4.1 Case study 1 (CS1 Hungary)

Concept focus	Determining rate of reaction – altering rate of reaction
Activities implemented	Activity B, Activity C
Inquiry skills	Planning investigations Forming coherent arguments Working collaboratively
Scientific reasoning and literacy	Scientific reasoning (data entry, drawing conclusions) Scientific literacy (presenting scientific data)
Assessment methods	Classroom dialogue Teacher observation Worksheets Student devised materials (graphs)
Student group	**Grade:** 9 (upper second level) **Age:** 15-16 years **Group composition:** co-ed (9 girls and 11 boys attending the same class) **Prior experience with inquiry:** None

This case study describes an after-school activity in which a cohort of students with no prior experience in inquiry or kinetics, who planned and carried out investigations using vitamin C tablets. Formative assessment was carried out at the group level, using a rubric to identify three performance levels in the skills of *planning investigations*, *scientific reasoning*, *forming coherent arguments* and graphical representation of data, a component of *scientific literacy*. Assessment methods included classroom dialogue, teacher observation and evaluation of student artefacts.

(i) How was the learning sequence adapted?

The **Reaction rates** unit provides ideas and recommendations while leaving the teacher plenty of freedom in implementing the activity. We exploited this freedom because we could not have dedicated the recommended ten class periods to the activity and decided to follow the alternative two-period version. As the regular course syllabus was too tight to fit in even two extra periods, we implemented the unit as an after school activity. The inquiry session took place during the first week of January, before which time the students had only had one opportunity to participate in lab work this school year. That lab session followed a strict structure. Thanks to this experience, however, we did not need to spend time on discussing lab safety. The students were also familiar with certain technical details such as handling a Bunsen burner. The syllabus, however, does not discuss reaction kinetics until April. The students in the group trying out the activity volunteered to participate (20 of 36 students). The students in the class have specialisations in French or informatics rather than science. The twenty students in the group show average performance in chemistry.

The activity was implemented in a double period of 90 minutes. The participants did not receive any prior information; they only knew that they were going to conduct an experiment. They divided into five groups of four students each. They formed the group themselves without my intervention.

Although I was familiar in theory with the role of a teacher in inquiry learning, this was the first time I had actually led such an activity. Since during the preceding four months of the school year we covered very abstract topics (such as atomic structure and chemical bonding), instruction was mainly teacher-centred with explanations combined with a question-and-answer method, where the main goal was to discover cause-and-effect relationships. During that time, the students had difficulty applying the laws and regularities they had learnt and practiced. I was therefore looking forward to finding out how creative they could be in a problem-centred lab activity.

We implemented Activity B: Determining rates of reaction and Activity C: Altering reaction rate with some modifications. The students were given a worksheet, detailing two tasks (Figure 1). Task 1 correlates to Activity B of the unit, and Task 2 is a modification of Activity C.

We tried to measure the reaction speed first. The groups were handed out the first task in writing. When they came into the room, they found a 100 ml beaker and an effervescent tablet on their trays and some tap water in a test tube. I wanted to make sure that everyone had water at room temperature but the water running from the tap varies in temperature. The groups worked as far from each other as possible.

The worksheet instructs the students to plan the measurement and the wording of the instruction introduces the concept of reproducibility of an experiment. The students were given 15 minutes for this task. They quickly got their mobile phones out although I also had a stopwatch at the ready. This was followed by a short brainstorming session. I wrote the ideas on the board. We agreed that in order to be able to compare different measurements, we had to define the criteria marking the beginning and end of the measurement. Every group unequivocally decided on the moment of dropping the tablet in the water as the starting point, and the end point was eventually defined as the moment of the solution becoming clear. Changes in the reaction rate over time could not be measured in such a short time, because we would have had to trap the gases, which would have been too difficult for the students. There were, however, two questions aimed at finding out whether the students observed any change and if they did, what suggested a change to them: "Did you observe a change in the reaction rate during the process? What led you to think that?"

As the next step, the students were given the second task, which pointed out the significance of the factors affecting reaction rate. The groups first had to come up with some ideas and this was followed by a whole-group discussion. Based on the students' suggestions, the various factors were written on the board. The students could then say what equipment they needed. We decided to test more than one factor because this allowed us to give a complex answer to the question on the worksheet. It was clear to the students that if we wanted to test the effects of a single factor, the other variables had to be kept constant, i.e., we cannot heat and stir our solution at the same time. The groups could choose the variable they wanted to test. The tasks of the individual groups are shown below.

- Group 1: temperature
- Group 2: volume (concentration)
- Group 3: temperature
- Group 4: chopping (increasing the surface)
- Group 5: stirring and testing three different brands of effervescent vitamin C

With the exception of Group 2, everyone used 75 ml of liquid for the experiment; the liquid was water at room temperature for all but Groups 1 and 3; and with the exception of Group 5, everyone used a whole tablet of the same brand and did not stir the solution. A period of 35 minutes was allocated for this part of the activity. I walked among the groups but decided to interfere only if the students asked me to or had a question to ask. I took brief notes of my observations of the work of the groups. The measurements were followed by cleaning the equipment and tidying up and then the students plotted their data in a graphical form (this presented considerable difficulty). When the graphs were completed, the groups briefly summarised their results to the class. Based on the summaries, we discussed together how to answer the question "Can you suggest a method of speeding up the dissolution of the tablet?" from Task 2.

Finally, I assessed the work of the groups. Our time management was good since we finished the work as planned without any delay.

Experimenting with an effervescent vitamin tablet Group Number:

Find a solution the problems below.

Task 1. "In the morning, I have a drink with an effervescent vitamin-C tablet; however I usually have to drink it before the tablet has fully dissolved."

Can you measure the time it takes for the process to finish?

Plan the measurement. Add enough detail so that other people can carry out the same measurement based on your description and their results can be compared to yours.

Answer the following questions.

Is this a chemical or a physical process? Explain your answer.

....

....

What kind of gas is produced? ....

Which ingredient produced the gas do you think? ....

Why? ....

....

Did you observe a change in the reaction rate during the process? ....

What led you to think that? ....

....

Why did the tablet rise? ....

Task 2. "I'd like to make the table dissolve faster because I don't have a lot of time in the morning. I usually wait until it's stopped fizzing before I have the drink but sometimes I am running late."

Can you suggest a method of speeding up the dissolution of the tablet? Write down as many ideas as you can. Discuss your ideas with the other groups before preparing the experimental plan.

Add enough detail to your plan so that other people can carry out the same experiment based on your description and their results can be compared to yours.

Summarise the results of your experiments in a table and draw a graph on graph paper.

Figure 1: Student worksheet for CS1

(ii) Which skills were to be assessed?

The inquiry skills I wished to assess were *planning investigations*, implementation of the experiment and graphical representation of data, while the skills of *scientific reasoning* to be observed and assessed were the identification of cause-and-effect relationships and the use of scientific evidence in *forming coherent arguments*. The assessment was based on the worksheets and graphs handed in by the students, my notes of my observations of the work process and the students' brief summaries. I used a three-point assessment scale modelled on the sample given on the SAILS website (Table 1).

Table 1: Assessment scale used in CS1 Hungary

	Competencies	Beginner	Intermediate	Advanced
Inquiry skills	Planning investigations Implementing an experiment	The group needs the teacher's guidance to complete the task, their questions are not pertinent to the task, they record their results inconsistently. They do not know what the different pieces of equipment are used for.	The group needs occasional help. Their questions are not always pertinent. They record their results consistently but with omissions. They lack confidence in using equipment.	The group works without help. Their questions are pertinent to the problem. They record their results accurately. They can choose the appropriate equipment.
	Graphical representation	The independent and dependent variables are confused, the scale of the graph is inappropriate, graph title is omitted.	There are some inaccuracies in the graph, some labels are missing, the graph title is inaccurate.	The graph is accurate, the scales of the axes are appropriately chosen, the title is accurate (shows what is plotted as a function of what)
Scientific reasoning	Causality Forming coherent arguments	The members of the group do not recognise the chemical nature of the observed phenomenon, they do not know what is happening.	The members of the group have only partial knowledge of the chemical content of the observed phenomenon and they lack confidence in the knowledge.	The members of the group understand the chemical process observed and identify the cause-and-effect relationship without help.
	Proportional reasoning	The summary is incoherent; it does not focus on what is important.	The summary contains some inaccuracies or omissions.	The summary is coherent and the reasoning is easy to follow.

(iii) Criteria for judging assessment data

With respect to *working collaboratively* (social competencies), I expected the students to be able to work cooperatively and to remain focused on the task. With respect to inquiry skills, I was not unsure what to expect since neither the students nor I had previous experience with inquiry learning. As regards *scientific reasoning*, I expected the students to be able to make use of their knowledge of inorganic chemistry acquired in the previous school year and recognise the chemical nature of the phenomenon (e.g. that the bubbles should come from carbon-dioxide but if carbon-dioxide is not listed among the ingredients contained in the tablet, where do they come from? etc.) and identify causes and effects. The principles of graphical representation are part of the core curriculum in mathematics and it was reasonable to expect the students to be able to collect and tabulate data keeping quantities that change together in pairs and representing the relationships between varying quantities in a two-dimensional coordinate system. I further expected the students to be able to summarise the results of their observations briefly and efficiently.

I used formative assessment and evaluated the performance of the groups on the three-point assessment scale (see Table 1). The assessment was discussed with the students. I tried to provide constructive criticism to let the students see what could be improved and what they had to be able to do for an advanced level.

(iv) Evidence collected

Teacher opinion

My students enjoyed working on the activity (they volunteered to participate and were not under pressure) and were good at working together. The three boys in one of the groups caused the greatest surprise because while they tend to be quiet and moderately active in regular classes, they were now very lively and motivated and I got to know a different side of them.

We had to be careful with time management. There were no technical difficulties. Any difficulty we had was related to the tasks. The students were best at summarising their conclusions and worst at plotting their data with the other two skills in between.

The tasks of the activity form a didactic hierarchy as they are. It could be extended by including an investigation of catalyst effects for this age group, while the activation energy could be defined and the data could be linearised for the graph by older students.

Sample student artefacts

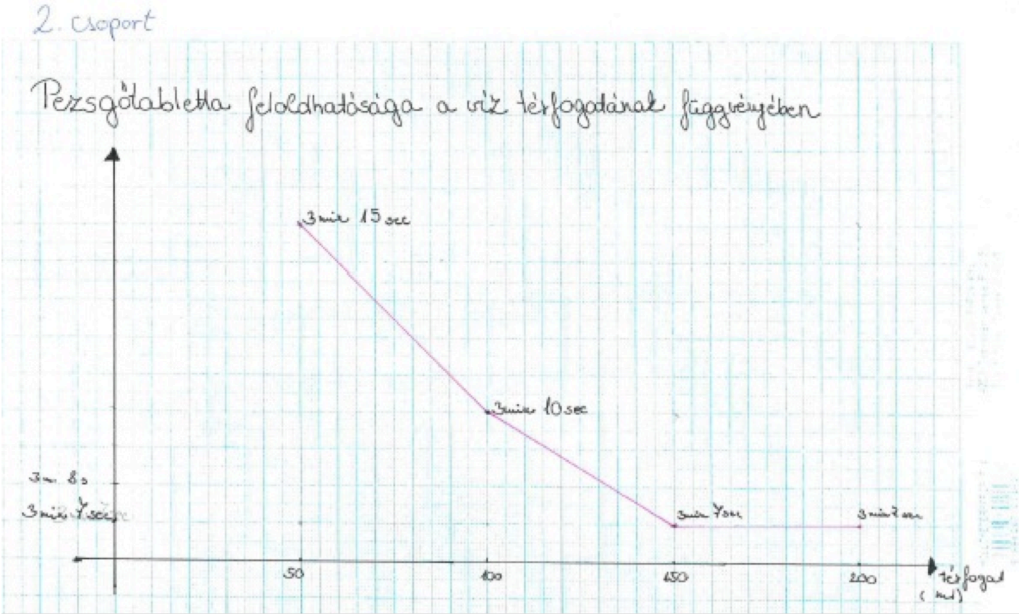
Student planning and implementation of the experiment shows a varied level of performance (Table 2). Plotting the data appeared to be the most difficult of the four competencies chosen for assessment (Figure 3 and Figure 4). I gave instructions at several stages but none of the groups managed to construct a perfect graph. The problems that came up included the identification of the dependent and independent variables and assigning the axes to them and choosing the scale for the axes (how many cm or mm should represent one unit of change in the physical quantity). None of the groups thought of giving the graph a title. None of the groups thought of repeating their measurements and using averages as their data

Table 2: Planning and implementation of experiments

Group and variable for investigation	Observations by teacher
Group 1: Temperature	An oversight in their plan was that they omitted a temperature best suited to drinking (around 10 °C to 20 °C). They linked the appropriate pairs of data correctly but they should have arranged them in a natural order to aid interpretation (0 °C should be first followed by 30 °C rather than by 50 °C). They did not have time to plot their data.
Group 2: Volume	First they used beakers of different shapes and sizes but later corrected their mistake and changed the plan to vary only the volume of the water. They used the same type of beaker for the four measurements and successfully observed the trend, although volume did not prove to be a significant variable.
Group 3: Temperature	They added hot water to the experiment, which of course resulted in a very fast reaction and in a little panic because the tablet fizzed so intensively. Although hot water is not really relevant to the question – who would want to drink an effervescent vitamin C tablet in hot water – the experiment proved to be useful.
Group 4: Increasing the surface area (**Figure 2**)	They realised that it mattered whether they put the powdered tablet in the water or poured the water over the powder. They measured very different reaction times.
Group 5: Stirring and brand of tablet	They combined two variables, which resulted in a rather chaotic record. Although I warned them that they would not be able to measure the rate of stirring accurately without a special instrument, they insisted on keeping this factor. They specified slow, medium and fast stirring, which is of course rather subjective and would be a bit of a problem if we wanted to replicate the experiment. They omitted the "no stirring" condition, however. They found differences between the brands but unfortunately the

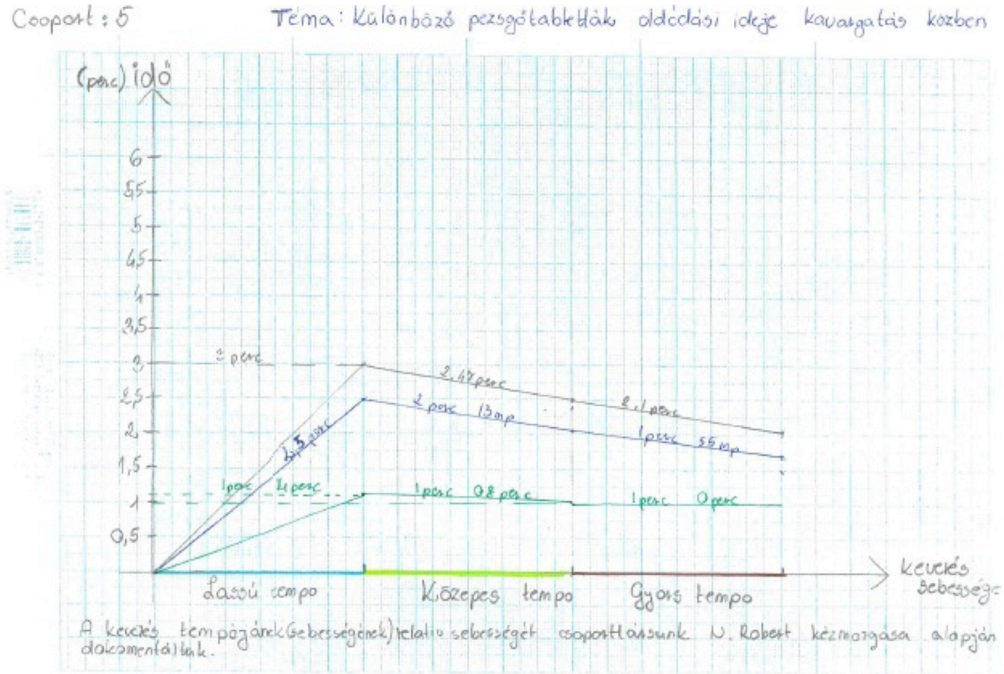
	packaging did not show the tablets' citric acid and sodium hydrogen carbonate content. It showed sodium content but that was no use to us because there are three other sodium compounds among the ingredients.

Figure 2: Group 4 ground a tablet to increase its surface to the greatest possible extent



The solution of the vitamin C effervescent tablet depending on the volume of the water

Figure 3: Student artefact showing a graph of the dissolution of the vitamin C effervescent tablet depending on the volume of the water



Time of solution of different effervescent tablets during stirring
The stirring is documented based on the speed of an other student's hand movement

Figure 4: Student artefact showing a graph of time of dissolution of different effervescent tablets during stirring

Every group did well in using their *scientific literacy* skills (Table 3) and summarising their conclusions. They gave confident, clear and well-structured presentations.

Table 3: Summary of student answers to questions of scientific literacy

Question	Sample student responses
Is this a chemical or a physical process? Explain your answer.	Only one group gave a correct answer. Most of the students did not know that dissolution could be a physical or a chemical change, or the difference between a physical and a chemical change.
What kind of gas is produced?	One group did not give an answer, three groups gave the correct answer and one group thought it was hydrogen. Since they were not asked to define the quality of the gas, the correct answer was an analogy with carbonated drinks. The group deciding on hydrogen reasoned that the bubbles rose to the surface, which suggests a gas of low density.
Which ingredient produced the gas do you think?	Interestingly, the correct answer was given by the group that identified the gas as hydrogen. The others did not know what to write or gave a wrong answer: • "the effervescent tablet", that is, they ignored the fact that the tablet is not a homogeneous substance but has different ingredients; • "the reaction of the water and the tablet," that is, they confused processes with materials. The packaging of the tablets was on the teacher's desk accessible to the students and they could also have asked me about the composition of the tablets. The only group to ask how they could find the ingredients was the one that gave the right answer. I gave them the packaging. Since they saw the word hydrogen in sodium hydrogen carbonate on the packaging, this seemed to confirm their hypothesis and they chose this as their answer. We strive to teach children to be conscious consumers by, for instance, encouraging them to read the product labels but our attempts do not seem to be very successful. Or could it be that they did not ask for the ingredients because they thought they had to know them by heart?
Why?	There was not a single correct answer. An inquiry activity would be useful to find the answer to this question (Activity 4: Qualitatively determine which reactant (or combination) produces the most CO_2) but the students could have guessed the correct answer by looking at the ingredients since they should have been familiar with the relevant theoretical rule. I was not surprised by the failure, however. We should implement Activity 4.
Did you observe a change in the reaction rate during the process?	I asked this question because the original unit has an activity measuring the rate of reaction. Since we did not trap the gas, we only had the opportunity to measure the time needed for the reaction from beginning to end. I wanted to find out, however, how careful observers the students were. Two groups did not detect a change in reaction rate.
What led you to think that?	The groups who gave a negative answer to the previous question did not write anything here. Of the remaining three groups, two gave a correct answer.
Why did the tablet rise	Two groups found the correct answer. Other answers: "the leaving carbon-dioxide lifts the tablet" and "the tablet has a porous structure and fills up with gases".

(v) Use of assessment data

The groups were first given feedback after the brainstorming sessions but this was restricted to positive feedback. I assessed the work of the groups after completing the experiment in Task 2. Feedback on the graphs and answers to the questions in Task 1 was given next time I met the students.

(vi) Advice for teachers implementing the unit

It is best to start with a simple task. If the teacher does not have a lot of experience in leading group work, they should not start with an IBL activity. We must stop ourselves from correcting the students at every stage – however difficult this may be. We should wait for the children to realise that they are following the wrong path. It is important to choose a task appropriate to the level of the students and it helps if we know what they have covered in other school subjects. It is best to select just two or three criteria of assessment.

The teacher's job is easier when every group performs the same task. Not only because of needing to have the experimental equipment and materials ready but also because it is easier to follow the progress of the groups during the activity. With a class of 36-40 students, implementation would be very difficult indeed. With a class of that size, I have only attempted to run a lab session with a student worksheet, structured tasks and "central command" in my career as a teacher. When planning the activity, we should specify how much time we allocate for each task. We can be flexible to some extent but we do not have an infinite amount of time. We should not plan more than we can complete in the given period including a conclusion of the activity. If the group presentations are left to a later period, the student charged with giving the presentation may be absent.

I warmly recommend the **Reaction rates** SAILS unit to colleagues because it is very well structured from a didactic point of view: we can start at a beginner's level and progress up to an advanced level or we can select just one or two tasks and adapt those.