4.5 Case study 5 (CS5 Hungary)

Concept focus	Construction of legorgs and measurement of "fitness" as a model for natural selection
Inquiry skills	Planning investigations Forming coherent arguments Working collaboratively (debating with peers)
Scientific reasoning and literacy	Not assessed
Assessment methods	Classroom dialogue Teacher observation Worksheets
Student group	**Grade:** upper second level **Age:** 18-19 years **Group composition:** mixed ability and gender; 15 students (11 male, 4 female); voluntary participation **Prior experience with inquiry:** Relatively little experience with inquiry, since this final year class mostly followed the traditional curriculum. However, they have participated in a few inquiry projects outside the classroom (at various programmes and trips organised by the school), they have some experience of similar problem-centred learning (e.g. in connection with the topic of health and environment) and they regularly work in groups.

In this case study, final year students volunteered to participate in the inquiry activity held over five lesson periods. Skills identified for assessment were *planning investigations*, *working collaboratively* (debating with peers) and *forming coherent arguments*, evidenced by students' ability to collect and analyse data, and interpret relationships. Assessment was primarily through formative feedback during classroom dialogue, and the teacher used rubrics to identify performance levels.

(i) How was the learning sequence adapted?

The **Natural selection** SAILS unit is very structured; it leads the students step by step to the solution. It is open, however, in the sense that it allows or even encourages students to develop hypotheses and form coherent arguments (draw conclusions based on scientific investigation).

The most prominent practical difficulty in implementing the activity was obtaining a sufficient number of the right types of Lego® bricks. Since this proved to be impossible, even after several attempts, the random selection of legorg genes was done using pieces of colour-marked paper after the second generation. The paper gene pool was made by cutting up the gene pool tables given in the worksheet. A disadvantage of this solution was that the pieces of paper were probably not mixed as thoroughly as real Lego bricks would have been.

A further difficulty was presented by the correct measurement of legorg fitness – i.e., the distance a legorg moved (Figure 1). We discussed what errors we could expect (and these were confirmed by the first moves) and how the groups could avoid these errors. One source of error, for instance, was pushing a built legorg by hand (which is dependent on the surface); to circumvent this problem, the measurements were made on sheets of plain paper and the positions were marked in fine felt tip pen. Then pen was also a useful tool for holding in place and then releasing the legorg.

Another difficulty in the implementation of the unit was that it wasn't easy for the students to understand the task; we had to stop and discuss the next step several times. Since we had 45-minute periods for the activity, the students' thinking or the implementation itself was frequently interrupted. The total time requirement of the activity exceeded the time reasonably available in a class period. The unit could be made better use of at an after-school club or extracurricular programme organised for those interested. This option was unfortunately not available to us.

Figure 1: Evidence of students engaging in the inquiry process.

The content knowledge embedded in the unit is the theory of evolution, which was studied by this group in the previous school year. The syllabus of the current school year focuses on the classification of living organisms and the unit was fitted into this topic. First we needed to revise the principles of evolution, which proved to be difficult for some of the students but gave an opportunity to use prior knowledge in a new context to others. These student differences reflect the heterogeneous level of the group and signal the fairly large differences in skills.

(ii) Which skills were to be assessed?

The unit offers a wide range of development options, but for assessment purposes we had to choose no more than three skills that were easiest to observe and for which the most evidence could be collected. Therefore the skills assessed were *planning investigations*, *forming coherent arguments* (collecting and analysing data, interpreting relationships) and *working collaboratively* (communication and collaboration).

The activity is very complex and requires a lengthy period of work from both teacher and student. This made it rather difficult to concentrate on assessment since I had to devote my attention to helping the students' work. To facilitate assessment, I discussed the educational goals and possibilities, and the targets of assessment with the students before starting the activity. We also discussed the level of performance I expected of the students and the requirements they needed to observe to achieve a better level.

The primary medium of formative assessment was oral feedback in connection with the observed group work. I paid special attention to the use facilitating of questions rather than direct instructions to correct misunderstandings and errors (e.g., in connection with the completion of gene pool tables for the second and subsequent generations). Part of the support was asking questions to recall the students' prior knowledge and guiding them to connect this to the task, For example, "what could be the effect of weighting legorg genes on the fitness of the next generation?" or "what would you expect to be the effect of building mutation into the model?"

Planning (and implementing) investigations

The activity was very complex and we had to pay attention to the differences between the various steps and the significance of repetitions. In order to avoid measurement errors the students had to repeat the same task several times, which tested their tolerance of monotony. A four-level rubric was developed for assessment of students' skills in *planning investigations* (Table 1), which included their ability to interpret the task (what to do), engage in the implementation (how to do it) and understand why they were doing these tasks. A final criterion was students' ability to identify sources of error.

Table 1: Assessment scale for planning investigations

Assessed skill	Emerging	Developing	Consolidating	Extending
Planning investigations Carrying out an investigation	Cannot interpret the task on their own but participates in the planning process and in the implementation with the help of peers. Appreciates the goal and significance of individual steps but cannot properly interpret the activity as a whole. Shows insecurity in measurement, does not notice possible sources of error.	Takes an active role in the planning and implementing process of the task and rectifies mistakes without help. Has a job in the implementation. Understands the goal and procedure of the activity in rough terms but correctly. Spots possible sources of error and attempts to avoid them with more or less success.	Takes an active role in the planning and implementing process of the task and helps peers when needed. Persistently and reliably works on the implementation. Strives to carry out instructions quickly and accurately. Incorporates measurement error avoidance strategies in the experimental design and works according to the specified protocol.	Quickly and precisely understands the goal and procedure of the activity. Helps and guides peers in planning and implementing process. Can suggest alternatives in order to achieve success. Can create their own alternative protocol if needed to avoid measurement errors.

Forming coherent arguments

An essential feature of the activity is that it does not involve a computational model in order to let students carry out and appreciate every step in all its detail. The aim is to avoid the "black box" effect but this is achieved at the price of having students repeat the same task through several steps and work with a large set of data on paper, which tests their patience. Using the data gathered, they have to deduce a theoretical explanation of the relationship between their model and reality. The students can argue coherently on the basis of the collected data. Again, a four-level rubric was devised for assessment of students' ability to form coherent arguments, assessing both their ability to produce coherent and reliable data and ability to draw conclusions based on their results (Table 2).

Table 2: Assessment scale for forming coherent arguments

Assessed skill	Emerging	Developing	Consolidating	Extending
Forming coherent arguments	Produces data and arguments that are not sufficiently coherent and reliable. Cannot draw conclusions and arguments without help.	Collects and represents data appropriately, can draw conclusions and arguments from them, but the conclusions are not sufficiently coherent.	Collects and represents data appropriately and draws conclusions and arguments coherently and shows precision reflecting on prior knowledge.	Draws conclusions and arguments coherently, in sufficient depth and precision and attempts to find an explanation for unexpected or contradictory results.

Working collaboratively (debating with peers)

To assess students' skill of *working collaboratively*, a four-level rubric was developed, which evaluates both collaboration and communication (Table 3).

Table 3: Assessment scale for working collaboratively

Assessed skill	Emerging	Developing	Consolidating	Extending
Debating with peers	Participates in group work but works with interruptions. Generally participates in group debates as a passive observer.	Participates in group work without interruptions but with varying intensity. Expresses opinions in debates but does not present coherent or persuasive arguments.	Participates in group work actively and without interruption. Actively participates in debates and supports opinions with arguments.	Efficiently organises and assists work and debate of peers. Brings up persuasive arguments for their position in debates, is able to appreciate others' points of views and can be convinced to change their mind if presented with persuasive arguments.

The activity was implemented with a somewhat heterogeneous group of students, who volunteered to participate. The reason was that the topic was related to the subject matter of earlier classes and several students preferred to work on an activity (also in groups) related to the current subject matter. I expected boys to be more interested in an activity involving Lego since they had more experience with it. The ratio of boys in the class is 3:1 and, contrary to expectations, there was a similar ratio in the volunteer group. The boys were more likely to build the Lego models while the girls tended to pick bricks and record data. They had lead roles in two groups. These two girls attend advanced physics and chemistry classes, which suggests an interest in science.

(iii) Criteria for judging assessment data

For the satisfactory completion of the task, the students were expected to

- Discuss and interpret the task in their group,
- Look up or ask the teacher for additional information needed for interpretation,
- Develop an efficient method of conducting the measurements,
- Minimise sources of error,
- Work fast and without interruption,
- Summarise interim results and represent them graphically,
- Discuss the results in their group,
- Link the data of the model simulation with the general theory of evolution.

In addition to the above, time planning and management also constituted part of the assessment criteria. The groups had to complete the steps of the experiment at roughly the same pace.

Assessment was necessarily formative; most importantly, the groups were given oral feedback on their work. This was greatly needed during the first two periods but I had more opportunity to observe the students and take notes in writing in the second phase of the activity. These observations were discussed with the students at the end of the activity.

(iv) Evidence collected

Teacher opinion

The class is not particularly scientifically minded, but the four groups consisted of students who volunteered because they were interested in evolution. They had asked several questions in connection with the topic when it was the subject matter of classes. At the beginning, the interpretation of the task, and later on the monotony of the repetitive activity, caused some difficulty. The students became more interested again towards the end, when the focus was on the evaluation of the model and the results.

Since some of the students take advanced classes in some field of science, it was reasonable to expect a high level of scientific thinking and disciplined and efficient work. While debating the interpretation of the task, the students had a lively discussion and communicated with each other a lot, with the result that the problems brought up were quickly resolved. Every group completed data collection, measurements and calculations quickly and mostly accurately. The interruptions due to the 45-minute class periods and the large number of repetitions tested their stamina, memory and tolerance for monotony, which had the effect of slowing progress. The students suggested that at least the recording of the data and the selection of genes could be computerised, which would not replace the model but would speed up the activity.

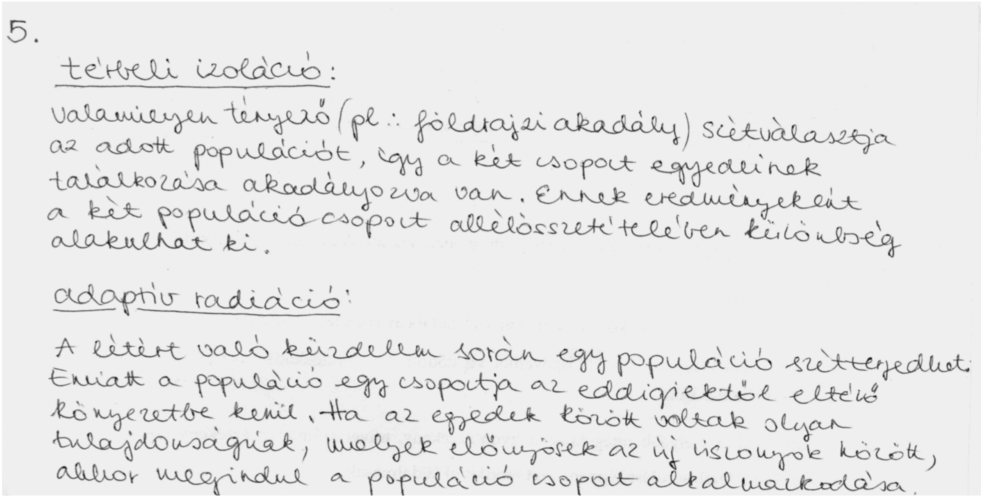
The system of assessment focusing on three skills proved to be successful from a practical point of view because these were the dominant skills in this activity and they could be observed accurately and for most students. Levels of achievement were identified based partly on the predetermined set of expectations and partly on modifications to it as dictated by the experiences of the activity. The scale of levels was finally successfully fitted to the actual observed elements and levels of performance.

Observer notes

There was no observer attending the sessions, but a colleague was implementing the same activity with another class in another grade. Therefore that colleague and I discussed our experiences after each class period. At first we did not quite understand the logic of the activity and thought that a more detailed and clearer description was needed. Later the shortage of Lego bricks was the problem, which were replaced by coloured pieces of paper in the other class, while we wrote the available gene combinations in the generation tables and gene pool tables, chopped the tables up (into 100 pieces) and drew the legorg genes from the pile. The activity took longer than expected for both classes, which meant that we could not reflect on the theory of evolution as much as we wished and could not exploit fully the possibilities provided by the model. An after-school club or extracurricular programme would have been a better opportunity to test the unit than were regular science class periods.

Sample student artefacts

The questions on the worksheet are perfect for exploring the relationship between the model and actual evolutionary processes. Unfortunately, we did not have enough time for this but some of the students tried to answer a few questions. They searched a library database to find sources. An example is shown in Figure 2: it is an answer to Question 5, where the concepts of spatial isolation and adaptive radiation are defined.


5.
térbeli izoláció:
Valamilyen tényező (pl.: földrajzi akadály) szétválasztja az adott populációt, így a két csoport egyedeinek találkozása akadályozva van. Ennek eredményeként a két populáció csoport allélösszetételében különbség alakulhat ki.
adaptív radiáció:
A létért való küzdelem során egy populáció szétterjedhet. Emiatt a populáció egy csoportja az eddigiektől eltérő környezetbe kerül. Ha az egyedek között voltak olyan tulajdonságok, melyek előnyösek az új viszonyok között, akkor megindul a populáció csoport alkalmazkodása.

5.

<u>Spatial isolation:</u>

Some factors (e.g.: geographical barriers) split the population, so the meeting of the two groups is blocked. As a result of this, the two groups' allele composition would differ.

<u>Adaptive radiation:</u>

A population can spread in the rat race, so a group of the population can reach a different environment. If the individuals of the population have beneficial properties in the new conditions, then the adaptation of the population will begin.

Figure 2: Example of student response to question 5 – describe some biological adaptations.

The measurement of the fitness of legorgs – i.e., the distance they moved – triggered disagreements in every group. The students finally agreed that the important thing was to use a consistent and uniform method. This still leaves room for plenty of errors determined by the properties of the push, the restoration to standing position and the base friction. Figure 3 shows the base sheet of one of the groups. It is quite difficult to make sense of although the group did their best to use a marking system. They also used compasses and a ruler to be able to measure the distances accurately.

Figure 3: Example of measurement of fitness

There were some inconsistences in the unit of measuring the distances with cm and mm mixed, but the group soon realised that consistency was important and corrected the table (Figure 4).

Generáció száma	2

Legorg száma	Jegyezd fel az allélt (színt) a legorg mind az 5 génjéhez és mérd meg a fitnesz szintjét						
	1. gén	2. gén	3. gén	4. gén	5. gén	fitnesz	
1	Sárga	fehér	piros	piros	sárga	1 mm	
2	fehér	fekete	fekete	fehér	Sárga	~~5 mm~~ ~~10 mm~~ 0,6 cm	6 mm
3	fekete	Sárga	piros	Sárga	zöld	1,2 cm	12 mm
4	fehér	zöld	piros	piros	zöld	~~[illegible]~~ 0,9 cm	9 mm
5	zöld	fekete	fekete	Sárga	Sárga	~~[illegible]~~ 1 cm	10 mm
6	fehér	fekete	fehér	fehér	Sárga	1 cm	10 mm
7	piros	fekete	piros	zöld	piros	1,4 cm	14 mm

Figure 4: "Second generation of legorgs" table
(*piros (P)* = red, *sárga (S)* = yellow, *zöld (Z)* = green, *fekete* = black, *fehér* = white, *fitnez* = fitness)

A gene pool table completed correctly by one of the best working groups is shown in Figure 5. They built at least 10 individuals per generation and thus reduced chance error.

Generáció száma	1	Allélok				
Gén száma	5					
Legorg száma	Fitnesz	Sárga	Piros	Fekete	Kék	Fehér
1.	12				12 mm	
2.	4		4 mm			
3.	7					7 mm
4.	9	9 mm				
5.	10					10 mm
6.	2			2 mm		
7.	0			0 mm		
8.	5		5 mm			
9.	0				0 mm	
10.	0	0 mm				
11.	10			10 mm		
12.						
	Σ fitnesz 59	Σ sárga súly 9	Σ piros súly 9	Σ fekete súly 12	Σ kék súly 12	Σ fehér súly 17
Relatív fitnesz (kerekítve)	Σ sárga súly / Σ fitnesz * 100 =	Σ piros súly / Σ fitnesz * 100 =	Σ fekete súly / Σ fitnesz * 100 =	Σ kék súly / Σ fitnesz * 100 =	Σ fehér súly / Σ fitnesz * 100 =	
	100%	15%	15%	20%	20%	30%

Figure 5: Gene pool table for first generation, gene 5
(*piros (P)* = red, *sárga (S)* = yellow, *zöld (Z)* = green, *fekete* = black, *fehér* = white, *fitnez* = fitness)

Another group built only 5 legorgs per generation, which gave a less accurate result (Figure 6).

Generation No.	2	Alleles				
Gene No.	4	note legorg's fitness in column of the animal's allele (color)				
Legorg No.	fitness	Yellow	Red	Black	Blue	White
1	1,6		1,5			
2	0,5					0,5
3	1,15		1,15			
4	1,5		1,5			0,55
5	0,55					
	Σ fitness 5,2	Σ yellow weight	Σ red weight	Σ black weight	Σ blue weight	Σ white weight
Relative fitness (rounded)		Σ yellow weight / Σ fitness * 100 =	Σ red weight / Σ fitness * 100 = ~~48~~80%	Σ black weight / Σ fitness * 100 =	Σ blue weight / Σ fitness * 100 =	Σ white weight / Σ fitness * 100 = 20%

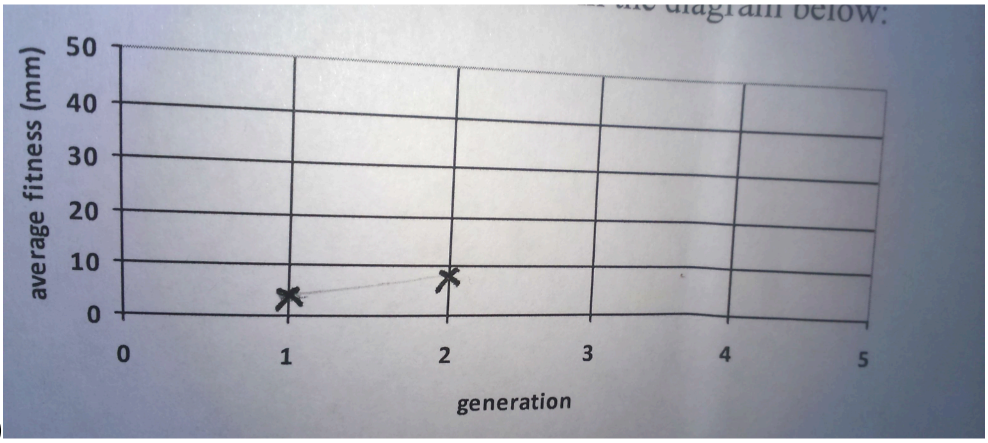
Figure 6: Gene pool table for second generation, gene 4

Another group built the third generation of legorgs, but did not have any time left to measure fitness (Figure 7).

Generáció száma	2					
	Jegyezd fel az allélt (színt) a legorg mind az 5 génjéhez és mérd meg a fitnesz szintjét					
Legorg száma	1. gén	2. gén	3. gén	4. gén	5. gén	fitnesz
1	K	FK	S	P	F	
2	K	FH	K	K	K	
3	FH	K	S	P	P	
4	FH	FH	S	S	K	
5	FH	FH	S	K	P	

Figure 7: "Third generation of legorgs" table

Examples are shown of student graphs, showing results for two generations (Figure 8a, not sufficiently accurate) and three generations (Figure 8b).

(a)


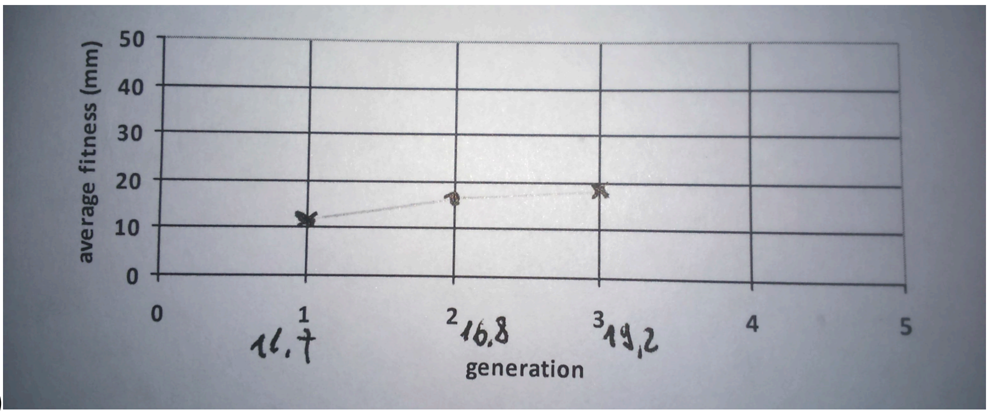
(b)


Figure 8: Plot of average fitness (y-axis) for each generation of legorgs (x-axis)

(v) Use of assessment data

I looked at the data tables completed by the groups to assess their work once again. Every group was then given detailed oral feedback. The feedback was based on the scoring rubric and we discussed the possible skill levels, the differences between them and the significance of these differences. The end-of-semester reports the students are about to receive show these levels for each student.

Since this activity was related to a topic studied earlier in the year, I can link the experiences of the activity to the decline of biodiversity and other ecological problems in future (e.g., endangered species and population decline due to habitat destruction).

(vi) Advice for teachers implementing the unit

This unit is not a typical inquiry activity, since the tasks to be completed are described step by step. The sequence is quite complex and the teacher must have a very good idea before class of what is expected to happen during the activity. Disagreements of interpretation hinder progress. It is also important to keep the students motivated, which can be achieved primarily with positive feedback and reinforcement. It is a principle of inquiry learning that the teacher assists the students when they make mistakes or are stuck with guiding questions rather than direct instructions. The activity is well suited to the development of scientific skills but we need to choose 2-3 elements of skills that we can definitely observe or about which we can collect evidence. Hypothesis formation could have been such a skill in this activity but the group of students did not have the necessary prior knowledge. Prior knowledge must always be taken into consideration when planning assessment.