How Best to Maintain a Metal Bridge?

Teacher Guide

This decision making exercise is intended to reinforce previous knowledge on rusting. It introduces through simple laboratory experiments, which students can plan (if the students are unaware), the need for oxygen and water to be present for rusting to occur. The exercise also allows students to explore the use of a sacrificial metal to protect iron and includes theoretical understanding of reactions between dissimilar metals (depending on the conceptual level required by the curriculum).

As a major aspect of the script, a decision making exercise is introduced. Students are called upon to reflect on factors (besides scientific ideas) that need to be taken into account in making a decision on the most appropriate way to protect a metal bridge. This may range from doing nothing - the cheapest, to galvanising it - a scientific answer. In between could be environmental, economic or societal solutions. All are possibilities, but the difficulty is to decide which is the most appropriate and then to explain the choice.

Lesson Learning Outcomes

Lesson 1

At the end of this lesson, students are expected to be able to:

- State that iron rusts
- Suggest ways to investigate the factors that cause iron to rust

Lesson 2

At the end of this lesson, students are expected to be able to:

- Undertake and understand experiments that can be performed to show the factors that cause iron to rust

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Lesson 3

At the end of this lesson, students are expected to be able to:

- Explain why oxygen and water are needed for iron to rust
- Suggest a formula for rust

Lesson 4

At the end of this lesson, students are expected to be able to :

- Suggest experimental procedures to determine the sacrificial metal when two metals are put together
- Predict the likely outcome when metals are put together in an atmosphere that prvides both oxygen and water.

Lesson 5

At the end of the is lesson, students are expected to be able to

- Identify the reactivity series
- Justify the decision as to the best way to protect a metal bridge.

Suggested Teaching Strategy

The guidelines are given in 4 parts – (1) previous knowledge (2) planning for the investigation (3) student experimentation and (4) post experimental follow-up.

Part (1) – obtaining students' conception about factors affecting rusting (5 minutes)

Lesson 1

The teacher can

- Write the word 'rust' in a box in the middle of the black(white)board
- Initiate a brainstorming session with students obtaining their ideas about rusting and, in particular, the conditions necessary for rusting to occur (as usual in brainstorming the teach access all student answers irrespective of whether they are, or are not appropriate or conceptually correct)
- Write the students ideas from brainstorming on the black(white) board linked to the term rust using appropriate connecting words

Part (2) - gaining evidence - testing ideas of factors affecting rusting (approx 20 minutes but may be much longer depending on students' prior knowledge and previous practice in planning experiments)

Lesson 1

The teacher can

- Guide students to explore the summary of ideas on the blackboard to determine potential factors affecting rusting
- Establish that air(oxygen) and water could be factors necessary for rusting (students may suggest others as well)
- Introduce the scientific research question 'how can we find out what factors affect rusting?'
- All students (in groups) to come up with possible procedures to investigate whether the factors identified influence rusting
- Go around the groups during the planning exercise advising as necessary, until student groups have completed their work or they have stopped because of insufficient guidance.
- (assuming time is sufficient) Select good ideas from the different groups (in a whole class situation) – the groups are selected by the teachers based on the teacher's prior knowledge gained from interacting with the groups in the group work session.
- (assuming time is still sufficient) Guide, based on the group submissions (or lack thereof) the experimental procedure to solve the problem posed by the question

Part (3) – experimentation (1 lesson)

Lesson 2

The teacher can

- Ensure student groups are
    - aware of the purpose of the experimentation
    - know what apparatus, chemicals they need
    - are conversant with safety procedures
- Allow students to prepare for the experimental work and put forward their hypotheses
- Allow students to set up the experiments which will then be left until next lesson to observe the outcomes
- (if time permits) Instruct students, individually, to describe the procedure they followed in their notebooks under the research question (the title) and to include their predictions of the likely outcome.

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Part (4) – post experimental follow-up (10-15 minutes – more if students write the report at this time)

Lesson 3

The teacher can:

- Allow students to examine their experimental outcomes and determine whether their predictions were, or were not correct
- Discuss, using a whole class question and answer, whether all outcomes were the same for each group and the meaning attached to the outcomes
- Ensure the students can conclude form their experiments (it is expected the conclusion will be that air(oxygen) and water are necessary for rusting)
- Request students to write down in their books their suggested formula for rust (go around the class to check whether students have sufficient background to complete this task which requires transference of understanding from one situation to another.
- Guide the whole class, by question and answer plus teacher input as needed, to a suggested formula (satisfactory for the whole class) (a suitable response here could be $FeO.H_2O$ unless students are familiar with oxidation numbers when $Fe_2O_3.H_2O$ is expected)
- Explain to the class that rust is thus a complex substance and not a simple oxide
- (if not already undertaken) Students write a report of their experiment explaining the procedure followed and whether their predictions were correct (if report was written earlier, then this part is now added). They can make the appropriate conclusion and give a suggested formula for rust.

Part (5) introducing sacrificial metals

Lesson 3

- Point out that some metals react more quickly in air or water and demonstrate the action of sodium on water compared with magnesium (where the magnesium needs the water heated and turn into stream to give a fast reaction.
- Suggest that metals more reactive that iron could react rather than the iron and thus offer a form of protection
- Guide the students to suggest how experiments where one metal is a sacrificial metal can be carried out. It is expected that with appropriate guidance the students will suggest wrapping one metal with another.

Part (6) – conducting experiments on sacrificial metals

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Lesson 4

The teacher can:

- The teacher can then suggest that it is appropriate to take iron nails and to test whether a metal can be sacrificial by wrapping the nail with strips of (a) copper, (b) zinc, (c) magnesium, (d) aluminium (other metals are possible).
- Provide worksheets for the students so that they can set up the experiments in petri dishes using salt water, add a drop of potassium hexacyanoferrate(II) solution [$K_4Fe(CN)_6$] which will turn blue if the iron rusts and then leave the dishes without lids until the next lesson.

Part (7) - interpreting and concluding for the experiment

Lesson 5

The teacher can:

- Allow the students to observe the outcomes from the experiments and make conclusions
- Expect the students to realise that copper cannot act as a sacrificial metal whereas the others can (aluminium has a coating of oxide and the metal is heavily protected by this and may not protect the iron)
- This illustrates that zinc and magnesium can act as sacrificial metals as they are more reactive than iron
- Guide students to explain what is happening

Part (8) - developing the reactivity series

Lesson 5

The teacher can:

- Guide students to suggest further experiments to determine the actual series for all the metals (in this case it is probably better to consider comparable rates of reactions with water and between metal (and metal oxide)

Part (9) Empirical derivation of the reactivity series

Lesson 6

The teacher can:

- Provide worksheets for the students to undertake experiments to determine the reactivity series for the following metals – copper, lead, zinc, magnesium, sodium,

- Allow student to undertake the experiments and try to derive the series
- Discuss the experimental outcomes with the students
- Provide a sheet giving the reactivity series for a range of metals and including hydrogen (and carbon?)

Part (10) Decide the best way to protect the metal bridge

Lesson 7

The teacher can:

- Ask the students to use their knowledge and decide on the best way to protect the bridge.
- through discussion, narrow down the possibilities of protecting the iron (from those originally suggested in the brainstorming and now extended, perhaps, with the use of sacrificial metals) to a manageable 3 or 4. Here the teacher may need to inject ideas. One important point needed at this stage is that the bridge should last for 18-20 years and that if the bridge is allowed to rust (i.e. no action is taken), the bridge will need replacing after 6 years. Nevertheless this could be a viable option, although safety considerations may eliminate this because it can never be certain that the bridge will rust at an even rate each year and that weather conditions do not promote accelerated rusting.
- The teacher also gives out additional information for the students to consider (see teacher notes)
- Allow the students to make a decision and to justify this.

8. In their groups, students are then asked to consider which method is the most appropriate for maintaining this important right-of-way ? It is important for the teacher to go around the groups and determine whether the students have a clear grasp of the problem and are considering a wide range of possibilities (there is a strong tendency, especially with weaker students to consider the science answer and possibly the economic answers only). If necessary it is appropriate to stop the group discussion after 5-10 minutes to here the possible solutions. Where choices are very different, this by itself may stimulate further discussion in the groups and encourage greater in-depth thinking. If choices are very similar (usually because the range of options students have considered is low), then the teachers will need to inject other considerations e.g. the aesthetic aspect - that it is important what the bridge looks like), societal factors (the need to provide unskilled employment opportunities because of mass unemployment) or simply asking the students to consider the use of metal within the society and to reflect on how this is actually being protected (it is inappropriate for students to put forward unrealistic decisions).
9. Following the group discussion, the teacher needs to ask each group to present their choice and its reasons. This can then lead to a general discussion session to see if consensus can be obtained for the whole class (if this is not possible, it is worth reminding the class that in a real

community, ways need to be found to overcome such a situation otherwise it could lead to violent confrontation. It is necessary to understand the points of views of others and this is only possible by considering all aspects of a problem).

- Make comments on the students' decisions as appropriate.

Achieving the objectives

The educational objectives for this exercise are expected to be met as follows :

Objective	to be achieved by:
1. Ability to use previous and acquired knowledge to decide how best to protect an iron bridge.	students' utilising knowledge gained about rusting and ways to prevent iron from rusting are consolidated through group discussions in which students determine how best to maintain a metal bridge.
2. Ability to appreciate that 'most appropriate' can apply to a particular situation and can change if circumstances change.	student appreciating that besides economic and scientific factors, there could be societal factors (employment needed as many persons out-of-work), business factors (finding the initial money to do the work and hence calculation of interest repayments), or environmental factors. An aesthetic consideration may be also important. The response is a balance between all factors - students should be aware that the balance is not constant and changes with circumstances.
3. Ability to identify suitable methods to protect iron from rusting.	student's ability to select suitable processes to protect iron from rusting is tested by classwork in which they take the results of the brainstorming exercise and then eliminate methods that would be inappropriate (in this case a concrete bridge would not be appropriate because, being on soft soil, a concrete bridge would need extensive foundations to take the much greater weight).
4. Ability to utilise information presented in tabular format.	students interpreting the data presented in the tables.
5. Ability to discuss meaningfully in groups.	students discussing the 'most appropriate ' through groupwork and realising that the 'most appropriate' is not an absolute answer, but dependent on choice and circumstances.
6. Ability to suggest experimental procedures for testing factors that could influence rusting.	students detailing a plan for the experiments to show that air(oxygen) and water are necessary for rusting.
7. Understand the factors that are needed for iron to rust.	students offering explanations for the experimental results which show both air (oxygen) and water are needed for rusting.

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8. Understand the corrosion process that may occur when two dissimilar metals are put together.	students explaining that zinc and other metals e.g. magnesium are able to protect iron from rusting by preferentially corroding themselves. Students appreciating that other metals e.g. copper do not protect iron but enhances the rusting process.

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