AN INQUIRY-BASED APPROACH TO GERMINATION

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How do we use the science laboratory to introduce students to the process of scientific inquiry? How do we encourage them to design and conduct their own experiments? Can inquiry help students collaborate with and learn from their peers?

What is the purpose of a science laboratory? Children may often associate a lab with test tubes, lenses, lab coats, and maybe even skeletons! And many teachers may see it as a space where experiments are presented to students as a prescribed set of steps to complete. But what if a lab is used to offer students an introduction to inquiry and experimentation? What if students are encouraged to formulate their own hypotheses, design their own experiments, observe the results of such experiments, make predictions and inferences, learn to address unanticipated outcomes, and communicate their findings to their peers?

I used a science lab to facilitate inquiry-based learning among Grade IX students around the concept of seed germination. This form of learning requires students to work like scientists by engaging in: *"the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments"*.[1] It also requires teachers to use an inductive, student-centered, and collaborative approach in class. Thus, the module around seed germination was designed to invite students to collaborate in small groups to:

- Design and conduct experiments to investigate factors that influence seed germination.
- Observe and present the results of their experiments to the rest of the class for peer review.

Introduction to germination

I begin the introductory class with questions about germination, specifically leading up to asking students to list out factors or conditions required for seeds to germinate (see **Box 1**).

This exercise helps draw out what students have learned and understood about germination from earlier grades as well as related real-world experiences. For example, students typically respond by naming conditions like water, sunlight,

Box 1. **Questions for the introductory session:**

Typically, I begin the introductory class with questions such as:

- What is meant by germination?
- How do seeds germinate?
- If a seed is placed on the table (I point to a table), will it grow or germinate?
- What is required for seeds to germinate?
- Can you list out all the factors or conditions that are required for seeds to germinate?

soil, nutrients or manure, temperature, and air or oxygen. This exercise can also help identify misconceptions. For example, students may insist that seeds cannot germinate in the absence of sunlight, soil, or manure. I list each unique factor on the board for the entire class to see while being careful to avoid giving ready-made answers or providing direction to their thoughts. Instead, I allow students to make 'mistakes' (see **Box 2**). This means that I do not leave out any factor that students come up with and encourage students to investigate each factor in subsequent steps. I do, however, allow students to check their textbook or the internet and change their responses as long as they are able to justify the change and the whole class is in agreement with it. I allot about 30 minutes for the introduction.

Initiating collaborative inquiry

For this part of the lesson, I divide the class into small groups (typically 3-4 people). The total number of groups and the size of each group depends on the class strength and the number of necessary conditions for germination listed on the blackboard. I copy out each of the proposed conditions for germination onto separate chits of paper, then mix all the chits up in a bowl or box. Once the students are seated in groups, a member of each group picks up one of these chits. Their group is expected to use experimentation to investigate the role that the factor listed on their chit plays in germination. This ensures that every condition listed on the blackboard, including any 'incorrect' ones (or ones that are known to have no impact on germination), is tested by at least one group in the class.

Once each group settles down at a designated workbench, I share a workflow for them to use for their investigation (see **Fig. 1**). I elaborate on how the members of a group will need to work together to formulate and test a hypothesis regarding the role that the factor they are investigating plays in germination. And that they will do this through an experiment that they will design and conduct together. I emphasize the need for them to design simple experiments involving reagents or instruments that are already available in the school lab. Each group is expected to give me a brief overview of their plan and submit a list of materials that they will need to be able to conduct their experiment.

Due to the novelty of this approach to lab work, students usually meet it with several questions. These include: *"Are we allowed to do any experiment that we decide on as a group?", "Are we allowed to refer to books?", "How much time will we get to do the experiments?".*

Once I have clarified their doubts, the members of each group begin to discuss their hypothesis and the design of an experiment to test it. The lab transforms into a chaotic and noisy space, occasionally interrupted by heated arguments, students prancing up and down the lab to look for resources or to refer to textbooks for ideas. It is a pleasure to walk around the class, listening to students express and debate their thoughts and ideas. Occasionally, the class can get very chaotic or students can get stuck and be unable to proceed. Or a group may start chatting with each other on a topic that is unrelated to their experiment. In these rare instances, I use a worksheet to help students guide and organize their ideas as a group (see **Activity Sheet I**).

By the end of this session, each group draws up their plan and shares it with me. I refrain from 'correcting' their experimental designs, as it would obstruct their learning process. However, I may challenge certain aspects of their plan, such as the necessity of some of the reagents or instruments that a group has asked for. For example, I may ask: *"Why do you need this instrument? Why do you need glass beakers? Why do you need distilled water and not tap water? Why do you think the soil needs to be red and not black? Why do you think the soil should not be clayey?".* Through this discussion, we negotiate for materials and instruments based on their availability in the biology lab. Mostly, students are encouraged to look for substitutes of the chemicals

Box 2. **The importance of mistakes:**

Often, we are taught to be so careful that we do not make any mistakes or hide the ones we make. We need to embody the opposite! We need to cultivate the habit of making mistakes and celebrating them! Why? Because mistakes are a vital part of any learning process and can enable our progress as learners. For example, making a mistake allows us to pause and reflect on how to make our next attempt better with the knowledge and clarity we acquire from a failed attempt. Thus, not only do we learn not to repeat the same mistake, but we also gain deeper insights into ourselves as learners. For these reasons, it is important for teachers to embrace mistakes (students and our own), openly acknowledge them in class, and actively explore learning opportunities that offer the possibility of new kinds of mistakes.[2]

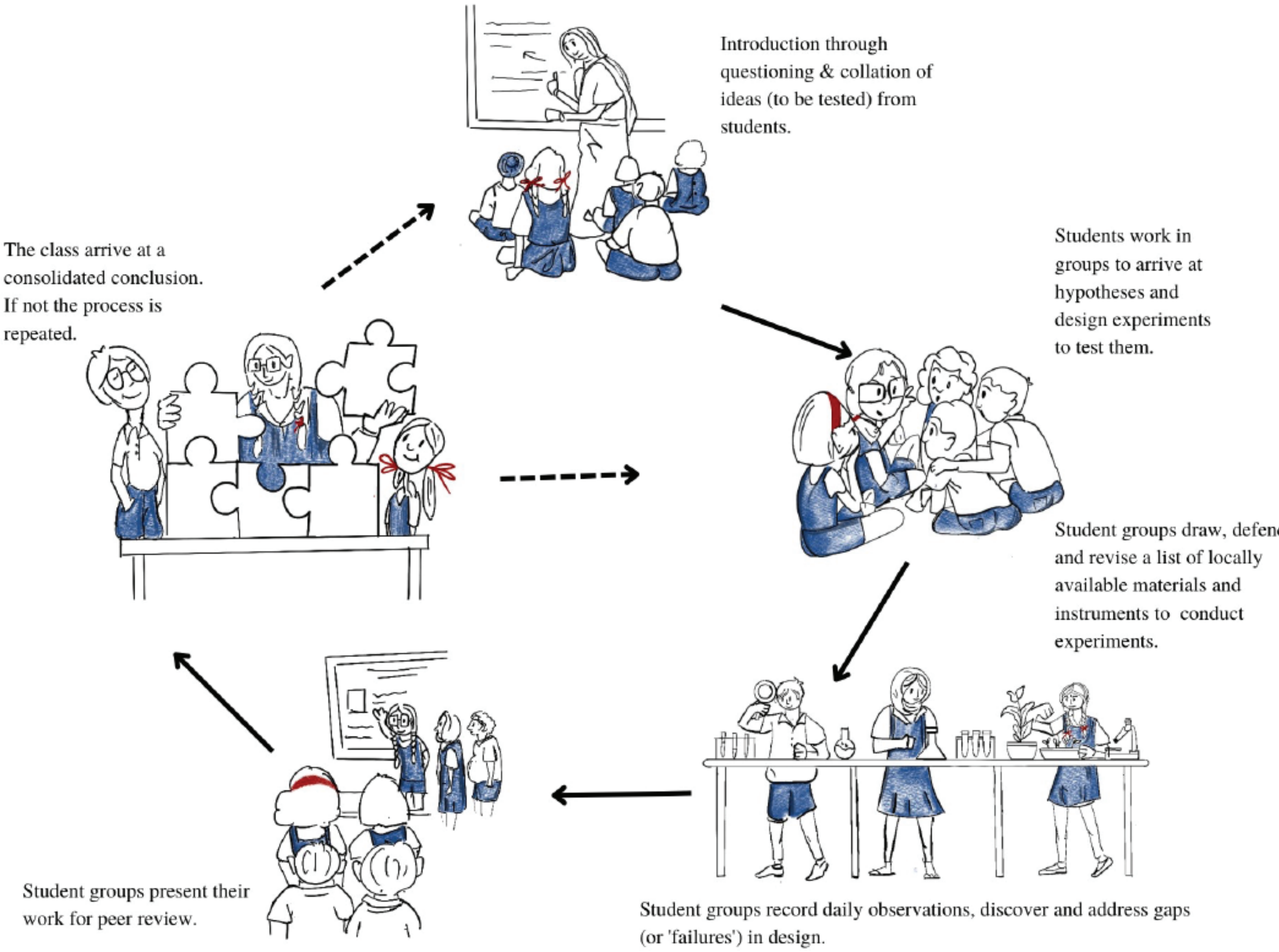

Fig. 1. Lesson workflow.
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or materials they need for their experiment; only rarely, they may need to redesign their experiment. By the end of the class, each group submits their final plan and list of required materials for the experiment. I allot about 40-60 minutes for this stage of the module.

Conducting the experiment and recording observations

I take 1-2 days to set up the the lab for the next class. This involves preparing workbenches for each group according to the final list of materials that they have submitted. This ensures that the lab is fully equipped for students to start their experiments.

Before each group sets up their experiment, I lay out some expectations and guidelines for work and behavior in the lab environment. For example, I touch upon the need for care in handling glassware, precautions in handling reagents and instruments, the importance of consistency in recording their observations, and basic lab etiquette. Over the next few classes, while the students conduct their experiments, the lab assistant and I supervise their work. We ensure an open, learner-centred environment, where we are not instructing, but observing and assisting whenever help is required, such as in using an incubator or water bath for the first time. In this way, the lab transforms into an interesting learning space that allows students to learn from their own mistakes (see **Box 3**).

Each group is encouraged to divide the responsibility to record observations on a daily basis among themselves. While there is emphasis on making these observations as regularly as possible, I am careful to offer minimal instructions and directions for observation. I also avoid using cue questions that direct their attention to observing specific aspects of the setup. This regular yet loosely structured approach to recording observations allows students to include spontaneous observations that emerge from their own experiences with the experiment. For example, some groups observed that not all seeds sprout at the same time. This led them to increase their sample size or repeat the same experiment with different types of seeds. This approach also offers scope to explore ideas and questions that go beyond the experiment at hand. For example, one of my students wondered if gravity plays a role in germination and conducted a separate investigation to test this possibility. Overall, I felt that this approach to experimentation

Box 3. Learning from our own mistakes:

I observed many examples of how students learn from their own mistakes. A group that started their experiment with just one seed learned to increase their sample size when that seed failed to germinate. Another group forgot to include controls in their experiment and learned how this constrained their interpretation of results during peer discussion. Often, groups that were investigating the role of temperature or air on germination neglected to provide water to their seeds. Such groups learned the importance of regular watering when they did not get the results that they expected to see.

Even students who tried to follow the protocol given in their textbooks observed unanticipated results, such as fungal growth on the seeds. This experience helped them pause and reread their textbooks in a more critical manner. Some students were not able to justify the use of a certain material, like cotton, that was specified in the experimental design shared in their textbook. When their need for this material was questioned, these students formulated the hypothesis that cotton may be essential for germination. They went on to test this by designing an experiment where they compared germination in seeds kept in water without cotton with that in seeds kept in water with cotton.

One of my own mistakes during the first iteration was to assume that students would be diligent in making and recording their daily observations. I had scheduled time for them to do this during their recess, but students would often forget. I found that reminding them at regular intervals helped address this. For the next iteration, I created an observation recording sheet and placed a copy of it on each of the work benches (see **Activity Sheet II**). This sheet has helped students to be more consistent in recording their observations. It has also helped me monitor each group's progress on a more regular basis.

allowed students more freedom with their learning (see **Box 4**). I give students about 40-60 minutes for setting up the experiment and about 5-10 minutes daily to record observations.

Class presentations

I allot a final session for each group to present their work to the entire class. Each presentation is expected to be less than 15 minutes in length. Often, students in a group take turns to share different aspects of their work. For example, if one draws a diagram on the blackboard, another explains the experimental setup, and so on. They are also encouraged to share any challenges that they may have faced. The rest of the class is expected to listen actively, point out contradictions, or critique the work in a constructive manner.

In my experience, presentations invariably lead to heated debates as well as laughter. Oftentimes, I observed that students used evidence from their work to argue a point quite successfully. They would do this both to defend a claim made by their own group and to contradict an idea or conclusion presented by another group (see **Box 5**).

Box 4. Learning from an inquiry-based approach to experimentation:

Since this approach to experimentation allows students to learn through their own experience of doing, learning is active and they develop a greater tolerance for mistakes. These factors seem to favour a shift in behaviour. I observed greater motivation and participation from students, even in those who were otherwise non-participative. For example, my students were curious and eager to monitor their experimental setups. They seemed more willing to discuss thoughts and ideas pertaining to their experiments with peers and teachers. In fact, they would often seek me out in school to discuss the progress of their experiment or request help with troubleshooting. They also seemed less hesitant to discuss their mistakes.

Working with peers also seemed to have a positive influence on learning. For example, students who were using apparatuses or instruments such as incubators or water baths for the first time were eager to share their experiences with other students. This led to many peer-teaching-learning moments. It was also interesting to see how students took the initiative to communicate their specific needs to the faculty of other departments, often ransacking other labs or departments for accessories that they could use for their experiments. For example, a black box was borrowed from the physics department to study the role of light, a bottle of pyrogallol was borrowed from the chemistry lab to study the role of oxygen, and timers were borrowed from the sports department.

Box 5. Variation in the format of presentation:

Occasionally, I may invite students to participate in a marketplace activity.[3] Each group is expected to put up a stall to showcase their experiments and display their results. One group member stays with the stall and acts as the 'stallholder'. Other members act like 'customers'—they go out into the 'marketplace' to gather information from other stalls. Each stallholder is expected to present the work and results of the group. They are also expected to answer questions raised by customers from other groups. Customers are expected to make notes on all aspects of the experiments performed by other groups. Towards the end of the activity, the members of each group reassemble at their own stalls. Members who acted like customers take turns to share details of their visits with other group members. Each student is then expected to submit an individual report of what they learnt about germination from all the experiments conducted by their class.

Assessing student learning

Typically, my assessment of student learning from such lab units involves two components. One component is their score on a test with questions related to the experiments (see **Box 6**). The other component involves my descriptive observations of each student's work based on criteria like their general conduct, contribution to peer interactions and presentations, and the lab records they keep. If writing such descriptive term-end reports is a challenge, a well-crafted rubric can be of help.

Box 6. An example of an assessment question:

Aman placed three seeds of *rajma* in two identical glass jars, A and B. Both jars were lined with the same amounts of damp cotton wool. Jar A was wrapped with a piece of black cloth, while Jar B was **not**. Both setups were left in the garden (see **Fig. 2**).

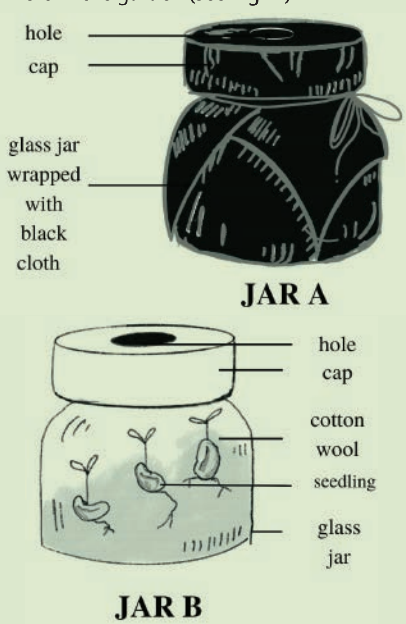

Fig. 2. The experimental setup.

Answer the following:

(a) What was Aman trying to find out in this experiment?

(b) In which of these jars would the seeds germinate? Explain your answer.

(c) What is the function of the hole in the cap of each of the jars?

Box 7. Some guidelines:

These are some broad guidelines that can be of help to teachers who are eager to try an inquiry-based approach in their own classrooms and labs:

- Unlike traditional teaching methods, this approach takes time. So, plan for at least 4-5 classes to conduct an inquiry-based lesson.
- Start this activity by clearly communicating your expectations regarding collaborative group work as well as peer-based review and discussion.
- Larger groups tend to result in unequal participation, with some students taking dominating roles. To avoid this, I recommend creating small groups with not more than 5 students per group.
- Regularly monitor student progress and group interactions.
- Although the overall design is structured, be prepared to build on student's prior knowledge, to stimulate student curiosity with effective questioning, and to challenge them in accordance with their abilities.
- When you first try this approach, classes may seem more chaotic than usual. You may find it challenging to engage in complex and sustained reasoning with students. Be assured that it takes time and practice for the class and you to settle into this different rhythm.
- Be open to creating an environment that encourages students to make mistakes without fear of judgment or failure, and to give them time for reflection.
- Use the terms 'correct' or 'incorrect' for student answers and responses sparingly.
- The focus of this approach is on learning as a process and not on the results of experiments. Hence, assessment of student work needs to be similarly oriented. This expands the scope of assessments beyond a few summative ones to a range of formative ones.

Parting thoughts

A common approach to lab work is to give students recipe-like instructions that direct them to carry out a procedure designed by someone else. In contrast, the National Education Policy (NEP) 2020 emphasizes the need for a more 'experiential, holistic, integrated, inquiry-driven, discovery-oriented, learner-centred, discussion-based, flexible, enjoyable' pedagogy. To move in this direction, our classrooms and labs need to transform into spaces where teachers and students learn together, and where making mistakes is recognized as an integral part of learning. The inquiry-based approach to lab work that is described in this article is aimed at building such a space (see **Box 7**).

I have used this inquiry-based approach to germination with five consecutive academic batches of Grade IX students. I have observed that it helps students to grow comfortable with being confused, making mistakes, and fearlessly exploring questions with their peers. In addition to nurturing curiosity and active participation, it also offers students the opportunity to develop scientific inquiry skills. Seeing this change in how students relate to learning can be encouraging enough for teachers to motivate them to overcome any challenges they may face in trying this approach in their own labs.

Key takeaways

- An inquiry-based approach to engage students in experimentation nurtures their curiosity while also helping them develop important skills in the practice of science.
- Students become more active participants in their own learning when offered a space that encourages them to be less fearful of making mistakes and to learn from mistakes.
- Nurturing a collaborative environment where students experience the creativity and freedom of working with their peers is empowering.
- This approach allows teachers and students to focus more on the process of learning rather than just on its outcomes.

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Notes:

1. To know more about inquiry-based learning: Swan M, Pead D, Doorman M & Mooldijk A (2013). 'Designing and using professional development resources for inquiry-based learning'. ZDM, 45(7), 945–957. https://doi.org/10.1007/s11858-013-0520-8.
2. Additional reading for practitioners: Raghavan N (2019). 'The Reflective Learner: Seeing "Missed Takes" in Mistakes'. Notion Press Media Pvt Ltd.
3. Source of the image used in the background of the article title: An inquiry-based approach. Credits: Shreya Kedia. License: CC-BY-NC.

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1. PRIMAS. 'The PRIMAS project: Promoting inquiry-based learning (IBL) in mathematics and science education across Europe.' (2011, March 31). Retrieved on December 22, 2022, from https://primas-project.eu/wp-content/uploads/sites/323/2017/10/PRIMAS_Guide-for-Professional-Development-Providers-IBL_110510.pdf.
2. Dennett DC (2014b). 'Intuition Pumps and Other Tools for Thinking.' WW Norton & Company.
3. Ginnis P (2001). 'The Teacher's Toolkit: Raise Classroom Achievement with Strategies for Every Learner.' Crown House Publishing.

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ACTIVITY SHEET I : FACTORS OR CONDITIONS NEEDED FOR SEED GERMINATION

Date:

Names of group members:

(a) Your group's hypothesis:

Hint: One factor or condition that you think is needed for a seed to germinate?

(b) Justification for your hypothesis:

Hint: Why do you think that the factor or condition you listed is needed for a seed to germinate? Share your reasons.

(c) Procedure to test your hypothesis:

Hint: What experiment would you design to test if the factor or condition you listed in your hypothesis is needed for a seed to germinate?

(d) Materials and equipment required for testing:

Hint: List all the materials and equipment you need to perform the experiment you have designed. State the exact number of items required for each category as well. Check your list carefully. Remember, you will not be allowed to make any changes to this list later unless you can justify the change with a valid reason.

(e) Expected results:

Hint: If your hypothesis is true, what results do you expect to get from your experiment?

(f) Observed results:

Hint: What results did you actually get from your experiment?

(g) Conclusions:

Hint: Does the evidence from the experiment support your hypothesis?

Questions

For before you start the activity:
Q1. What do you know about seed germination?

Q2. What do you want to know about seed germination?

For after you have completed the activity:
Q3. What did you learn about seed germination?

Lab report guidelines:

Introduction: Include background information justifying why you are testing your specific hypothesis. End this with a clear statement of your hypothesis and expectations.

Methods: Include a detailed description of how your experiment was conducted even if it was unsuccessful. It should be so detailed that someone else could read it and recreate your experiment.

Results and data analysis: Clearly describe what your results were (even for experiments that were unsuccessful) and what you did to make sense of the data. This includes writing about how and why you made each graph or table.

Conclusions: Include your interpretation of the results (even from unsuccessful experiments) and key conclusions about your research. If no clear conclusions can be made, mention how you have improved the design of your experiment. This section could also include experiments that could be done in the future based on the knowledge and results you have obtained through this experiment.

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The Science Educator at Work

ACTIVITY SHEET II : OBSERVATION SHEET

Aim:

To test the role of .... in the germination of seeds.

Group members:

Tasks:

Name of group member	Task	Observations	Date	Time	Sign here (after your assigned task is complete)

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