection only a synonym was used (no explanation). The students represent a basic level of knowledge on the processes involved.***

Example 4: Group IV

Natural selection - or "natural choice", it is a process of evolution of the organisms; it consists in the increase of the level of adaptation to the changing environment conditions. E.g. the greater quantity of offspring may survive, heritability of the characters, genetic variability – who will adapt that will survive.
Fitness – resultant of lifespan to the number of offspring.
Genetic drift – random change in the alleles frequency in genes, it happens in small populations in a short time, is independent of the natural selection, e.g. a deserted island colonizing, diminishing population size as a result of a cataclysm.

Teacher evaluation: ***The students explain the notions correctly.***

Example 4: Group IV

Natural selection - evolution mechanism that facilitates adaptation to a change in environmental conditions.
Fitness – changes of a given organism caused by external factors, e.g. rapid increase of pollution.
Genetic drift – dependence of a population of given species from the environmental conditions.

Teacher evaluation: ***The students explain the notions correctly, however in respect to the genetic drift the definition is incomplete.***

After the inquiry activity was completed, the teacher set a post-implementation evaluation. This was a written test, which consisted of seven multiple-choice questions, for which students were asked to choose just one answer (Figure 1). A summary of the results obtained by five groups is shown in Table 5.

Table 5: Results of knowledge increase in the conceptual comprehension domain

Question:	1	2	3	4	5	6	7	Overall mark (%)
Group I	0	1	0	0	0	0	0	1 (14%)
Group II	0	1	0	0	0	1	0	2 (29%)
Group III	0	1	1	1	1	0	0	4 (57%)
Group IV	1	1	1	1	0	0	0	4 (57%)
Group V	0	1	1	0	1	0	1	4 (57%)

Lego experiments, evaluation
Please check only one box in each question

1) A population can adapt to environmental changes in few generations by
- ☐ mutations
- ☐ exploiting the genetic variation in the population
- ☐ interspecific exchange of genetic material
- ☐ genetic drift
- ☐ migration

2) Natural selection is
- ☐ the description of the history of life
- ☐ a mechanism that produces adaptation
- ☐ domestication of wild-type plants and animals
- ☐ the theory that organisms adapt as needed

3) Natural selection can result in
- ☐ perfect individuals
- ☐ optimally adapted individuals
- ☐ sufficiently adapted individuals
- ☐ individuals with large genetic variation

4) By artificial selection the population is stripped of
- ☐ all non-preferred alleles after many generations
- ☐ all non-preferred alleles after few generations
- ☐ most non-preferred alleles after some generations
- ☐ 75% of the non-preferred alleles per generation
- ☐ 50% of the non-preferred alleles per generation
- ☐ 25% of the non-preferred alleles per generation

5) The *fastest* evolutionary adaptation to sudden environmental changes happen in a
- ☐ very large population
- ☐ small population
- ☐ population without sexual reproduction
- ☐ population with migration

6) The *highest* probability of loss of specific alleles is in a
- ☐ very large population
- ☐ small population
- ☐ population without sexual reproduction
- ☐ population with migration

7) In the theory of evolution, fitness is a measure of...
- ☐ the physiological state of an individual
- ☐ the genetic variation of an individual
- ☐ the probability that an individual transfers genes to the next generation
- ☐ the proportion of recessive lethal genes in a population
- ☐ the risk of genetic drift in a population

Figure 1: Post-implementation assessment written test

Sample student artefacts – documentation of activity (Group II)

During this activity, students generate a large volume of data. Shown here is a sample of the results obtained by one groups. They prepared two generation of legorgs, with 5 individuals in the first

generation and 5 in the second generation. Included with the data are images of one of the legorgs (Figure 2) and of the measurement of fitness for each of the legorgs (Figure 3).

Generation 1: First generation table

legorg no.	Gene 1	Gene 2	Gene 3	Gene 4	Gene 5	Length [mm]
1	red	yellow	white	blue	green*	306
2	red	blue	green	yellow	white	156
3	yellow	green	red	white	blue	164
4	yellow	blue	red	white	green	110
5	yellow	blue	red	white	green	235
					Total length:	971
					Mean length:	194.2

**- green colour replaces black (because of lack of black blocks)*

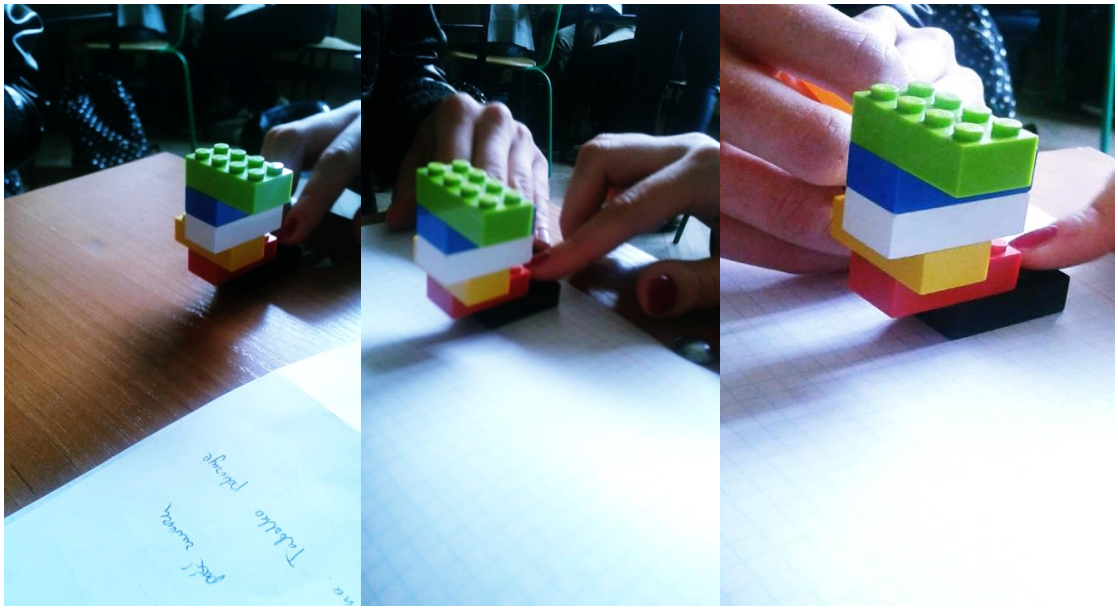

Figure 2: Assembly of first generation legorg 1

Generation 1: Gene pool table for gene 1

Legorg no.	length	yellow	red	green	blue	white
1	306		306			
2	156		156			
3	164	164				
4	110	110				
5	235	235				
total	971	509	462			
Relative length	-	52	48			

Generation 1: Gene pool table for gene 2

Legorg no.	length	yellow	red	green	blue	white
1	306	306				
2	156				156	
3	164			164		
4	110				110	
5	235				235	
total	971	306		164	501	
Relative length	-	32		17	51	

Generation 1: Gene pool table for gene 3

Legorg no.	length	yellow	red	green	blue	white
1	306					306
2	156			156		
3	164		164			
4	110		110			
5	235		235			
total	971		509	156		306
Relative length	-		52	16		32

Generation 1: Gene pool table for gene 4

Legorg no.	length	yellow	red	green	blue	white
1	306				306	
2	156	156				
3	164					164
4	110					110
5	235					235
total	971	156			306	509
Relative length	-	16			32	52

Generation 1: Gene pool table for gene 5

Legorg no.	distance	yellow	red	green	blue	white
1	306			306		
2	156					156
3	164				164	
4	110			110		
5	235			235		
total	971			651	164	156
Relative length	-			67	17	16

Figure 3: Measuring fitness (length) for each legorg

Generation 2: Second generation table

legorg no.	Gene 1	Gene 2	Gene 3	Gene 4	Gene 5	Length [mm]
1	red	yellow	red	yellow	blue	265
2	red	yellow	blue	green	yellow	160
3	red	green	yellow	blue	red	210
4	red	yellow	red	blue	red	267
5	green	yellow	blue	red	blue	193
				Total length:		1094
				Mean length:		218.8

Generation 2: Gene pool table for gene 1

Legorg no.	length	yellow	red	green	blue	white
1	265		264			
2	160		160			
3	210		210			
4	267		267			
5	193			193		
total	1094		901	193		
Relative length			82 %	18 %		

Generation 2: Gene pool table for gene 2

Legorg no.	length	yellow	red	green	blue	white
1	264	264				
2	160	160				
3	210			210		
4	267	267				
5	193	193				
total	1094	884		210		
Relative length		81 %		19 %		

Generation 2: Gene pool table for gene 3

Legorg no.	length	yellow	red	green	blue	white
1	264		264			
2	160				160	
3	210	210				
4	267		267			
5	193				193	
total	1094	210	531		353	
Relative length		19 %	49 %		32 %	

Generation 2: Gene pool table for gene 4

Legorg no.	length	yellow	red	green	blue	white
1	264	264				
2	160			160		
3	210				210	
4	267				267	
5	193		193			
total	1094	264	193	160	477	
Relative length		24 %	18 %	15 %	44 %	

Generation 2: Gene pool table for gene 5

Legorg no.	length	yellow	red	green	blue	white
1	264				264	
2	160	160				
3	210		210			
4	267		267			
5	193				193	
total	1094	160	477		457	
Relative length		15 %	43 %		42 %	