Cool glass

Equipment per group: dry glass, ice-cold water, paper, oil, access to the refrigerator, high precision scale (to 1 mg), whiteboards, markers. Note: the higher the humidity in the room, the more clearly visible will be the outcomes of the experiments (in our experience humidity of air should be 60% or higher). Alternatively, the teacher may show slides with photos.

a. A teacher will put a dry and empty glass on your group's desk and pour an ice-cold water into the glass. Carefully observe the glass for few minutes. Describe in simple words what you observe. Share with the rest of the class – did everyone else observe the same things?

b. Work with the members of your group to propose different explanations for the observed patterns. Try to devise as many explanations as possible. Put them on the whiteboard.

c. How can you find out which explanation is correct? In science we conduct testing experiments. A testing experiment is an experiment whose outcome you predict before conducting it using the idea under test. You do not need to agree with the idea but the prediction of the outcome must be based on it. After you design the experiment and make predictions based on all explanations that you devised, you will conduct the experiment and compare the outcome to the prediction. Work with your group members to propose testing experiments that you can run to test the proposed explanations. Try to propose as many as you can.

d. For *each* testing experiment, make prediction for its outcome based on *each* explanation that you proposed in b. Indicate any assumptions that you made when making predictions. (Note: The best testing experiments are those that give different predictions for different explanations).

e. Perform testing experiments that you proposed in b. (if necessary, ask teacher for additional equipment).

f. Compare the outcomes of the testing experiments with the predictions that you made in c. What can you say about the explanations under test now? Can you reject some

explanations? Do not forget to include the assumptions when making any judgements. Can you verify some assumptions?

Below we describe the approximate progression of student thought and discussions (in this case the students are either pre-service teachers or in-service teachers):
The students observe the glass after cold water was poured into it (figure 5.1). They do not need to predict anything, but observe.

Figure 5.1. Observational experiment (from left to right).

Teacher: What did you observe? Please answer using the words that a 5-year-old can understand. Please do not use any scientific terms.
Students: After cold water was poured into the glass, the glass got wet on the outside.
We can see water droplets on the outside. (*Note: there is no fancy scientific language here. Anyone can be successful.)*
Teacher: Now come up with several possible explanations of where this water came from. Try to think of how you could test each explanation experimentally.

The students work in groups coming up with explanations. The teacher looks at the whiteboards and decides with which explanation to start first. We recommend starting (if the students come up with it) with the explanation that "Water goes out from the top and settles on the outside".

Teacher: Group A came up with the explanation that water goes out from the top and settles on the outside. How can we test it?
Students (*after working in groups for a min*): Take a glass filled with cold water and cover it.

Teacher: What should happen if your explanation is correct?

Students: It should not get wet. (*Note that the explanation does not need to be correct, it just needs to be experimentally testable*).

Here either the students perform the experiment or the teacher shows the outcome (see figure 5.2):

Figure 5.2. Outcome of the testing experiment 1.

Teacher: What is the outcome of this testing experiment? What does it tell us about the explanation under test?

Students: The glass is still wet! So, we can reject this explanation.

Teacher: Group B has a different explanation. Can you please describe it?

Student from Group B: The water seeps through the glass. And we have the testing experiment for it! We will take an empty dry glass, put it into a cold place and then take it out.

Teacher: What should happen IF the water seeps through the glass?

Student from Group B: *If* the water seeps through the glass *and* we do not have any water in the cold glass, *then* it should not get wet *because* there is no water to go through! (Notice the *if-and-then-because* statement which shows the hypothetico-deductive reasoning chain).

Teacher (who already had an empty glass in the fridge), takes the glass out: What do we observe (see figure 5.3)?

Figure 5.3. Outcome of the texting experiment 2.

Students: The glass is still wet! We can reject the second explanation!

Teacher: I see that Group C has yet another explanation. Please share!

Students from group C: The material of the glass "sweats" and the water comes from the material of the glass, similar to us sweating when we run.

Teacher: How can we test this explanation?

Students get together in groups and think of a testing experiment.

Student from group C: Pour another cold liquid into the glass. If the glass sweats water and we pour another cold liquid (let's say cold oil) into the glass, then the glass should still have water on the outside, not oil because in our explanation it sweats water.

The teacher already has prepared cold liquid (can be oil, or vinegar). The students observe the experiment (see figure 5.4).

Figure 5.4. Outcome of the testing experiment 3.

The glass has water on the outside, not oil!

Teacher: We have the outcome that matches the prediction. Does it mean that we just proved the explanation that water on the outside is the result of "sweating glass"? Here the teacher has a short discussion about the impossibility of one testing experiment whose outcome matches the prediction to prove the hypothesis that was used to make that prediction. How many experiments does it take to prove something? The students should come up with the answer that this number should be infinite.

Students from group D: We have another explanation! The water comes from outside! We could test it and possibly rule it out or rule out the sweating glass explanation!

Teacher: Great! Think of an experiment for which you can make two different predictions using these two different explanations!

Student from group D: We thought of using a scale. Weigh the glass right after we poured cold water into it. If "glass sweats", then the mass should stay the same or decrease (in case some water evaporates). If the water comes from the outside air, then the mass should increase.
The teacher has already the scale ready (or the video). The students observe the experiment (see figure 5.5; you can watch the video of the same experiment at https://youtu.be/x6bNApNaeQA)

Initial 3 minutes later

Figure 5.5. Outcome of the testing experiment 4.

The students observe increase of the mass. They agree to reject the sweating glass explanation and continue testing the explanation that water comes from the air.