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Report on the assessment frameworks and instruments for IBSE skills - Part A

SAILS
Strategies for Assessment of Inquiry Learning in Science

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D 2.2 Report on the assessment frameworks and instruments for IBSE skills - Part A

Authors: Benő Csapó, Csaba Csíkos Erzsébet Korom, Christine Harrison, Paul Black, Odilla Finlayson, Paul van Kampen, Eilish McLoughlin and Deirdre McCabe
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Contact: info@sails-project.eu
Website: www.sails-project.eu

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Contents

Introduction

The SAILS project aims to present a framework for assessment of inquiry learning in science. The purpose of this framework is to provide a detailed description of the content of assessment and to describe what and how to assess in the context of IBSE. Every major national and international assessment program has its own framework defining the major characteristics of the assessment. These frameworks are usually prepared at the beginning of an actual project, and their basic function is to provide a sound basis for the preparation of the assessment instruments. They are also published to provide an overview of the assessment, and to inform assessment professionals, stakeholders and the general public. Although the orientation and the purpose of these assessments may be different, there are many similarities between these documents. (For the concept offramework, and differences between taxonomy, standard and framework, see Korom, B. Németh, Nagy, & Csapó, 2012;pages 149-155).

In this work these frameworks may be used as models, in particular the way of presenting assessment content and examples for the assessment items. Particular examples of useful recent frameworks arethat of TIMSS (Mullis, Martin, Ruddock, O'Sullivan, Arora, & Eberber, 2005; Mullis, Martin, Ruddock, O'Sullivan, & Preuschoff, 2009) and PISA (OECD 2009, 2013). A further example of a framework is that prepared for the Developing Diagnostic Assessments project (see http://edia.hu/) for the first six grades of the primary schools with the participation of the Hungarian SAILS team (Csapó & Szabó, 2013).

In this report, the structure of the proposed framework for SAILS is outlined. As developing the complete framework will take time, the structure was operationalised in order to develop the initial assessment items for piloting and trialling. Three topics were selected to provide physics, chemistry and biology teachers with a view of the type of assessment opportunities that could be developed within each of their subject areas and provide specific examples of what and how to assess inquiry skills. The topics chosen for the initial assessment items were Food, Rates of Reaction and Speed aimed at the lower second level students and these topics were chosen so as to be applicable across most countries. These initial assessment items are presented in Section 2 and the report on their piloting and trialling with teachers is given as D3.1.

1. Assessment Framework for Inquiry Learning in Science

1.1 Structure of the framework

The framework is based on the conceptions elaborated in the document in assessment strategies in inquiry-based science education (Deliverable 2.1) The structure of the framework is summarized in Table 1. Slots of the table indicate sections of the document. The framework highlights inquiry opportunities, the scientific literacy/application and reasoning that will be considered for particular scientific content. The inquiry skills will focus on the elements of inquiry already identified within the SAILS project and discussed in D1.1. The main chapters of the document will be organized by grades, then according to the cells in the table.

Grade	Curricular content				Reasoning	Scientific literacy, application	Inquiry skills
	Physics	Chemistry	Biology	Cross Disciplinary			
7-8							
9-10							
11-12							

TABLE 1 STRUCTURE OF THE ASSESSMENT FRAMEWORK

Curricular content describes the disciplinary knowledge covered in the respective school subjects. In the context of IBSE, development of great ideas, depth of understanding, concept development, conceptual change and treating of misconceptions, are of particular interest. The framework describes the "common core" content of science curricula of the participating countries. Under the entry of cross-disciplinary content, those themes may be described which are (might be) taught in more the one discipline, and/or offer opportunities for complex inquiries. The sources for compiling these sections are the national curricula and standards, furthermore, current literature on science education and IBSE. We are not going to cover the entire science curricula, rather those aspects of science education will be highlighted in these sections of the framework which are particularly important for inquiry learning, e. g. where inquiries may contribute to the improvement of the quality of learning the disciplinary content.

Reasoning describe those skills that can be exercised in the process of learning science at the given grades. As the same reasoning skills may be exercised at several areas of science, the framework indicates – with actual examples – of which reasoning skills may be practiced in the given content, especially, but not exclusively by IBSE. The sources for creating these sections are national curricula and textbooks and some reasoning examples can be found in the TIMSS frameworks. Nevertheless, these sections require the most creative contributions. There is a rich research literature on the development of reasoning in the context of science education what can be applied here.

Scientific literacy and application of scientific knowledge is especially well elaborated in the PISA frameworks. As the given science knowledge may be applied at a number of areas, only examples may be described here. Especially that application might be relevant which could be promoted by IBSE.

The inquiry skills section shows examples for inquiry work related to the given content. They can be from any discipline, or can overarch several disciplines. Collecting disciplinary content, reasoning, application, and inquiries, and presenting together may inspire designing further inquiries. This connection may help identify and highlight the function of the given inquiries.

1.2 Operationalising the framework

As developing the overall framework, as outlined above, takes a lot of time, it was decided that the group could work with an operational version that would assist in development of the first assessment items. Figure 1 shows the Operational framework, which builds on D2.1 and the Assessment of inquiry skills document in D3.1. Particular topics relevant to school curricula across

Europe could be selected; these topics would also be informed by the resources for inquiry that already have been developed through other European projects or national projects (such as ESTABLISH, PRIMAS, etc). Having selected the topics,then the content knowledge could be identified. As the inquiry lesson (or lesson sequence) is developed, the particular elements of inquiry could be highlighted throughout the lesson as well as the reasoning processes involved.

The assessment items then can be developed to assess the inquiry skills identified, the associated reasoning as well as the content knowledge. The criteria for the assessment could also beconsidered. These assessment items, after piloting and trialling (see D3.1), would then be fed back into the Teacher Education programmes and also the output from the teacher education programmes would further inform the criteria for the assessment items.

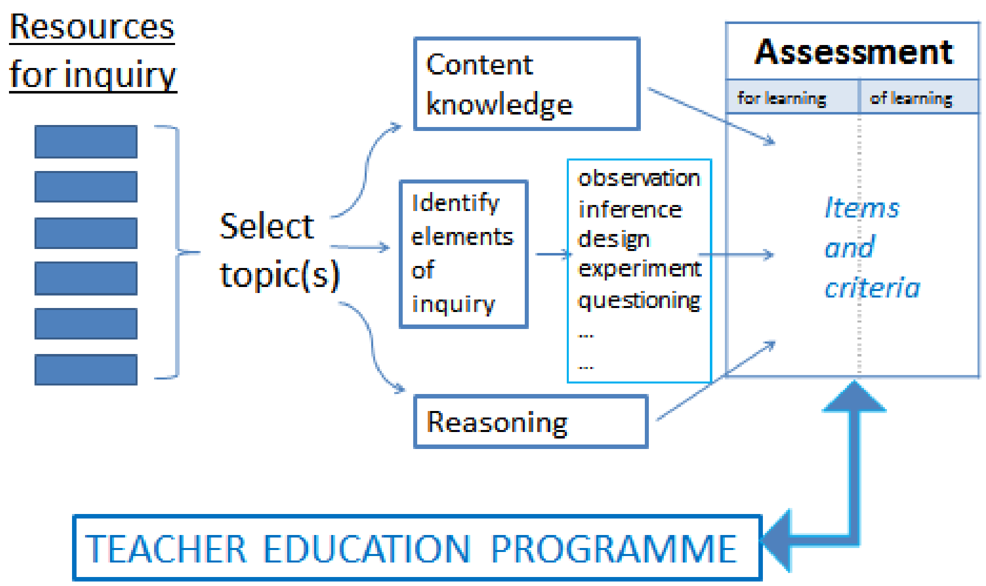


FIGURE 1 OPERATIONAL FRAMEWORK

2. Assessment items

2.1 Background to first three assessment items

The working document (M33) outlined an approach to assessment of science inquiry that enables teachers to create opportunities in their classrooms for both formative and summative assessment.
A small group from WP2 and WP3 over a two day workshop devised an approach to developing assessment items for each country to pilot with experienced teachers that provided opportuniy for both formative and summative assessment opportunities in their own classrooms. Three topics were selected to provide physics, chemistry and biology teachers with a view of the type of assessment opportunities that could be developed within each of their subject areas; these topics chosen for the first assessment items were Food, Rates of Reaction and Speed aimed at the lower second level students. These topics were chosen so as to be most applicable across all countries.

Within each topic, the content knowledge was based on that required at lower second level. Proportional reasoning was identified as the key reasoning skill to be included and then of the inguiry skills, the skill of planning an investigation was highlighted in the assessment topics.

The three topic areas are given in section 2.2. Note there are two different versions of the Speed topic, as they were developed for different student groups.

As these topics are all taught using an inquiry methodology, the framework developed by Fradd, was included in each assessment item, just to highlight to teachers the level of open inquiry that they were considering within their classroom. The framework asks the teacher to decide on the level of control that the teacher or student has for particular poarts of the inquiry process.

Using your Fradd et al(2001) framework, work out what evidence you would be looking for in each of the cells where students take control of the inquiry. Table 1 shows the framework (from Fradd 2001) and for each activity within the lesson (e.g. questioning) , the level of inquiry alters depending on the source of the questions (i.e. teacher or student).

INQUIRY LEVEL	Questioning	Planning	Carrying out plan	Analyse data	Conclude	Report	Apply
0	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher
1	Teacher	Teacher	Student/ Teacher	Teacher	Teacher	Student	Teacher
2	Teacher	Teacher	Student	Student/ Teacher	Student/ Teacher	Student	Teacher
3	Teacher	Student/ Teacher	Student	Student	Student	Student	Student
4	Student/ Teacher	Student	Student	Student	Student	Student	Student
5	Student	Student	Student	Student	Student	Student	Student

TABLE 2 FRAMEWORK FOR INQUIRY (FROM FRADD, 2001)

2.2 Assessment items

2.2.1 Investigating Food

Why teach this topic?

This is a topic that is returned to many times throughout a child's time in school and one of the main reasons for including it in the curriculum is the hope that children will begin to understand what makes a healthy balanced diet. From this stance they can then look at their own diet and that of others and make recommendations about how to improve the diet. The problem however is that too often the ideas behind obtaining a balanced diet are not considered in sufficient detail to allow youngsters to understand what a balanced diet means in reality with foods simply categorized as healthy or unhealthy or as fat or protein and the true composition of foods and the amounts needed to keep someone healthy are not looked at. So youngsters are not equipped with sufficient knowledge and skills to make the choices that they need to when it comes to their own diet. This set of materials attempts to help with developing better ideas about food and incorporates an investigative approach to aid the skills development required and also to motivate students to want to understand these ideas better.

We will be looking at two different types of skill in this topic. The first is the skill of **proportional reasoning** because the students will need to be able to compare different amounts and types of food in their diet. The second is a raft of skills that fall under the umbrella of **investigative/process skills.**

Background Information

A healthy diet involves consuming appropriate amounts of all essential nutrients and an adequate amount of water. Nutrients can be obtained from many different foods, so there are numerous diets that may be considered healthy. A healthy diet needs to have a balance of fats, proteins, and carbohydrates, calories to support energy need and micro nutrients (vitamins and mineral salts) to meet the needs for human nutrition. Fibre in the diet also bulks the food intake and keeps the gut contents moving.

The following table lists the Daily Values (DVs) & Recommended Daily Intakes (RDIs) based on a calorific intake of 2,000 Cal, for adults and children four or more years of age.

Nutrient	**DV**
Saturated Fatty Acids	20 g
Cholesterol	300 mg
Sodium	2400 mg
Potassium	3500 mg
Total Carbohydrate	300 g
Dietary Fibre	25 g
Protein	50 g

Nutrient	RDI
Vitamin A	900 µg
Vitamin C	60 mg
Calcium	1000 mg
Iron	18 mg

Vitamin D	400 IU (10 µg)
Vitamin E	30 IU
Vitamin K	80 µg
Thiamin	1.5 mg
Riboflavin	1.7 mg
Niacin	20 mg
Vitamin B6	2 mg
Folate	400 µg
Vitamin B12	6 µg
Biotin	300 µg
Pantothenic acid	10 mg
Phosphorus	1000 mg
Iodine	150 µg
Magnesium	400 mg
Zinc	15 mg
Selenium	70 µg
Copper	2 mg
Manganese	2 mg
Chromium	120 µg
Molybdenum	75 µg
Chloride	3400 mg

Sample Activities

Packed Lunches

• Set up the scenario of preparing packed lunches.
• Focus on the question - How did you work that out?
• Use the first few questions as whole class activities with students discussing answers in small groups and reporting back. Good idea to use mini whiteboards, voting systems or simply asking other groups to agree/disagree with answers and different ways of working out or articulating how they did each question.

1.John likes apples but his sister, Ruby, only likes kiwi fruit. So when their dad does the shopping he has to work out how many to buy. He reckons that Ruby would need 2 kiwi fruits and John would need 1 apple each day.

a)So how many of each fruit would he need to buy for 5 days in school?
b) If he buys a saver bag of 8 apples, then how many kiwi fruits does he need to provide for the same number of days?
c) If he buys a saver bag of 12 kiwi fruits, then how many apples will he need to buy for John for the same number of days?

2. Jack and Amy's mum decided to replace their Saturday sweet treat with fruit. Jack chose strawberries and Amy chose satsumas. Mum decided that for every Satsuma that Amy had, Jack could have 3 strawberries.

a) How many strawberries does Jack get if Amy has 4 satsumas?
b) How many strawberries does Jack get if Amy has 7 satsumas?
c) How many satsumas does Amy get if Jack has 15 strawberries?

3. Susan likes pears and her brother Lee likes plums. Their mum decided that for every 2 pears that Susan had Lee could have 5 plums.

a) How many plums does Lee get if Amy has 4 pears?
b) How many plums does Lee get if Amy has 10 pears?
c) How many pears does Amy get if Lee has 20 plums?

4. A lunchbox has a packet of crisps that weighs 25g and contains 8g of fat per 100g of crisps. How much fat is there in 1 bag of the crisps?

A. 2g
B. 8g
C. 25g
D. 32g
E. 100g

5. Wheetos crisps are sold in 30g bags and contain 6g of fat per 100g of crisp. Quipo crisps are sold in 20g bags and contain 7.5g of fat per 100g. Which bag of crisp contains the most fat?

6. Most crisps contain about 80g of carbohydrate per 100g of crisp. Bread has about 40g of carbohydrate in every 100g. A slice of bread weighs about 50g, so what amount of crisps contains the same amount of carbohydrate?

A. 8g
B. 20g
C. 25g
D. 40g
E. 100g

7. A 125g pot of fruit yogurt had the following food label:

Energy	500kJ
Protein	5g
Carbohydrate	25g
Fat	1g
Vitamin C	1.25mg
Calcium	200mg

a) How much of each food type would there be in a 250g pot?
b) How much of each food type would there be in a 100g pot?

8. Get pairs of students to use some of the food labels in the appendix to compare amounts of carbohydrate or fat or protein. When you are sure they have some idea of proportionality ask them to prepare some questions for their peers. Get them to judge which are the best questions to demonstrate that they can investigate data and use proportional reasoning.

Food Cards

• Make some sets of food cards (see appendix).
• Give each pair of students the banana and the white bread food cards. Ask them to compare the similar foods with the banana and the white bread. Ask them to explain how they did this.

• Give each group of students 3-4 more food cards and ask them to find the food with the highest amount of carbohydrate. Ask them to explain how they decided this. Collect the 3 highest cards in and display so the whole class can see them
• Now ask them to find the food with highest protein content out of their remaining cards. Again ask them to explain their process and collect and display the cards.
• Next ask them to find the food with highest fat content out of their remaining cards. Again ask them to explain their process and collect and display the 3 highest cards.
• Ask each group to compare the food cards they still have with the high carbohydrate, high protein and high fat cards. How much more of each food group do the 'high' foods have?

The Washing Line

Set up 3 pieces of string as washing lines over about a 2-3m distance. Label one washing line CARBOHYDRATE, the next PROTEIN and the final one FAT. Make 3 copies of the food labels in the appendix. Get the students to work out the range from low to high values for each of the washing lines from the food labels. Mark the range and the midpoint with the values. Then get the students to place the labels on the washing lines with pegs or paperclips.

Ask students to work in groups to compare the foods on the washing lines. How would they describe the spaghetti in tomato sauce in terms of their amounts of carbohydrate, protein and fat?

Then ask them to pin up other labels (perhaps that they have brought in). How do these food compare with the ones they first placed up?

This activity can be developed to look at making changes in their diet. Get students to write out what they eat in a day listing each food or ingredient in a meal separately and ask them to use the details on the washing line to consider amounts of carbohydrate, protein and fat in each. How might they increase the protein/reduce the fat/spread the carbohydrate over more meals etc. in their diet for that day? What might they replace food X with if they wanted to keep up the same amount of protein but reduce the fat?

Testing for Vitamin C

This is an investigation. Read through p11-13 of the PRIMAS report which discusses how closed or open an investigation might be. Using the Fradd et al(2001) framework decide which level of inquiry you want your students to do. The amount of support you give at each stage will determine the level of inquiry and so plan this out carefully.

Demonstrate the effect of vitamin C on DCPIP by showing that a solution of vitamin C solution decolourises the blue DCPIP. Get students to test 2 or 3 of the juices you provide to practise the technique. Ask students to develop a hypothesis to test, and to investigate it systematically. Your classroom organisation may depend on the equipment you have available.

For each group of students:

Vitamin C solution, 1% See CLEAPSS Hazcard. CLEAPSS Recipe card recommends a concentration of 0.1%; this protocol suggests 1%. This solution is LOW HAZARD.

DCPIP solution, 1% (2,6-dichlorophenol-indophenol) is LOW HAZARD; see CLEAPSS Hazcard. CLEAPSS Recipe card recommends a concentration of 0.1%; this protocol suggests 1% so dissolve 1.0 g of dye in 100 cm^3 of water

Graduated pipette, syringe or burette.
10 pipettes
10 test tubes and rack
Fruit juice and squash samples

Assessing your students:

Using your Fradd et al(2001) framework, work out what evidence you would be looking for in each of the cells where students take control of the inquiry.

INQUIRY LEVEL	Questioning	Planning	Carrying out plan	Analyse data	Conclude	Report	Apply
0	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher
1	Teacher	Teacher	Student/ Teacher	Teacher	Teacher	Student	Teacher
2	Teacher	Teacher	Student	Student/ Teacher	Student/ Teacher	Student	Teacher
3	Teacher	Student/ Teacher	Student	Student	Student	Student	Student
4	Student/ Teacher	Student	Student	Student	Student	Student	Student
5	Student	Student	Student	Student	Student	Student	Student

TABLE 3 FRAMEWORK FOR INQUIRY (FROM FRADD, 2001)

2.2.2 Speed 1

Why teach this topic?

Everyday language uses these terms in relation to journeys, whether on foot, bicycle, car or ‘plane. So there is relevance to pupils, and a wealth of opportunities to assemble and interpret these everyday associations. As the discussion extends to the problems of safety in travel, such topics as acceleration, braking distance and reaction times become significant.

A second reason is that the topic offers many opportunities for numerical work, quantitative reasoning, measurement, and use and interpretation of graphical representations. A particular reason for this is that everyone, and particularly those who study science, are trapped between everyday use of both Imperial and international unit systems, so such intra-conversion becomes necessary.

A third reason is that the concepts and measures involved pervade all parts of science, particularly in topics associated with the physics of motion. The links between force, acceleration and mass are fundamental, and studies of motion is straight or curved trajectories are necessary components in studies of the motions of objects ranging from the galaxies to electrons. More broadly, rates of reaction and rates of growth are other areas in which fluency with the topics concerned here is essential.

Background information

Several of the activities involve changing between different units and/or between different unit systems. The extent to which pupils are helped with these aspects of the task is up to the following data might be a guide:
I mile = 5280 feet = 1.610 km.
I m = 39.37 inches; 1 km = 3280 feet = 0.62 miles.
1 mile per hour = 1.47 feet per second.
Acceleration in free fall under gravity = 9.81 m per sec^2 = 32.2 feet per sec^2.
Thus for example, as 30mph= 44.1 ft per sec., so to stop in 1 sec means (44.1÷32.2) =1.37g

The activities give several opportunities for students to search the web for data. For example, several websites, e.g. Wikipedia, give extensive information about effects on the body of large accelerations and decelerations e.g effects depend on whether your body is aligned along, or perpendicular to, the direction of travel, and around 5g or more it can be dangerous

For the measurement of speeds in the classroom or lab. pupils will need metre rules and stopwatches. For exploring journey times, they will need local maps with clear indications of the scale of the map, and 30 cm. rules.

For the measurement of reaction times, metre rules and stop watches are required, but pupils have to use their measurements, of the distance a ruler fell in free fall under gravity if it starts from rest, to calculate the time of fall. They might be asked to calculate that for themselves, or given the following data :

Distance(cm.)	15	16	17	18	19	20	21	22	23	24
Time (secs.)	0.175	0.181	0.186	0.192	0.197	0.202	0.207	0.212	0.217	0.221
Distance(cm.)	25	26	27	28	29	30	31	32	33	34
Time (secs.)	0.226	0.230	0.235	0.239	0.243	0.247	0.252	0.256	0.259	0.263

Sample Activities

Activity A – how fast can you go?

Pupils can be asked to make measurements to find out:

How long does it take you to walk 5 metres, walking slowly, then walking quickly?

How far you can walk in 5 seconds, walking slowly, then walking quickly?

How can the time and the distance measurements be related to one another? What can you work out from the measurements?

In each case they could be asked to estimate the possible error in their result and then be asked – are your answers to the first two questions above consistent with one another?

Activity B – getting to school

(a) Make a measurement of the length of your journey from your home to your school.
How long does your journey take?
What can you calculate from these measurements? How does your result compare with the answers you worked out in Activity A?

(b) If you get to school in a car or in a bus, how long would it have taken you to walk (i) at a comfortable speed (ii) at your fastest speed (use the Activity A results).
A similar question can be asked for those who come by bicycle, whilst those who walk can be asked to estimate how long it might take by car.

(c) For any one of the results from parts (a) or (b), draw a graph of speed against time (i) assuming uniform speed (ii) representing what really happened What would a pair of graphs, one for walking, one for traveling in a car or bus, have in common if both were drawn for the same journey? What does the area under each of these graphs represent?

(d) For the two graphs used in part (c), draw the corresponding pair of graphs of distance against time.

Activity C – getting away from it all

Find out some data to enable you to draw a graph of speed against time for an aeroplane journey from London to New York. Your graph should represent the journey as accurately as possible.

Compare the values of acceleration that you could estimate from your graphs for activity B: how do these values compare with the acceleration for free fall under gravity?

Activity D – fast and slow speeds

Some motion can be so slow that it may not be noticeable. List some very slow speeds – you must give an approximate numerical value to every item listed. What is the slowest speed you, or others, can think of ? Similarly, list some very fast speeds – again with numerical values. What is the fastest speed you can think of ?

Some movements can be so slow that with a quick look you may not notice that there is any movement at all. Can you think of some examples? (Speed of growth of different plants, an object just heavy dense enough to sink in a very viscous fluid, rate of growth of your own hair or finger-nails)

A possible experiment here is to place a drop of a very viscous liquid (a thick honey or syrup might be suitable) on the flat part of a plate, then slowly tip up the plate until the liquid just starts to move. Then the plate can be supported at an angle just below the angle at which there is perceptible movement, and left for some time to determine whether movement has occurred, and if so to measure the speed.

Activity E - speeding up and slowing down

Here is a velocity-time graph for a driver's journey. Draw the acceleration-time graph for this journey.

The area under the line in the velocity time graph represents the distance travelled. What does the area under the acceleration-time graph represent?

This can be a tough one: label the first graph in mph – say up to 50mph, against minutes – say in the range 0 to 120 minutes – and then they have to choose a scale for accelerations – feet/sec^2 might do. A graph with two periods of acceleration and one for the final deceleration, with all three having different gradients, and with stretches of uniform speed in-between, would serve the purpose. Then pupils have to distinguish the positive and negative accelerations. The first graph should be straight lines only, so all accelerations are uniform, then the second is a set of rectangular blocks, and if the journey ends with the driver having stopped, the net area will be zero. The question can be made easier by giving hints about these issue. A sample graph is available).

Activity F – quick on the draw

(a) In Western films, it's the cowboy who can react the fastest who wins the duel, but reaction times matter in many more everyday situations. So how can you measure your own reaction time? Can you think of a way to measure your own, or one another's reaction time, given that typical values are around 0.2 seconds?

(b) Whatever may be the outcome of that discussion, pupils might then be asked to work in pairs to measure their reaction times. One pupil holds a one-metre stick vertically; the other stands with her/his lower arms horizontal so that the hands hold the bottom end of the sick; then that pupils opens her/his grasp a little so that the stick can fall freely between the hands.

Then, without giving any warning, the first pupil lets go of the stick: the second pupil grasps t he stick as quickly as she/he can to stop it falling, but because of the delay due to that pupil's reaction time, the stick will have fallen part of the way towards the floor. The pupils have to measure the distance fallen i.e. the distance from the bottom end of the stick to the point at which the hands grasped it to stop it falling. They can then be asked to work out how long it took to fall this distance – which gives the reaction time. Pupils will need to have the value of the acceleration for free fall under gravity: alternatively, the teacher may give them a table of values of distance against time for free fall over (say) 15cm. to 35cm.

(c) This work can be followed up by asking pupils to estimate how far they would travel in a bicycle between noticing a danger ahead and starting to swerve or apply the brakes: the same question can be asked about a car travelling at the speed limit on a busy town road.

Activity G – too many g's ain't good for you

An inventor claims that he has found a way to bring to rest a car travelling at 60mph within half a second. Some say this can be dangerous, for even if his body does not hit anything, the driver's internal organs can be damaged by the rapid deceleration involved. Is this a valid objection? To find out, use the web to find out about deceleration dangers for pilots and astronauts.

Activity H – straight or curved?

There is a distinction between velocity, which is the rate of travel in a straight line, and speed, which is total distance travelled whether or not it was in a straight line. Which of your measurements or estimates in the above activities were about velocity, and which were about speed ?

A driver travels from home to his friend's house and is accused of breaking the speed limit: he denies this, saying that he did not go the long way round, but went by a direct route. Is this a good argument?

The moon goes round the earth at an (approximately) constant speed but not at a constant velocity. What difference would it make if it went at a constant velocity? Why doesn't it do so?

2.2.3 Speed 2

Background:
Speed is one of the key concepts of science. Its foundation takes place during the teaching of kinematics, but the children have to understand the concept in other parts of physics, in chemistry (speed of reactions) and in biology (for example the motion of animals). In disciplinary dimension it can be understood as a vector (velocity) *or* as a scalar quantity (speed). In the tasks below the students interpret and calculate the speed on the basis of distance and time, thus developing their content knowledge, practice their investigation skills in science, carry out measurements and observations, record and analyze data, design experiments, identify variables and check their predictions. Proportional thinking stands in the focus of cognitive dimension of knowledge, the students predict and compare different speeds and explore the factors influencing speed. The social dimension of knowledge is also important, ie. speed is embedded into everyday contexts. The aspect of safe transport, the designing of transport in the individual's life and the world of sports also appear.

Learning environment:
The structure of the tasks are guided, ie. they give opportunity for inquiry-based learning in such a way that the students are motivated to learn and think individually with the help of questions and scaffolding. During the teaching mainly the group work methods are recommended, but there is opportunity for the whole class to discuss the definition of the problem, to formulate the research questions, evaluate the results and to draw the conclusions. In the case of some tasks individual reasoning and searching for solution might be an effective method. The experiments can be carried out with relatively simple tools partly in the classroom, partly out of the school. If the opportunities are given, the computerized measurement tools can be used as well (see *task 3*).

Sample Activities

<u>Activity A: Way to school</u>
<u>Research question:</u>
- How would you design your way to school?
- What data and aspects are to be considered during planning?
- How could you compare your possible routes and vehicles with one another?

<u>a) Measuring the speed of a pedestrian</u>
Planning/ execution:
(Tools available: stopwatch, long tape-measure)
- Design measurement methods to measure your walking speed!

Planning and guiding questions:
- How could you make the measurement more exact?
- What mistakes might occur?
- How could you identify the difference between the speed of hasty walking and strolling?
- Can you suggest a practical method to keep a relatively constant speed?

<u>b) Measuring travelling speed</u>
- Measure the average velocity of the vehicles (eg.: car, underground, bus, tram, bicycle) used during travelling to school!
- Include the data of each phase of the path and the forms of transport into a chart!

- Compare the distances and forms of transport on the basis of your charts!

Planning and guiding questions:

- How could you tell the length of each phase of the paths?
- What traditional or modern tools could you use?
- What advantages and disadvantages are there of the possible tools and methods?
- How could you design the chart in such a way that
    - each phase of the paths are transparent,
    - every measurement data and calculated result appears,
    - the spatial location of each phase is clearly identifiable?

Discussion, conclusions:

- What factors influence the average velocity of each form of transportation?
- In the case of which form of transportation are the fluctuations of speed the biggest?
- How could you decide which form of transport is the fastest?
- What factors do you take into consideration while designing your route and choosing the paths and forms of transport?
- Could you find an alternative route/ form of transport?
- What advantages and disadvantages of the alternative routes have?
- What further communal and global factors might influence your choice?

<u>c) The estimation and comparison of speeds</u>

Every morning four students walk to the same school nearby. Kate and John live in the same house, therefore, they cover the same distance, but not within the same time. Peter lives further, and arrives at the school at a longer period of time. Mary lives the closest to the school and her route takes the shortest time. All the four students measured the length and duration of their way to school. The data are included in the chart below:

	Kate	John	Peter	Mary
Distance *(m)*	1600	1600	2400	1400
Time *(mins)*	26	24	28	14
Speed *(m/sec)*				

- Which student was the fastest?
- Using estimation align the four students on the basis of their speed!
- Prove your estimations with calculations!

<u>Activity B: Speed and safe transport</u>

<u>Research questions:</u>

- How safe is transportation by car?
- How much risk of an accident does traffic mean?
- How does the choice of speed influence the safety of transport by car?

<u>a) Measuring the speed of transport:</u>

Planning/ execution:

(Tools available: stopwatch, long tape-measure)

- Design a measurement method for measuring the speed of cars running on the road near the school!

- Make a chart from the measurement results!
- Provide the data with different measures!
- On the basis of what aspects can the data be analyzed?

Planning, guiding questions:

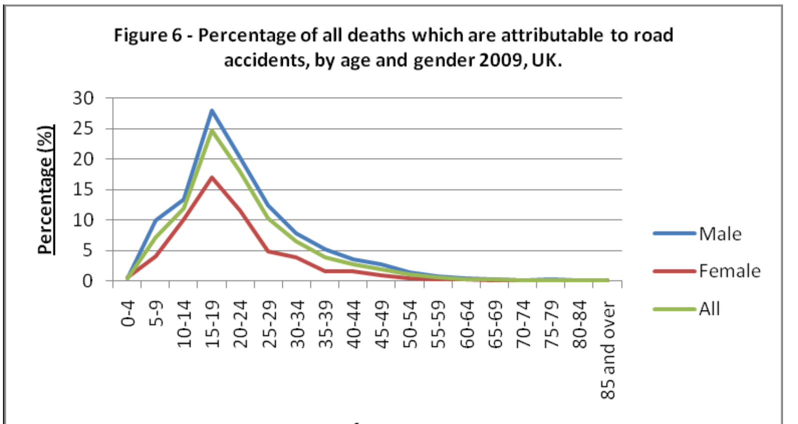
- What speed can be measured with the chosen method, how is it different from the laser method the police use?
- How shall the measurement be changed so that you can calculate the average velocity of the transport?

Discussion, conclusions:

- Did the drivers keep the speed limits?
- Can the examined part of the road be regarded safe from the viewpoint of the pedestrians?
- What dangers did you experience?
- What advice could you suggest in order to increase safety?

b) Graph analsyis:

- What relationship does the graph present?
- Identify the age group which is the most endangered in the respect of the risk of accidents!
- How could you explain the differences between the age groups?



http://www.rospa.com/roadsafety/default.aspx

c) Data analysis:

- What conclusions can you draw on the basis of the chart below?
- What additional data would you need in order to be able to tell which form of transport means the biggest and the lowest risk of accident?
- Estimate the missing data!

Mortality statistics in accidents (England – Wales, 2011)

Total mortality in accidents	17 201
Total mortality in transport	1 970
Car (driver, passenger)	808
Motorcycle	347
Pedestrian	153
Cyclist	96

http://www.guardian.co.uk

Activity C: Speed and braking distance

Research question:
What factors determine the stopping distance of cars?
How does the starting speed influence the car's braking distance?

a) Stopping and braking distance

Decide on the basis of data and pieces of information on the a braking distance calculating site:

- What is the difference between braking and stopping distance?
- Which are the fixed, independent and dependent variables in the case of calculating braking distance?

Braking distance calculator: http://forensicdynamics.com/stopping-distance-calculator

b) Measuring braking distance

(Tools necessary: toy car, tape-measure, sand, rough rubber; for the slope: thick books, hard cardboard or wooden table; for measuring the speed: stopwatch or instrumental measure tools, eg.: webcam system)

Planning/ execution:

- Design a measurement system using the available tools!
- In order to settle the starting speed of the car, use a slope, the height of which can be varied!
- Measure the speed of the car coming down from the slope, eg.:
  - on the basis of time necessary for covering a given distance (eg. 1m), or
  - with the help of light gate, or
  - with the use of Webcam Laboratory, *(http://www.webcamlaboratory.com/kinematics.php)* or
  - any other way
- Construct an adequately long track for the stopping of the car with
  - a few mms thick sand layer, or
  - a rough rubber
- Record the data of measured speeds and braking distances!
- Illustrate the length of the braking distance in relation to the speed!

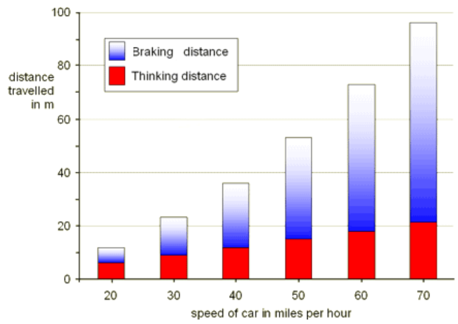
Planning, guiding questions:

- What is the optimal height of the slope?
- How can you keep the thickness of the sand at a constant measure?
- What is the optimal number of measurement at the given speed?

Discussion, conclusions:

- On the basis of the graph what conclusion can be drawn in connection with the relationship of the speed and the braking distance of the car?
- On the basis of the above stated relationship argue why is speed limited more strictly in a populated area than on the open road?

c) Graph analysis (*after finishing part b) of the task*)



On the basis of the graph answer the following questions:

- How does the length of reaction time change with increasing speed?
  (Compare it with the braking distance!)

- What is happening during the reaction time, why is it necessary for the driver?
- What factors might cause the increase of the reaction time?
- What regulations try to avoid accidents originating from this?

http://www.bbc.co.uk/schools/gcsebitesize/science/

Activity D: Record keepers

The results of the running competitions during the a 30th Olympic Games in 2012 in London:

Name of the Olympic Champion	**Country**	**Distance** (m)	**Time** (min:sec.)
Usain Bolt	Jamaica	100	9.63
Usain Bolt	Jamaica	200	19.32
James Kirani	Grenada	400	43.93
David Lekuta Rudisha	Kenya	800	1:40.91

- Illustrate the results of the four runners in separate distance-time graphs!
- Link the points with a line! Choose the times necessary for the covering of 100 meters and indicate them in the graphs, then link these points with a line!

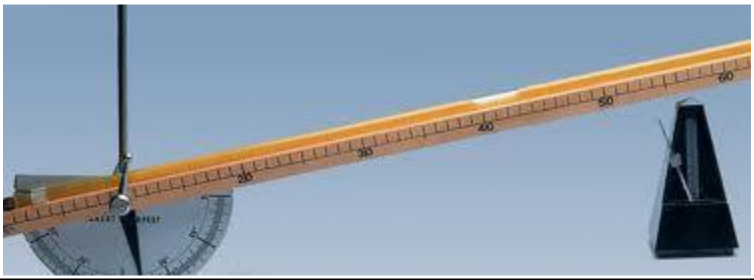
Questions:

- What is the difference between the graphs?
- What shape is the line connecting the four points?
- What can be stated about the speed of the runners on the basis of the graphs?
- What result would have Usain Bolt achieved if he had run 800 meters with his average velocity of the 100 meters?
- Why is the above case impossible?

Activity E: Uniform Linear Motion and Uniformly Accelerated/decelerated Linear Motion (for ages 12-14)

The investigation of uniform linear motion

<u>Task: the investigation of the characteristics of uniform linear motion with Mikola tube and making a distance-time graph.</u>


(Mikola tube)

- The introduction of the investigation process. The metronome ensures the equal time sequences, the children label the actual position of the bubble with a chalk. They measure in three different inclination angles. Two methods of data recording are possible: either the children record the distances from the starting position of the bubble to the end of each click, or they record the distances between two clicks.
- The preparation of the chart representing the investigation data.
- Carrying out the investigation in group work, with the help of the teacher if necessary.
- The preparation of the distance-time graph on the basis of the investigation chart with the help of the teacher if necessary.
- The analysis of the distance-time graph.
- How does the speed of the bubble change if we increase the angle of the tube?

(As the graph has a maximum, there is direct proportion only in the case of small angles (eg. 10°, 15°, 20°).)

- How long distances does the bubble come within the same time intervals?

1) <u>Track pattern</u>

<u>Task: the recording of the track pattern of an object in motion, for example a thrust toy car, and the implication of the characteristic of the motion on the basis of the track pattern.</u>

- Tools: Ruler, chalk, pencil, exercise book, watch and a toy car on the side of which an empty can is tied, on the bottom of which there is a tiny hole, so that the water will uniformly drop. The children shall take this down to a blacktopped yard where they push the car and measure the distances between two drops.
- The preparation of the chart representing the investigation data. The unit of time is second and the unit of distance is centimeter.
- The negotiation of the results.
- What was the toy car's motion like? How do we know this?
- The graphic representation of the motion.
- The analysis of the graphs of the two tasks, ie. the investigation with the Mikola tube and the investigation with the toy car.

The Relationship Between Distance-time, Speed-time and Acceleration-time

<u>Task: Preparation of graphs on the motion of a tram between its two stops, making the distance-time, speed-time and acceleration-time graphs.</u>

In order to simplify the task, the tram line is straight, the vehicle does not turn and its acceleration is constant during the motion.

The track pattern of the motion looks like this:

Data

- the distance between two stops: 500 meters
- acceleration of the tram: 0.5 m/s^2
- the duration of the acceleration: 20 seconds then it goes with steady speed and then slows down again for 20 seconds

Solution

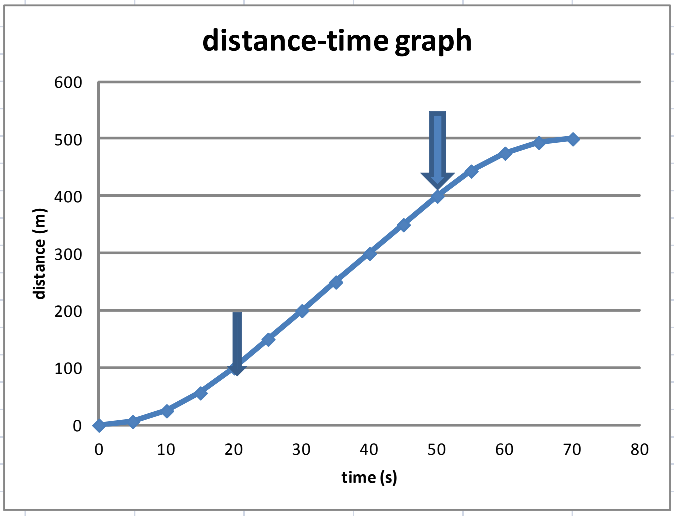
We can calculate the speed like this: $v = a \cdot t = 0.5\ m/^2 \cdot 20\ s = 10\ m/s$. The tram goes 100 m in 20 s. It decelerates for 20 s as well and goes 100 m again. So, the tram goes 300 m with 10 m/s steady speed in 30 s. The tram goes for 70 s altogether.
When the tram accelerates, the distances making in the same time, get longer. The ratios of the distances are 1:3:5:7. Therefore the formula for the distance is: $s = a/2.t_{gy}^2$
The distance gets evenly longer: $s = v_{max} \cdot t_e$.
When the tram decelerates, we can calculate the distance like this: $s = 400\ m + v_{max}.t_l - a/2.t_l^2$

Time (s) – distance (m) chart. We choose 5 seconds as a unit of time.

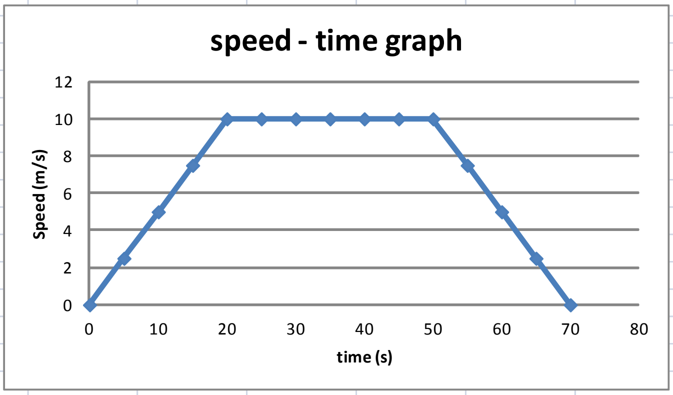
The unit for distance means the distance covered within the first time unit –in this case 6.25 meters. This is the unit in relation to which we compare the distances covered during the other time units. During acceleration 1:3:5:7, during steady speed it is 8, during deceleration it is 7:5:3:1.

Time of measurement (s)	Distance measured from the starting point (m)	Distance between the points	Unit for distance
0	0		
		6.25	1
5	6.25		
		18.75	3
10	25		
		31.25	5
15	56.25		
		43.75	7
20	100		
		50	8
25	150		
		50	8
30	200		
		50	8
35	250		
		50	8
40	300		
		50	8
45	350		
		50	8
50	400		
		43.75	7
55	443.75		
		31.25	5
60	475		
		18.75	3
65	493.75		
		6.25	1
70	500		

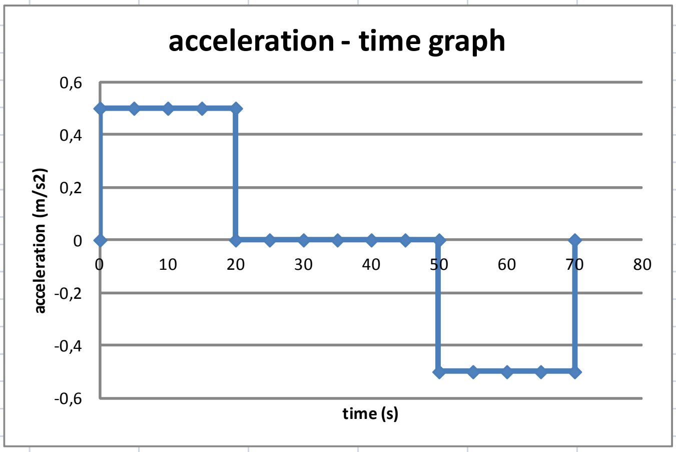
time (s)	distance (m)	
0	0	
5	6,25	
10	25	
15	56,25	acceleration
20	100	
25	150	constant speed
30	200	
35	250	
40	300	
45	350	
50	400	
55	443,75	deceleration
60	475	
65	493,75	
70	500	



time (s)	speed (m/s)	
0	0	
5	2,5	
10	5	
15	7,5	acceleration
20	10	
25	10	constant speed
30	10	
35	10	
40	10	
45	10	
50	10	
55	7,5	deceleration
60	5	
65	2,5	
70	0	



time (s)	acceleration (m/s2)
0	0
0	0,5
5	0,5
10	0,5
15	0,5
20	0,5
20	0
25	0
30	0
35	0
40	0
45	0
50	0
50	-0,5
55	-0,5
60	-0,5
65	-0,5
70	-0,5
70	0



The graph of the motion of tram line 4

- Analyze the graphs and indicate in the first graph where the tram accelerates, where it goes with a steady speed and where it slows down.
- In the second graph describe the changes of the tram's speed.
- In the third graph indicate how long the tram accelerates, how long it goes with a steady speed and how long it slows down.

2.2.4 Reaction Rates

Why teach this topic?

Rates of reaction is a topic that has relevance in everyday life from cooking, to taking medicines to aging! Usually this topic in investigated in schools using tetheffect of acids on marble chips – both of these materials are mainly unfamiliar to the students when they are starting their studies in chemistry. Therefore the context as outlined below of effervescent vitamin C tablets was chosen as it familiar to the students and is non-threatening in that students can handle these materials without fear of burns or acids spills.
Using a context that is known to the students can increase interest and motivation in the subject matter. In this series of activities, effervescent vitamin C tablets can be used to distinguish between solubility and reaction and also to discuss ideas of the factors that can affect the reaction rate, particularly surface area and temperature. The following is a number of activities that can be used with students to develop their understanding of key concepts underlying rates of reaction while also developing investigative and inquiry skills.

These activities are suggestions only and can be used in a variety of ways to suit the particular class grouping.

Key areas:

Concepts: factors that affect reaction rate – including temperature, concentration of reactants, surface area of reactants
Reaction of acids with carbonates, release of CO_2

Investigative skills: Planning an investigation, identifying variables (relevant and irrelevant), handling complex system to reduce number of variables

Determining relationship between variables

Determining causality

Reasoning: Causality, proportional reasoning, (graphical interpretation)…

Context: **effervescent vitamin C tablets**

Required: effervescent Vit C tablets, Na_2CO_3, citric acid, ascorbic acid
Apparatus to trap CO_2 (funnel, tubing, lime water), range of beakers, measuring cylinder, deionised water, pH probe (universal indicator paper)

Sample Activities

Initial Questions:

- What is happening when I place a tablet in water?
- What is present in the tablet that may be causing this?

Students can do this themselves in groups and should make note of their observations which may include: see bubbles, movement of tablet, 'dissolving of tablet', 'fizzing sound'….

From reading the packet, there is Na_2CO_3, citric acid and ascorbic acid present

- Encourage the students to come up with their own question to investigate

Possible investigative questions:

- What gas is present in the bubbles and where has it come from?

  Students can collect the gas formed and check if it turns lime water, combustion characteristics, etc. (distinguish it from oxygen)

  Students can determine the combination of reactants that will produce CO_2 e.g. addition of any one of Na_2CO_3, citric acid or ascorbic acid to water on there own does not liberate gas to the same extent, but addition of both citric and ascorbic acids to Na_2CO_3 produces CO_2.*

  Important here to distinguish between dissolving and reaction e.g. each of the substances Na_2CO_3, citric acid and ascorbic acid will dissolve in water but it is only when the carbonate is combined with the acid that reaction occurs (as seem by formation of new substance CO_2)

- Can we measure the rate of this reaction?
  - (i) Students can devise a way of measuring the time for the total reaction when tablet is dropped into water (e.g. by measuring time for bubbles to stop – but decision has to be made when is the last bubble! – devise a statement such as 'when there are no bubbles for 3 secs' or such like; by measuring the time taken for the tablet to move from the bottom of the container)
  - (ii) Students can then devise experiment to determine the total amount of CO_2 produced from one tablet
  - (iii) Students can then devise an experiment to determine the amount of CO_2 produced with time from one tablet

  Reproducibility – variation within the class group or variation within students own experiments

- Quantify the rate – is the rate of release of bubbles the same all the time?, drawing graph of e.g. amount of CO_2 released vs time; how can the rate be determined from the graph – is the rate constant, where is it fastest/slowest (determining slope at different time intervals)
- Can we change the rate of this reaction? Design a series of experiments to investigate their hypotheses.

  Students could suggest **

  - using hotter water /temperature
  - using different amounts of tablets /concentration
  - changing the amount of water used per tablet / concentration

With more advanced chemistry group, it is interesting to investigate the rate of reaction between Na_2CO_3 and citric acid and compare to that between Na_2CO_3 and ascorbic acid. Then to suggest explanation of why citric acid is added to these tablets (Na_2CO_3 reacts with citric acid first to release carbon dioxide leaving solution of ascorbic acid) – leading to further questions in terms of the amount of citric acid required, limiting reagent, which one is in excess – are more bubbles produced if more citric acid added/more ascorbic acid added/ more Na_2CO_3 added.

- Do all these effervescent tablets have the same rate of reaction?

  Students could suggest using different products with varying amount of Vit C (ascorbic acid).

  Can they interpret the labels to explain the rates of reaction determined.

  Some of these tablets contain 1000mg of Vit C, well in excess of the recommended daily allowance – so how many tablets should you take to have your RDA?

The Fradd et al (2001) Framework could be used to note evidence you would be looking for in each of the cells where students take control of the inquiry (attached at end).

INQUIRY LEVEL	Questioning	Planning	Carrying out plan	Analyse data	Conclude	Report	Apply
0	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher	Teacher
1	Teacher	Teacher	Student/ Teacher	Teacher	Teacher	Student	Teacher
2	Teacher	Teacher	Student	Student/ Teacher	Student/ Teacher	Student	Teacher
3	Teacher	Student/ Teacher	Student	Student	Student	Student	Student
4	Student/ Teacher	Student	Student	Student	Student	Student	Student
5	Student	Student	Student	Student	Student	Student	Student

Assessment

* Students should devise a matrix of 3X4 to determine all the possible combinations of the 3 reagents with water

** Designing the experiment – students should have considered –

their hypothesis,
variable that they will measure, variable that they can change, variables that they must keep constant,
set up of the experiment (including necessary equipment)
manner of recording results.

Questions focussed at Scientific Concepts:

Q.1 Marble chips reacts with acid to produce CO_2 gas. Marble is available as a board, large lumps and as ground powder. Suggest, with explanation, which forms of marble should be used to generate CO_2 most quickly.

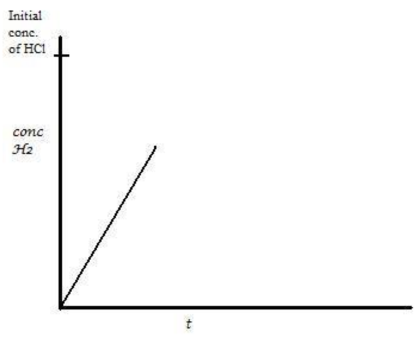
Q.2 Vinegar is often used to clean surfaces at home. If you have a marble ($CaCO_3$) worktop, would you use vinegar – explain why/why not.

Q.3 Discuss a reaction that you know and the affect that temperature would have on it

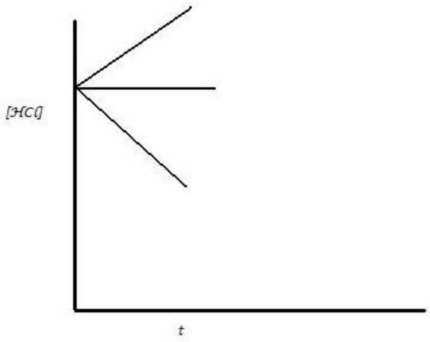
Q.4 Give a set of data – e.g. amount of CO_2 produced vs time in a given reaction;
represent the data on a graph,
describe what the graph tells you – in terms of where the slope is greatest and slope least.
(advanced) Draw on the graph a line showing the change in concentration of Na_2CO_3 over this time

The following questions could be applied directly to the experiments carried out or can be given within a different context of the Mg plus HCl reaction.

Q 1 (i) In the reaction of HCl with Mg to form H_2 (reaction HCl + Mg → $MgCl_2$ + H_2), the change in concentration of H_2 is shown on graph (A). From the point shown, draw in how the HCl concentration would change over the same time
(Alternative question - select which line in graph B shows how the HCl concentration changes over the same time).



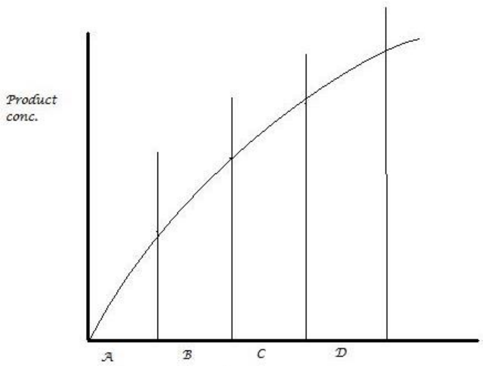
Graph A



Graph B

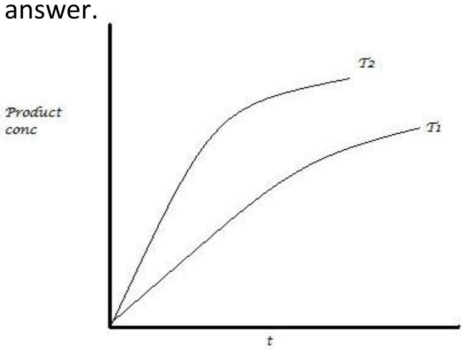
ii) If the reaction continued until all the Mg was used up, extend the graph (A) to show how the H_2 concentration would change.

Q2. In a particular reaction, the concentration of product is shown (graph C). During which time interval (A – D) is the rate of reaction the fastest <u>or</u> put rate of reaction in order from fastest to slowest.



Graph C

Q3. For the reaction shown in Graph D, at which temperature is rate of reaction the highest/ slowest? Explain your answer.



Graph D

References

Csapó, B., & Szabó, G. (Eds.) (2012). *Framework for diagnostic assessment of science*. Budapest: Nemzeti Tankönyvkiadó. http://edia.hu/sites/default/files/books/Science_Framework_English.pdf

Csapó, B., Csíkos, C., Korom, E., & B. Németh, M. (2013). Assessment strategies in inquiry-based science education. Manuscript, SAILS project.

Korom, E., B. Németh, M., Nagy, L., & Csapó, B (2012). Diagnostic assessment frameworks for science: Theoretical background and practical issues. In B. Csapó & G. Szabó (Eds.). *Framework for diagnostic assessment of science* (pp. 147-174). Budapest: Nemzeti Tankönyvkiadó.

Mullis, I. V. S., Martin, M. O., Ruddock, G. J., O'Sullivan, C. Y., Arora, A., & Eberber, E. (2005). *TIMSS 2007 Assessment Frameworks*. Boston: TIMSS and PIRLS International Study Center, Lynch School of Education, Boston College. http://timss.bc.edu/timss2007/frameworks.html

Mullis, I. V. S., Martin, M. O., Ruddock, G. J., O'Sullivan, C. Y., & Preuschoff, C. (2009). *TIMSS 2011 Assessment Frameworks*. Boston: TIMSS and PIRLS International Study Center, Lynch School of Education, Boston College. http://timssandpirls.bc.edu/timss2011/frameworks.html

OECD (2009). *PISA 2009 assessment framework – Key competencies in reading, mathematics and science.* Paris: OECD Publishing. http://www.oecd.org/pisa/pisaproducts/44455820.pdf

OECD (2013). *PISA 2012 assessment and analytical framework. Mathematics, reading, science, problem solving and financial literacy.* Paris: OECD Publishing. http://dx.doi.org/10.1787/9789264190511-en