Doing Science*
Introducing Scientific Inquiry to Elementary Classes

Sujatha Varadarajan and Sujeet Sanzgiri

Science textbooks impart static content knowledge to students, which means exposing students to facts, laws and theories. However, the interesting and important process of arriving at these laws and theories is often neglected. Additionally, science experiments—one of the ways to arrive at such knowledge [1]—are largely taught only to secondary and higher secondary students. The possibility of utilizing the laboratory spaces for exploring and introducing scientific thinking, inquiry and process skills to primary and middle school students is mostly ignored, even though experimentation is captivating and motivating to all age groups. Some reasons quoted for the misplaced importance are—infrastructure issues, resource constraints, safety, etc.

To address this concern, a qualitative exploratory study was conducted with a small group \((n = 28)\) of primary and middle school students from different schools who were involved in a weekend post-school activity at an activity centre in Pune. The action research focused on designing and exploring activities that would require limited resources while engaging students in meaningful discussion, investigation, data collection and collaborative critical reviews. The experiments’ topics were particularly chosen so that students were familiar with them from their school curriculum.

Data collection included field observation, feedback forms, students’ diaries and questionnaires.

The qualitative analysis of the study results indicates that students when exposed to such activities, started to get a sense

---

*Vol.28, No.6, DOI: https://doi.org/10.1007/s12045-023-1623-3
of scientific process skills. The activities being from a familiar context, students had pre-requisite knowledge, resulting in student-driven discussions. Additionally, we found that, given an opportunity, middle school students are capable of engaging in model-based reasoning while primary students learn to collect data. Our result indicates that exposure over an extended time period is needed to introduce the concept of variables in experiments to students.

1. Introduction

Science can be structured as three different strands— (a) science as a tool for learning logical reasoning (where different pieces of evidence are stitched together coherently to enable an explanation), (b) science as a tool for proposing theory-change (where existing knowledge claims are re-examined upon finding new evidence), (c) science as practical experiments (where scientific knowledge is gained through hands-on experimentation and applied in practical situations) [2]. Students need exposure to all three strands of science through their formal schooling.

Introducing students to the first strand of scientific thinking/logical reasoning is possible by engaging students in discussions and allowing them to argue and debate while pointing out any logical inconsistencies or fallacies that may arise.

The second strand of science is theory change. Quite often, stu-
students have alternate conceptions requiring restructuring their knowledge, which can be considered theory change. Such a change is achievable through discussion, argumentation and debate. Experiments, similarly, offer critical testing of theories and any anomalies noticeable in the results may lead to conceptual change among students.

The third strand of science is experimentation. Science as an experimental subject helps students build curiosity and inquisitiveness about the world around them [3]. Through science experiments, students learn to identify, control and change variables, leading to a deeper understanding of causal and correlational relationships between variables.

For students to get a holistic view of ‘doing science’, all three strands need to be introduced into their learning experiences as early as possible. Such an approach to science education helps develop a rational mindset within students and avoid a distorted view of the nature of science as ‘unchangeable and uncontested’.

2. Research Objectives

We aimed to explore the feasibility of introducing scientific inquiry to elementary classes. The following instructional principles were identified for designing the activities that would give affordance to the three strands mentioned above.

2.1 Instructional Principles

2.2 Discussion and Arguments in the Classroom

The rationality of science lies in its ability to engage students in meaningful dialogue, to enable them to construct persuasive arguments for or against a theory in question and to come up with competing theories based on their observations [4].
2.3 Collaborative Learning

Collaborative learning practices identify positive interactions and interdependence—the benefits being multifold, from academic to psychological and social [5]. In addition, the theory of ‘distributed cognition’ contends that cognition is beyond the individual and encompasses interaction with people, materials and other resources in the environment. Students tend to engage in what is called cognitive load balancing with social organization [6].

2.4 Affective Domain

The affective domain considers students’ attitudes, feelings, appreciation and values towards science, scientists and scientific methods [7]. The affective domain encompasses not only attitudes, beliefs, and perceptions but also emotions such as anxiety, motivation, etc. [8, 9]. Teachers should aim at designing models of instruction that integrate both the cognitive and the affective domains to deliver a wholesome and effective learning experience to their students.

Thus, the research questions we ask are:

- What activities/experiments can we introduce to elementary school students that would help them in ‘doing science’?

- How do students perceive these activities?

3. Participants of the Study

Researchers approached various schools to announce the post-school activity. The participating students were self-selected. There were 13 boys and 15 girls in all, belonging to different English medium schools following the CBSE, ICSE, and Maharashtra State Board curriculum. The students were keen on science, and a small survey indicated that they were academically medium to high achievers.
### Table 1. Learning objectives of the activities.

<table>
<thead>
<tr>
<th>Learning Objectives: Experimental Activities</th>
<th>Learning Objectives: Non-experimental Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making Observations</td>
<td>Critical Thinking and Reasoning</td>
</tr>
<tr>
<td>Identifying Variables</td>
<td>Debating</td>
</tr>
<tr>
<td>Measurements/Errors</td>
<td>Presenting Errors</td>
</tr>
<tr>
<td>Reasoning</td>
<td>Collaborating</td>
</tr>
</tbody>
</table>

## 4. Methods

During the study, we explored the possibility of introducing process skills at the elementary level. A mixed group of students ($n = 28$), both girls and boys from grades 4 to 8, were engaged together for a 10-week (20 hours) program in three different batches. Each session was held for 2 hours per week, during which students were engaged in different activities.

### 4.1 Role of Researchers

The researchers involved in the study focused on designing and exploring activities that would require limited resources while engaging students in meaningful discussions, investigation, data collection and collaborative critical reviews. We carried out some experimental and non-experimental activities. The topics for the activities were particularly chosen in a context that students were familiar with and which followed their school curriculum.

### 4.2 The Study

The action research followed three iterations of these activities, with necessary modifications incorporated into our approach after every batch. Students were divided into groups and had to note down the observations they wished to make with respect to the activities. Table 1 presents the overall learning objectives of both these activities.

For experimental activities, students initially performed an experiment to understand the procedure, after which they were asked to come up with a question that they could explore with the given experimental setup. The groups had to identify variables for further
investigation. Each activity was designed to have some measurable aspect. For non-experimental activities, students were typically given a problem statement or asked a lead question at the beginning of the session. A discussion followed this. The objective was to get students to actively participate rather than be passive listeners. Some activities required the students to present their findings to the class.

Discussions and debates were a consistent part of student engagement. Students were given lead points for discussions to build the background for the activity. The data comprised classroom observation/notes, feedback forms and audio recordings of the discussions in the class.

4.2.1 Activity 1 (Leaves)

Leaves are abundantly available all around us. The sheer variety of leaves, with their similarities and differences, makes them interesting tools for student study. Students can very easily learn to observe, generalize and hypothesize about leaves. For example, the ‘presence of veins’ might be a recurring pattern, while the variations in leaf margins and venation could help in categorization. A typical question arising out of the discussion could be, “Why venation?”

• Results

Students hypothesized as to “why” veins would be present on leaves. We noticed that many older learners, who have, in school, learnt the words associated with a leaf—lamina, margin, compound leaves, reticulate venation, etc., are typically challenged when asked to describe, for example, the margin in a compound leaf, or the difference between a leaf and a leaflet.

One apparent question which led them to carry out further investigation was whether coloured leaves have chlorophyll or not. Students brought leaves of their own choice and performed chromatography of leaf extract. Chromatogram was developed, and the observations were discussed. Table 2 presents the learning
Table 2. Learning scope of chromatography experiment of leaf extracts.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Variables</th>
<th>Scope for measurement</th>
<th>Possible observations</th>
<th>Questions providing scope for discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromatography</td>
<td>Type of paper</td>
<td>Length of paper</td>
<td>Dot rises up (against gravity)</td>
<td>Do leaves other than green coloured have chlorophyll?</td>
</tr>
<tr>
<td></td>
<td>Type of solvent</td>
<td>Breadth of paper</td>
<td>Dot splits into constituent colours</td>
<td>Why does the dot rise?</td>
</tr>
<tr>
<td></td>
<td>Time for development of the chromatogram</td>
<td>Amount of solvent</td>
<td>Solvent rises farther than dots</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type of leaves</td>
<td>Height to which dot and liquid rises</td>
<td>Patterns in splitting</td>
<td></td>
</tr>
</tbody>
</table>

Theodore 2. Learning scope of chromatography experiment of leaf extracts.

scope of the experiment.

There was a divide between learners regarding the presence of chlorophyll in non-green plants.

While performing the experiment one of them noticed that the vial containing red-leaf extract, on standing, showed a tinge of green colour. This was an exciting moment for the student to move closer to their hypothesis against those who did not believe that red leaves may contain chlorophyll.

*Table 2* provides the scope for the process skills presented by this activity on leaves.

### 4.2.2 Activity 2 (Measurement)

Introducing the concept of ‘measurements’, students were asked to make any measurement related to the dimensions of the leaf. They measured the length, the max width, the area (on graph paper), etc. Students were also introduced to data collection. Students measured and collected data related to the length of a piece
Table 3. Measurement.

<table>
<thead>
<tr>
<th>Experiment and Errors</th>
<th>Variables</th>
<th>Scope for measurement</th>
<th>Possible observations</th>
<th>Scope for discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variant in data</td>
<td>Height</td>
<td>Least count of various devices</td>
<td>Why is there variation in the data?</td>
</tr>
<tr>
<td></td>
<td>Variation in units</td>
<td>Weight</td>
<td></td>
<td>How do we accept or reject a data?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time</td>
<td></td>
<td>Type of errors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Length</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

of thread, the time taken for a paper toy (rotocopter) to fall, and the length of their work table. Table 3 presents the scope of learning objectives of this activity.

- Results

One of the groups of students developed correlations like: “The length of the leaf is x times its max width”. Some of them hypothesized how the accuracy of the area calculated depends on the area of the boxes of the graph sheet selected (e.g., using a one sq-cm box on the graph paper would be less accurate than using a one sq-mm box).

The entire data from all the groups were pooled. Discussion ensued on how to accept or reject a data point. Different types of errors were discussed.

4.2.3 Activity 3 (Classification)

The foundational principle on which any taxonomy is based, i.e., the similarity and differences of organisms, is often lost when students are introduced to a rigid and standardized classification system in textbooks (e.g., the names of different kingdoms). To enable students to internalize the basis of any classification, we
gave students the names of 30 objects and asked them to place the objects into groups. They had to follow certain constraints for grouping—(a) there would be a minimum of 2 objects to a group (i.e., students could not create a group with just 1 object) and, (b) an object could not belong to two different groups (i.e., unique group membership). Students were to maximize the number of groups they could create and write precise definitions for each group they created. The idea behind this exercise was to help students create precise group definitions such that the objects automatically become members of a group based on the group definition. Students also had to ensure unique group membership. Mathematically, with 30 objects and 2 objects per group, the maximum number of groups that can be created is 15 (this is the best-case scenario). Given the constraints, however, creating 15 groups with precise definitions and unique membership is extremely challenging, and often objects end up belonging to two groups. Students could create, on average, 11 groups in our study.

- Results

We found that most middle school children could create interesting groups. For example, one of the groups created included a herbivore, a carnivore, a human being and a robot as group members. A discussion ensued about why the robot was included. The reasoning given was that a robot needs energy to function just as the other group members do. Consequently, everyone agreed that they needed to define food and energy, which would become the basis for classifying these objects/organisms. It is clear that including student-exploration as a pedagogy can invigorate students into thinking out of the box (energy as a parameter for classification) and to self-learn unplanned concepts (definitions of food and energy).

4.2.4 Activity 4 (Acid-Base Reactions)

Students were then given the leeway to carry out experiments for acid-base reactions by varying the types of acids, bases and indicators provided to them. The highlight was using syringes to note
<table>
<thead>
<tr>
<th>Acid Used/common name</th>
<th>Base Used/common name</th>
<th>Indicators used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citric acid (Citrus fruits)</td>
<td>Sodium carbonate (Washing soda)</td>
<td>Phenolphthalein</td>
</tr>
<tr>
<td>Ascorbic acid (Vitamin C)</td>
<td>Sodium bicarbonate (Baking soda)</td>
<td>Methyl organe</td>
</tr>
<tr>
<td>Acetic acid (Vinegar)</td>
<td>Potassium hydroxide</td>
<td>Universal indicator</td>
</tr>
</tbody>
</table>

**Table 4.** Chemicals used in acid-base reactions.

Many primary and middle school students associate the word ‘chemicals’ with ‘liquids’. We conducted an activity that started off by engaging students in a discussion and debate on whether or not the examples given by fellow students were chemicals. While it was easy for them to think of water as a chemical substance (as it is made up of hydrogen and oxygen atoms), it was difficult for them to conceive of hair as a chemical substance, even though they could appreciate nearly everything around them to be chemical substances, e.g. bottle, bag, leaf (presence of chlorophyll), blood, etc. Post-discussion, they arrived at the understanding that chemicals could exist in any of the three states of matter. This typically serves as an example of ‘theory change’. This experiment touched the affective domain of students—inspiring and motivating them as though they were doing higher-level experiments and considering themselves as young scientists working with laboratory glassware like test tubes, beakers and flasks. Mixing liquids to get a rich array of colours excited the students. This serves as an excellent activity to expose students to the joy of doing experiments and works for both younger and older students.
### Table 5. Acid-base reactions.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Variables</th>
<th>Scope for measurement</th>
<th>Possible observations</th>
<th>Scope for discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid base reactions</td>
<td>Type of acids</td>
<td>Dilution for acid</td>
<td>Colour change</td>
<td>What are chemical substances?</td>
</tr>
<tr>
<td></td>
<td>Type of base</td>
<td>Dilution for base</td>
<td>Evolution of gas</td>
<td>Is water a chemical?</td>
</tr>
<tr>
<td></td>
<td>Type of indicator</td>
<td>Amount of acid</td>
<td>Change in temperature</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Addition of acid to base</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Addition of base to acid</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4.2.5 Activity 5 (Solubility)

In this experiment, a lead question on physical vs chemical changes was posed to the students. They engaged in a discussion, after which the class automatically got divided into two camps. One camp had the prior understanding from their textbook that “physical change happens at the physical state level, and chemical change happens at the molecular level”. The other camp had the notion of “reversibility and irreversibility” as the primary underlying difference between physical and chemical change, respectively. The arguments persisted until students realized the need to pursue further reading before supporting their own idea with more evidence or accepting others’ idea.

An equally interesting discussion that ensued was whether solubility is a physical or a chemical change.

The two models for the dissolution process discussed and debated are shown in Figure 2.

- **Results**
**Figure 2.** Students model describing the process of solubility as physical/chemical change. (a) Physical change (b) Chemical change.

Students discussed how these two models could explain various phenomena like evaporation, saturation, etc. However, when it came to explaining the dissolution of saturated solution on heating, students supporting model (b) accepted that their model could not explain it. Thus, students agreed that model (a) could be a better representation of the phenomenon of solubility. *Table 6* represents the scope of process skills this activity offers.

**5. Implication**

*Table 7* presents the overall result of the activities briefly.

Giving students the opportunity to explore and discover may appear trivial and obvious to educators, but it is a huge step in increasing student motivation levels in schools. At the same time, it nudges science pedagogy away from the typical fact-based exposition found in most classrooms to a discovery/discussion-based pedagogy. Students explicitly stated that they had never gotten a chance to do any experiment in school or think out of the box; thus, this experience was enjoyable.

It may be difficult to achieve the entire set of scientific and process skills, starting from observation to theory building through one activity; it may be more feasible to introduce each of the process skills as the focus of one activity, especially for this age group. While a smaller class size can be nudged to participate in the discussions, a larger class size can be handled by dividing them into smaller groups. When discussions and debates become the
<table>
<thead>
<tr>
<th>Experiment</th>
<th>Variables</th>
<th>Scope for measurement</th>
<th>Possible observations</th>
<th>Scope for discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solubility</td>
<td>Type of solvent</td>
<td>Amount of solute</td>
<td>Change of colour solution</td>
<td>Is solubility a physical or chemical process?</td>
</tr>
<tr>
<td></td>
<td>Type of solute</td>
<td>Amount of solvent</td>
<td>Insoluble if excess solute is added</td>
<td>Why does a solute dissolve?</td>
</tr>
<tr>
<td></td>
<td>Amount of solvent</td>
<td>Time taken for discussion</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amount of solute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stirring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stirrer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Particle size</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Solubility.

norm of the class, there exists a possibility that the students who are listeners get into the mode of contributing to the discussions. This becomes the larger goal of such pedagogy. Further work needs to be done to assess students’ responses in larger class sizes.

It was interesting to note that each of these activities required minimal resources and included one or the other of the process stage. Activities like leaves or solubility are superior as students get exposed to all three strands of science, i.e., scientific thinking, theory change and experimentation. One difficulty often quoted as hampering the implementation of any innovative pedagogy is the availability of laboratory space for junior students. The results of our study indicate that many of these activities can be performed even at a desk space. For the experiments needing chemicals and glassware, it is feasible to use household chemicals and plastic ware to make the setup safe and economical.

The other challenges pertaining to implementation are time man-
<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Learning Outcome/questions discussed</th>
<th>Scope presented by the activity</th>
</tr>
</thead>
</table>
| Leaves   | Observe, generalize and hypothesize about leaves. Chromatography of leaf extract. | Correlation between length of the leaf and its max width. Possible reason for venation. Experiment to prove that non-green leaves contain chlorophyll. | a) Scientific thinking  
b) Experiment  
c) Theory change |
| Measurement | Measuring various objects.                                                  | How to accept or reject data  
Type of errors.                                                                                       | a) Scientific thinking  
b) Experiment |
| Classification | Grouping a list of 30 different objects/organisms.                | Defining the basis of classification and grouping.                                                   | a) Scientific thinking |
| Acid-Bases | Titration using syringe.  
Variables: three acids, three bases, and three indicators. | Influencing the affective domain.                                                                    | a) Experiment |
| Solubility | Identifying variables and seeing how these affect solubility.            | Is solubility a physical or chemical process?  
Why does a solute dissolve?  
Model based reasoning about the nature of solubility. | a) Scientific thinking  
b) Experiment  
c) Theory change |

**Table 7.** Results of the activities.

...agement and teacher competence. The teacher needs to change her role to facilitator and has to elicit answers from students rather than providing ready-made answers. Further, since the discussion is student-driven, the facilitator has to be cognizant of the time and prudently decide when to provide the answers to get the
discussion going and how to prevent digression for effective time management. Thus, the competence required here is little different from the pedagogical content knowledge required in the regular teaching methods. This is not very difficult; it only requires practice and commitment to inquiry-based teaching.

We need to relook at the current practice. Orientation needs should be identified, and teachers should be sensitized to the pedagogy as the content is fairly simple for a committed teacher to comprehend. Our results indicate that the load on the teacher reduces when students are given directionality and adequate/optimal freedom to explore.

6. Conclusion

Laboratory experiments in schools are aimed at imparting laboratory skills and reinforcing some concepts learnt in class. However, the larger objective of experimentation as a way to introduce process skills and drive exploration remains relatively ignored. Through our study, we conclude that it is feasible to design activities to introduce scientific inquiry and process skills to students as early as elementary level.

Suggested Reading


