Article

A Module Integrating Conventional Teaching and Student-Centered Approach for Critical Reading of Scientific Literature

Anuttama Kulkarni*
Rekha Vartak

From the Homi Bhabha Centre For Science Education (HBCSE), Tata Institute of Fundamental Research, V. N. Purav Marg, Mankhurd, Mumbai, 400088, Maharashtra, India

Abstract

One of the well-accepted ways of introducing undergraduates to the method of scientific inquiry is to introduce them to primary literature. A matter of concern is that undergraduate students of Indian universities are generally not trained to read primary literature. We combined traditional teaching and student-centered approach in a 3-day module for introducing first-year students to critical reading of primary literature. This article describes the design of the module, the method of assessment of student performance, the learning outcomes, and student feedback. We received positive feedback from students and observed significant improvement in their understanding of the rationale and results of the research paper under consideration. The module may be viewed as an example of a simple introductory activity to enthuse and initiate college students to scientific thinking and research paper reading. © 2019 International Union of Biochemistry and Molecular Biology, 47(5):581–588, 2019.

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Introduction

The traditional method of teaching biology in the classroom by directly delivering textbook content is often uninteresting. It is more so in the current era of easy access to information on the internet. Several different approaches have been proposed to make the biology classroom more interactive and interesting [1–3]. These include combining hands on activities/practical sessions with lectures, field trips, group discussions/assignments, critical reading of primary literature to name a few. Among these, the approach involving critical reading of scientific literature seems to be in our view the most feasible in the Indian context, for it does not require much additional infrastructure and cost and can be incorporated in a standard course schedule. Besides, there are significant positive points in its favor. Exposure to primary science literature early in their career enhances students' understanding of the process of scientific inquiry [4–7]. They not only appreciate the methodological rigor of science but also acquire a more "humanized" view of science and scientists. They become aware of the effort, debates, and excitement the scientific community goes through before a scientific theory is established. On the whole, the approach tends to nurture students' critical thinking and analytical skills, which can help them in making informed decisions in general and about their career path in particular.

In India after the 12th grade, students may enroll in colleges, universities, or some research institutes for their Bachelor of Science (B.Sc.) degree. Recently (from 2015), the University Grants Commission (UGC), India has introduced the Choice-Based Credit System (CBCS) that aims at making undergraduate education more student centered. The new system allows much flexibility (absent earlier) with regard to the choice of subjects/courses in undergraduate curriculum; students are allowed to study at different times and at different institutions to complete a course. The examination system is now based on the widely prevalent credit-based system; also, the credits earned at one institution can be transferred to another institution. More relevant for this

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**To whom correspondence should be addressed.*
Tel.: +91-9930076768. E-mail: anuttamakulkarni@gmail.com.
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work is the fact that a research-based component is now an option offered under the head "discipline-based elective." Yet, most of the colleges and universities do not offer this option in their (B.Sc) curriculum. Some leading research institutes, which conduct integrated BS-MS courses do include courses that emphasize primary literature reading, but these are available only after the undergraduate level.

The reasons for this omission despite the UGC recommendation are not hard to understand. It is generally thought that reading and comprehending a good piece of primary literature requires considerable background knowledge that includes familiarity with experimental techniques, statistical methods, and expert terminologies, besides facility with reading and interpretation of graphical data, and so on. All this, it is thought, is difficult and can be overwhelming at the undergraduate level [8, 9].

Yet, elsewhere in the world, science teachers and educators have successfully designed different approaches to include research paper reading in undergraduate courses [3, 6, 10–16]. One of the most serious efforts in this connection that we have come across is "CREATE." In this approach, students read four consecutive publications (from the same biology research laboratory) over the course of a semester [3, 14]. Another approach called Process Oriented Guided Inquiry Learning (POGIL) has been found to be adaptable for research paper reading [15]. Yet another approach consists of designing questions specific to a research paper, and grading the students based on their written answers [6]. In this approach, the research paper is related to the topics covered in the course. Another most common practice is the "Journal Club," wherein a student presents a paper to the rest of the class. In this case, however, all students may not actively participate in the process [16]. Another data-centric approach termed "Figure Facts" [12] is discussed by Campbell *et al.* 'Figure Facts' emphasizes structured reading of data figures. However, it does not give students an overall understanding of the paper. "CREATE", "Figure Facts," and most of the other approaches were designed for a one-semester course. While they are all excellent pedagogical tools, it is impractical at present to adapt them to Indian University/College environments; the system simply does not have the required flexibility to try any innovation over an entire semester.

This circumstance forced us to design and explore a primary literature-based intervention that is outside the college academic calendar and limited in its scope and ambition. Luckily, this was possible. Every year, in the short winter vacation in December, our institution hosts about 25–30 first-year undergraduate students from across the country. All the students have biology as one of the subjects in their first year in their colleges. Going through the literature cited earlier, we found that a few of the papers [6, 13] involved first-year undergraduates. Encouraged by their results and constrained by the circumstances indicated previously, we decided to carry out a short 3-day intervention on the sample of 29 first-year students who visited our institution in 2018. The results of the intervention were encouraging. The details of the sample and methodology appear below.

Methodology

Design of Module

For reasons already indicated, the module to be designed for introducing first-year students to primary literature reading had to be of very short duration. Only then it would be feasible in the near future to accommodate it in any university/college schedule. Further, Indian students are used to only the lecture mode of instruction till the 12th grade. Also, most of the first year B.Sc students are not familiar with the techniques and terminologies used in research publications. We were keen to ensure active participation of all the students in the process. Accordingly, the module was designed in such a way that student-centered active learning was introduced gradually. Thus, we combined traditional teaching and student-centered learning in the module and decided that it be of 3-day duration (Table I).

The module including the questions for student assessment was vetted and modified through group discussions among the six staff members working at the biology cell of our institution.

Schedule of Activity

Before carrying out the module, the instructor/facilitator had the choice of selecting the research paper. We regarded it important that the facilitator is comfortable with the primary literature chosen.

On the first day, a conventional lecture was given on the terms and techniques and the basic concepts that were essential for understanding the particular paper chosen. First, the core concepts were discussed, such as function of cell–cell and cell matrix junction, structure of cell–matrix junction in epithelial cell, integrin and basement membrane, and other important terminologies that the students would encounter in the selected paper. Next, the techniques were discussed such as antigen–antibody reactions, western blotting, and mammalian cell culture. Students were given time to ask questions or add to the facilitator's explanation. We asked all the students to list down the new terminologies they had just heard in the lecture on a common board and explain them. This was a way to ensure that almost the entire class was on the same page with respect to background knowledge. The class was then given "homework" of reading the first half of the research paper. Outside the class, they were free to discuss the paper with their peers, search the Internet for any doubts and difficulties, or refer any books. They were informed that they would be asked questions pertaining to the first half of the paper. They were also encouraged to watch available videos of molecular biology and biochemistry techniques in their free time.

Right at the beginning of Day 2, the students were handed over a set of six questions (Supporting Information S1). The six questions were related to the research question taken up in the paper, hypothesis, methods, data collection, results, and future directions/significance of the work. Most of the questions had

TABLE I *Details of primary literature reading activity designed for first-year undergraduate students*

DAY & TIME	Activity Design	Participants and Lead in Activity
ONE 1 to 2 Hrs	**Conventional Teaching** 1. Teach biological concepts e.g. cell –cell and cell-matrix junctions, Cell Polarity. 2. Teach research methods e.g. immunostaining, Western blotting.	Class activity led by facilitator
	3. Home assignment for students - Reading part I of the research paper.	Individual reading
TWO 2 to 4 Hrs	**Student Centered Session - Part I** 1. Written test on part I of the research paper. The test combines MCQs and subjective questions.	Individual writing
	2. Discuss all questions and answers in depth.	Class activity led by facilitator
	3. Home assignment for students - Reading part II of the research paper.	Individual reading
THREE 3 to 4 hrs	**Student Centered Session - Part II** 1. Written test on part II of the research paper. The test combines MCQs and subjective questions.	Individual writing
	2. Assign one question from written test to one group of students and give them time to arrive at an answer/explanation agreed by all members of the group.	Group discussion
	3. Each group leads discussion of answer to the question assigned to them.	Class activity led by students

Increasing Student Participation

possible answers mentioned in the form of options. Students were asked to choose the correct option and provide explanation for their choice. During the written test, communication with the peers was not permitted. However, they were free to refer the paper under study, the Internet, and textbooks. After the test, each of the questions was discussed in depth by the facilitator. All the students participated in the discussion. At the end of the session, reading the rest of the paper was given as home assignment.

On Day 3, a written test (Supporting Information S2) that focused on the second half of the same research paper was given to the students. After the test, students were put into six groups. Each group was provided with one question from the second test. They were then given time to discuss that question with their teammates. All the groups arrived at consensus answers to the question allotted to them. They presented and explained the answer to the rest of the class. This discussion was led by students and the facilitator intervened only when the students got stuck or misinterpreted something. Thus, the 3-day long activity that began with a conventional lecture ended up in enthusiastic student-led conversations and presentations.

Our module is designed to enhance novice biology students' confidence and to initiate them further into the reading of scientific literature. The facilitator needs to focus only on one article of his/her choice. It reduces the workload of the facilitator. Assessing each student for each aspect of the paper would be difficult if many publications were included in the activity. The 3-day schedule has three important elements. It encourages active individual learning, interactive classroom activity as well as group activity. The reading of the paper and taking the written test is done individually by the student. Hence, tracking the progress of each student is possible. The total classroom time requirement of the module is not more than 10 h (Table I). Thus, the module besides being flexible can be accommodated in any college/university schedule in India without much difficulty.

Choosing a Research Paper

The idea of the module was to stimulate student's interest in research paper reading. This would be possible only if students understood the rationale behind the publication under study. We focused on choosing a well-written paper that was of considerable significance in the field. Yet, we wanted to refrain from landmark primary literature of the highest importance that is generally well known (e.g. the discovery of DNA or DNA polymerase). We also avoided choosing recent publications with very complex technology and data analysis. This would have been difficult for students to comprehend and not very fruitful. We shortlisted a few among the very significant papers in biology and after some reflection converged on the following paper for the module: "Control of Mammary Epithelial Differentiation: Basement Membrane Induces Tissue-specific Gene Expression in the Absence of Cell-Cell Interaction and Morphological Polarity" by Streuli *et al*. [17].

Participating Students

The biology cell of our institution arranges a 7–9 day-long camp every year. About 25–30 first-year undergraduate students from different regions of the country and from different universities/colleges/research institutes participate in the camp. All the students have biology as one of the subjects in their first-year curriculum. In 2018–2019, most of the 29 participating students were reasonably conversant with English; two of them had vernacular medium of instruction in school and had difficulties in English comprehension; 75% of the students enrolled were from colleges and universities, the rest (25%) were taking their course in research institutes. They belonged to the age group of 18–20. The geographic location of the institutes/colleges where the students had enrolled varied widely. Thus, although we had not adopted any rigorous sampling procedure, our sample was reasonably diverse. To ascertain the background of scientific literature reading of the participants, some questions were asked and their response analyzed (Fig. 1). Seventy percent

(a)

	Survey Questions (serially plotted on X-axis)	Options chosen (Y axis)
1	How many articles from the primary scientific literature (e.g., Research Papers) have you read?	A = 0 B = 1 C = 2 D = 3 E = > 4
2	On a scale of A–E, rate your understanding of "the way scientific research is done" or "the scientific research process."	A = zero confidence B = slightly confident C = confident D = quite confident E = extremely confident
3	On a scale of 1–5, rate your confidence in your ability to read and analyze science journal articles.	A = I don't understand it at all B = I have a slight understanding, C = I have some understanding D = I understand it well E = I understand it very well
4	Do you know the difference between Research Paper and Review Article?	Yes or No

(b)

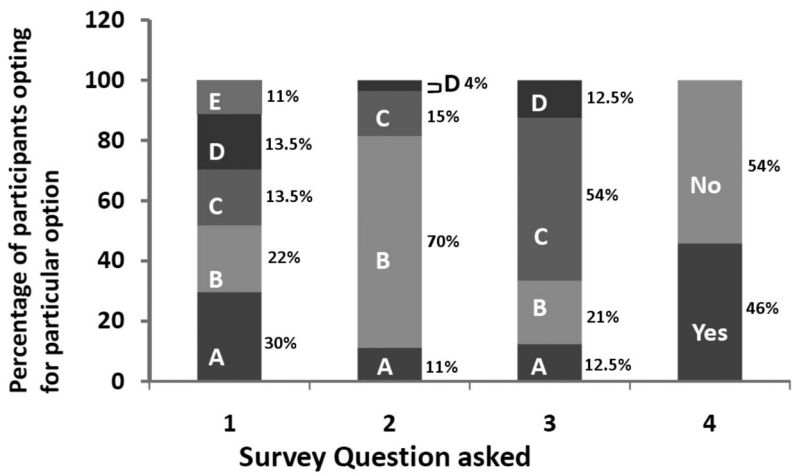

FIG 1 *Primary literature-related awareness and confidence of participants (*n *= 29). Survey questions and options are given in table (A). Data of students' response are displayed in B.*

of the students were only slightly confident about how research was done and about the same percentage of students said they had slight or some understanding of research paper reading. Not many were confident about the entire process. Many of them (54%) were not sure about the difference between a review article and a piece of primary literature. Thirty percent of the participants had never read any research article and about 89% of them had read less than

TABLE II

Explanation of grading system. Question 1 from Test 1 is taken as an example

1. What question is addressed by this Research paper for the first time?
(Select appropriate option/s from A to D or/ and write your own answer)

A. How does cell-extra cellular matrix interaction and cell-cell interaction affect phenotype and differentiation of mammary epithelia?
B. Do mammary epithelia function correctly in the absence of basement membrane?
C. Can lactating hormones alone determine differentiation of mammary epithelia?
D. Does ECM dependent regulation of tissue specific gene expression depend upon physical and biochemical signal transduction in mammary epithelia?
E. Write your own answer
F. Explain (either your answer or all/any answers you have chosen from the options)

Expected Answer :	**Student answers**		
	Grade 1	Grade 2	Grade 3
Option A Earlier studies have proven that Phenotype and differentiation of mammary epithelia depends on lactating hormones and extra cellular matrix (ECM). But it was not known whether cell-ECM interaction can induce differentiation in 'absence' of cell-cell interaction. **Role of cell-ECM interaction, independent of cell-cell interaction was studied for first time in this paper.**	Answer written by student with serial No.32	Answer written by student with serial No.24	Answer written by student with serial No.27
	Options A and B The question addressed in the paper says that **does the cell differentiate and produce milk when they cultured single cell at a time on a basement membrane or whether they produce milk only when in clusters i.e. cell-cell interaction.** The motif is to find what effects cell differentiation and production of milk.	Options A,B and C In order to know **whether mammary epithelia function correctly in absence of basement membrane** they took single cells on two medium i.e. on EHS matrix and other is on collagen matrix. They found that the cells on EHS matrix produce β-casein and that on collagen I did not.	Option A Regulation of differentiation of mammary epithelia is determined by cell and cell-cell interaction. Basement membrane play important role in regulating mammary phenotype. **Mammary epithelial cells regain their differentiated phenotype in suitable hormones and substratum condition. Because of this mechanism this model is use to understand the tissue specific gene mechanism.**

Grade 1 for an answer implies understanding of most of the concepts by students, Grade 2 implies that the student has only partly understood the concepts or has provided an incomplete explanation, Grade 3 implies that the student has completely misunderstood the concepts or has written an irrelevant answer or that the answer is copied as it is from the paper. Sometimes, there is more than one sub-question under each major question. Grades like 1.5 or 2.5 are given by averaging in such cases.

Most important part of the answers is highlighted in bold letters.

four articles. It was fair to assume that the participants had very little exposure to primary literature reading.

Assessment of Student Performance

Guidelines provided by Wenk and Tronsky[6] were used for grading students in critical reading of primary literature. The students were graded 1, 2, and 3 for very good, satisfactory, and unsatisfactory answers, respectively (Table II). The responses to MCQs were not the only input for assessment. Actual grading was based on the combination of correct choice of MCQ and more importantly, the explanation provided by student. An example of a question graded 1, 2, and 3 is given in Table II.

Results (Student Learning Outcomes)

Overall Understanding of the Students

Each student individually answered six questions on Day 2 and six questions on Day 3. Students were graded as described in Table II for all 12 questions and the average score obtained. For this part of analysis, a qualitative code was adopted for the level/extent of understanding reflected by the average score (Fig. 2*A*). Fifty-two percent of the students expressed good understanding of the literature (Fig. 2*B*). This was remarkable considering their minor primary literature exposure, before the module (Fig. 1).

Student Understanding of Rationale, Hypothesis, and Results Improved on Day 3 of the Module

On Day 2 of the module, after the individual test was done, the instructor dealt with all the questions in depth. In this session, students got many doubts cleared. Several of the questions raised were surprisingly deep for first-year undergraduates. We expected the discussion on Day 2 to improve students' ideas about what a research paper is and how to read it. The module therefore incorporated the assessment of students' learning, before Day 2-part I and after Day 3-part II discussion.

For this purpose, question papers were designed to test student understanding of each section of the research article. For example, Question 1 on Days 2 and 3 dealt with the rationale behind the studies; Question 2 on Days 2 and 3 dealt with the hypothesis of the study (Supporting Information S1 and S2). Analysis of students' answers showed their increased understanding of the rationale behind the study, the hypothesis, and the overall results of the study, from Day 2 to Day 3. The experiments given and the results obtained in the first half of the paper were different from the ones in the second half of the paper. Thus, the students successfully applied what they learnt on Day 2, to a new situation and had analyzed the literature better on Day 3. We performed paired T test as we tracked each individual student for the 2 days and found that the improvement in the student grades was statistically significant (Fig. 3*A*).

Student Understanding of Materials, Methods, and Future Directions Did Not Improve Much on Day 3 of the Module

We also assessed students' understanding of materials, methods, ways of data collection, and understanding of the future directions of the project. On Day 2 of module, students had many technical doubts. This was expected because students had rarely performed molecular biology practical sessions in their colleges. Thus, the immunoprecipitation experiments, even fluorescence imaging experiment described in the study were difficult for them to comprehend. Most of them understood what the data implied but could not visualize how the authors had collected the data. Their understanding on this aspect did not show any significant improvement from Day 2 to Day 3 (Fig. 3*B*).

(a)

Average score for all answers in two written tests	What it inferred
1-1.5	Excellent Understanding
1.5-2	Good Understanding
2-2.5	Somewhat understood
2.5-3	Misunderstood Concepts

(b)

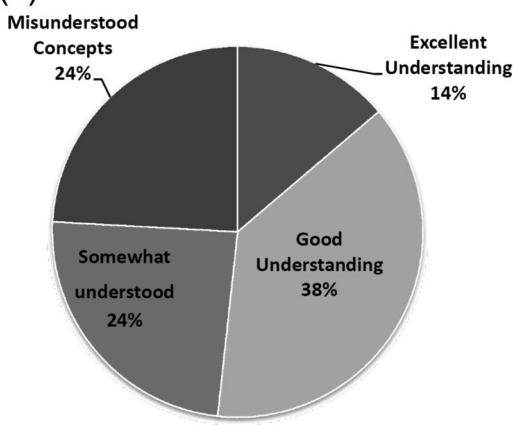

FIG 2 *Qualitative code for the level/extent of understanding reflected by the average score (A). Pie chart for the level of understanding (B).*

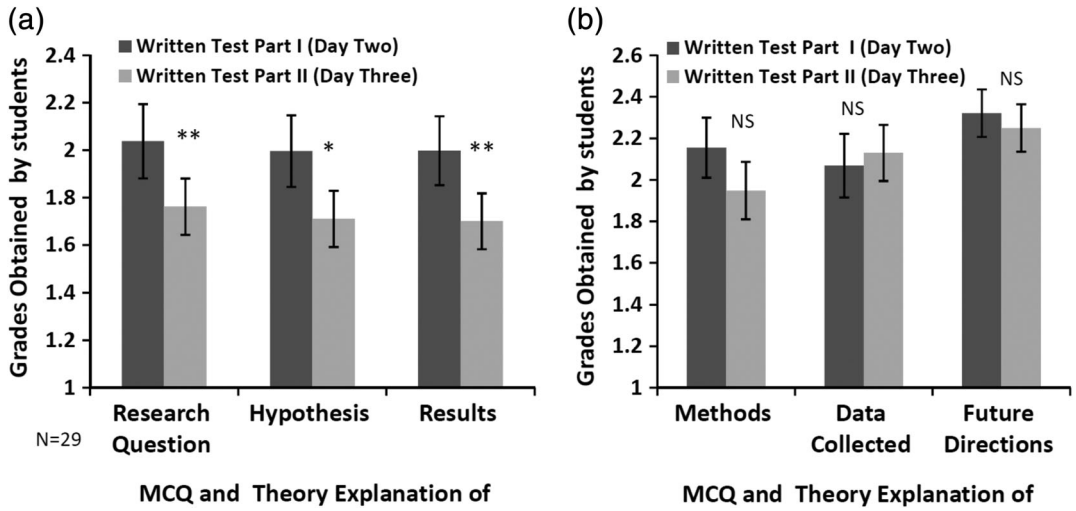

FIG 3 *First-year students showed improved understanding of research question, hypothesis and results on third day, compared with their performance on Day 2(A). No significant change was observed in students understanding of materials and methods or future directions of work (B). Paired T test was performed. One asterisk (*) indicates* p *< 0.05. Two asterisks (**) indicate a* p *< 0.01. Error bars represent standard error of the mean.*

Student Feedback about the Module

The last session on Day 3 was led by the students. All the students participated with enthusiasm. Their articulation and presentation seemed reasonably good, although the session was not systematically assessed. On the last day of the 9 day camp, of which this module was only a 3-day component, a general anonymous feedback about all the sessions conducted in the camp was taken from the students. We were skeptical about the response, as the research paper reading activity was the only theory-based activity in the entire camp. However, the overall assessment of the research paper reading sessions by the students was very positive. Eight-four percent of the students rated the activity to be very good to excellent (Fig. 4). None of the students thought that the activity was not good. The lone student, who rated the activity as average, suggested that the instructor should explain every figure one by one and did not like the student-centered approach in general.

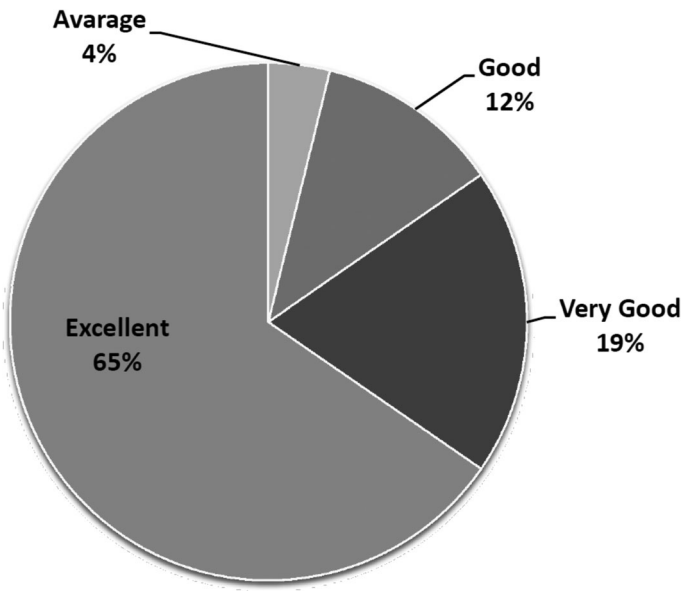

FIG 4 *Overall assessment of the research paper reading sessions by the students (*n *= 26, three students were absent on the day of the feedback). Eighty-four percent of the students rated the research paper reading activity as excellent or very good.*

Discussion

Increasing awareness about the scientific method/enquiry has both cognitive and social significance [18, 19]. Every science graduate needs to be aware of the process of how science is practiced. Primary literature reading is an excellent way of introducing students to the method of scientific enquiry. For the students who aspire for a career in science, it is essential to understand and read scientific literature [6].

Typically, in post-graduate courses in India, students are expected to make presentation of research papers or write a literature review and are often graded for the same. However, training or initiation into reading of research papers is usually not a part of any course work. Indian universities rarely follow suitable rubrics to assess understanding of students about the literature. Misunderstandings of students or the extent of their conceptual clarity about a research paper are not realized until they are judged individually in research project examinations. Not surprisingly, a large number of undergraduate students consider the task of reading a research paper difficult. As mentioned earlier, many of the students who participated in the module did not know the difference between a review article and a research paper. Several of them had not read even a single research paper.

With this background, this module aimed to introduce students to research paper reading through a partially guided approach. It begins with an introductory lecture session on the terms and techniques that are essential in understanding the research paper chosen. This builds students' confidence to read a part of the paper at home. Student participation is gradually increased through the course of the module. Since it is only a 3-day module, recalling what is learnt in the introductory session is not difficult for students. They recall and apply knowledge gained in the first 2 days quite effectively on the third day. As we saw, their overall understanding of the results of research, its rationale and hypothesis, showed improvement on Day 3. On the other hand, lack of exposure to experimental equipment and procedures hindered students' understanding of the materials and methods and data collection. The modest documented success of our module suggests that inclusion of research component in undergraduate curriculum in India will help in improving not only the students' understanding of the subject but also in their ability to benefit from primary literature.

We plan to replicate the module with research papers focusing on other areas of biology. We would like to check whether the success of the module is independent of the facilitator. For practical purposes, a paper of general interest was chosen here. The epistemic gains students made should hopefully help them in the reading of other research papers also.

As a final remark, we should clarify that this report on an intervention using a 3-day module cannot be compared with the much more comprehensive work cited earlier [12, 14], which involves primary literature reading over a full semester. The conclusions of the latter are far better validated than ours. Further, our sample size (29) is also rather limited, which means we need to replicate the experiment over several years with greater sample size for the results to be generalizable. Yet the work suggests that a module like ours can be a reasonable starting point for introducing the innovation of research paper reading in undergraduate courses in India, given the constraints of the system explained before. Should these constraints get relaxed in the future, and time and expertise are available at the university or college level, this module could be followed by Figure-Facts [12] or CREATE [14] to enhance the ability of motivated students to read and gain from primary literature in biology.

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