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REVIEW ARTICLE

Unlocking the Potential of Pedagogical Optimization in Undergraduate Science Education: A Case Study

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ABSTRACT

Education in science has undergone tremendous changes with the integration of innovative teaching-learning pedagogy and Information and Communication Technology (ICT) tools. In this paper, effort has been made to suggest some new and innovative pedagogies like students led Mentor-Mentee program, Design based labs, formative assessment by the stakeholders, framing of questionnaire with the solutions by the students amongst other to improve the understanding, skills and employability of Science Undergraduate students. These suggestions have been arrived at, based on the study carried out involving the undergraduate students of Physical Science studying Physics as one of their discipline (for a total of 2096 students from 1st, 2nd and 3rd year), admitted between 2020 and 2023, in one of the central universities of India viz., University of Delhi. The results have been analysed and discussed to suggest the scope of improvement in the existing teaching-learning pedagogy. Further, these suggestions have also been assessed in classroom settings with positive outcome and considerable success. Another important aspect analysed through this study was the effectiveness of the ICT tools, especially in a country like India where recent policy initiatives have ushered in a major overhaul of the entire teaching-learning system. This study has also focussed on the effect of ICT mediated teaching-learning pedagogy in view of the extraordinary challenges posed by the Covid-19 pandemic.

Keywords: Pedagogy, Research and Innovation, Higher Education, ICT

1 Introduction

Education in science has undergone a sea change especially in the last two decades to meet the demand and challenges of the changing world particularly for the industrial and trade sectors. Thus, the curriculum and pedagogy of science courses is being constantly updated by Higher Educational Institutions (HEIs) and an increasing attention is being paid on the teaching-learning methods and reforms to establish a link between learning and future employment of science graduates. Many HEIs are exploring processes to enhance the student learning through the real-world assessment strategies in the curriculum (Morley and Jamil, 2021). In recent years, one major change in the teaching-learning process is the integration of ICT in science education, whose advantages and disadvantages have been reported in several research studies (Qaddumi et al., 2021; Tang and Hew, 2022; Zaidi et al., 2021). Despite efforts to improve the learning and skill-set of undergraduate students, there still exists a skill gap between the requirements of employment and the competency of graduates (Cheng et al., 2022). In the backdrop of these challenges and opportunities in higher education, some suggestions are made regarding curriculum framing and pedagogy. These ideas are substantiated by the study on the undergraduate (UG) students of a central University i.e., the University of Delhi (DU), India. Being a central university, DU admits students from all sections of the society and students from different states accounting for around 80% of the intake and also from outside the country.

2 Methodology

The study was conducted on 2096 students (685 students of year-I, 715 students of year-II and 696 students of year-III) of Physical Sciences, newly admitted to outgoing, between year 2020 and 2023, studying Physics as one of their disciplines. The ideas, proposed here, have been implemented on the newly-admitted students to the outgoing students. In the entire study, the geographical background of the UG students of DU was also enquired and it was found that a total of 47.8%, 21.7% and 30.4% students were from rural, semi-urban and urban backgrounds, respectively. This study is representative of the needs and aspirations of the students across all boundaries, especially developing countries.

This article has a special relevance for the teaching-learning community in the formal system of education at UG level. Many suggestions have been incorporated for the improvement in the pedagogy of science education by taking into consideration the opinion of the students on various aspects of contemporary education. In order to obtain the opinion of students, a questionnaire was carefully framed (Supporting information) to cover several aspects related to geoeconomics, job feasibility and the extent of ICT in formal education in addition to assessing their expectations from their teachers and the institution.

3 Result & Discussion

The feedback so obtained was carefully examined, interpreted and its outcomes were taken into consideration while implementing the suggestions that have been proposed. The same have been discussed in detail below.

Suggested teaching-learning pedagogies

It is necessary to move beyond the traditional methods, hence on the basis of student's feedback some new and innovative teaching-learning pedagogies have been developed and tested which are elaborated below.

Content updation and Pedagogical alignment with Learning Objectives/Graduate Outcomes

In this study, 81.3% of students responded in the affirmative when asked whether they knew the learning objectives/graduate outcomes of their course of study. This was verified from newly admitted to final-year UG students between 2020 and 2023 regarding their familiarization with the learning outcomes of their course. An effort was made to familiarise the students with the learning outcomes and also to conduct various academic activities to perform gap analysis of these students with respect to their learning outcomes. About 35.5% of newly admitted students were not aware about the learning outcomes which, after our intervention, reduced to 17.9% for second year students and further to only 2.5% for final year students as shown in figure1. Thus, there is a need to ensure that all the students admitted to a course of study must be familiarised with the learning objectives/graduate outcomes. Also, many mediocre students who do not have proper preparation and skills to

understand graduate-level science find themselves at a greater disadvantage.

This is also highlighted by the fact that 12.1% of learners enrolled in a course of study said that they did not possess the knowledge as defined in its prerequisites while another 31.8% said that they understood the prerequisites only partially.

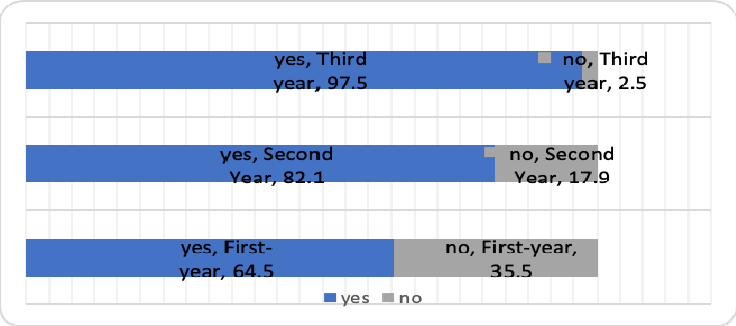


Figure 1: Percentage of students familiar with their learning outcomes

The students' response recorded regarding the relevance of the curriculum with respect to the job market or becoming an entrepreneur was 22.4% in affirmative and 32.7% in negative. The remaining 44.9% replied that the curriculum equips them only partially. Thus, around 3/4th of students felt that the curriculum needs to be better equipped for their requirements, a key focus point as envisaged in National Education Policy (NEP)-2020. For achieving this NEP-2020 lays significant emphasis on incorporating skill-based courses linked to disciplines of study. Therefore, suggestions and feedback from relevant industries, companies, employers, alumni and research institutions and skill-gap analysis regarding current demands and trends should be included for curriculum enrichment. These should also be used for formulating standalone skill-based courses and vocational/skill components of the syllabi for regular UG courses. When the students were asked about this suggestion, 57.9% students agreed that such an involvement of all stakeholders of the employment ecosystem will make the curriculum relevant and hone their capability. Hence provision should be made for the relevant industries, companies,

employers, alumni and research institutions to offer internships to the students wherein the progress-report for each student, obtained after the completion of internship programs, may contribute to their formative assessment.

3.1 Assessment and Evaluation

Each curriculum should contain detailed prerequisites for that course and students should be assessed for their knowledge and understanding of these prerequisites. Learners found wanting in these assessments must in addition to the regular curriculum also take up foundation or bridge courses. This is highlighted by the fact that an overwhelming 89.7% of students said that such bridge and foundation courses will be highly beneficial for developing a better understanding of their course of study. These are also supported by the findings of this study, where 86.9% learners said that the formative and summative assessments should carry elements from learning objectives/graduate outcomes so that such assessments help the teacher or instructor to focus on the weak areas of the learners and tutor them accordingly. In our current pedagogy, more emphasis is laid on summative evaluation for assessing any learner. However, this approach needs to be discouraged in favour of formative evaluation because it offers the learner the opportunity to improve while the learning process is still in progress, as reflected in this study.

A good 60.7% of students are in favour of both formative and summative assessment carrying equal weightage while 24.3% support only formative assessment. Thus, there is a need to give more emphasis to the formative assessment and credible mechanism be evolved for deriving meaningful benefit from it so that the students get an opportunity to understand their weaknesses and strengths. An outline is designed for the continuous evaluation as represented in figure 2 in which the weightage of formative and summative evaluation was kept equal and tested it in a particular class of students. A considerable improvement in the learning outcomes of these students was found in comparison with their performance in the previous year. Therefore, the formative evaluation process should be made more rigorous with at least the same weightage as summative evaluation. A pedagogy is suggested wherein teachers and other stakeholders organize formative

assessment on basic and relevant concepts of each topic to determine whether the learning objectives and outcomes of the said topics have been achieved or not. Based on these assessments, the teaching faculty may discuss its outcome with the students and accordingly plan the course delivery to familiarize and develop an understanding amongst the students on these basic concepts. This will help students focus more on the part where they lagged previously.

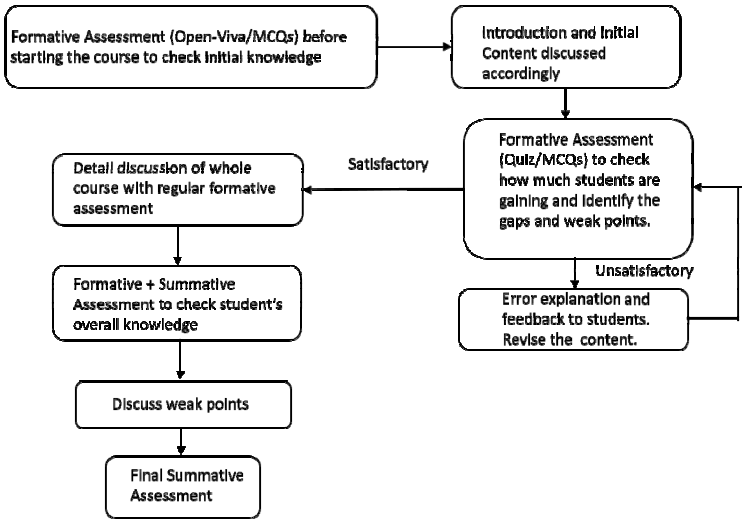


Figure 2: Outline regarding formative and summative assessment implemented throughout the course

3.2 Pedagogy Transaction Strategies

Another suggestion regarding the pedagogy is with respect to transaction strategy of the curriculum. Teachers can make some study material, relevant to the topics being discussed, available to the students periodically. Based on this material the students could prepare a set of questionnaires and numerical along with their solutions. This exercise would help develop and improve the understanding of students in respect of their courses of study. Further, based on the kind of questions framed and solutions provided by the students, the teachers can get a fairly good idea about the grasp of concepts by the students and their understanding.

This exercise can also help in bringing to light the topics in which the students are weak, and the teachers can then selectively have discussions with students regarding the same. This will not only be a good model to assess the weaknesses of the students but also provide an opportunity for improvement without the students getting penalised through a summative assessment. This pedagogy was tested by giving different topics discussed in the class to the students throughout the semester and they were asked to frame questionnaires with solutions based on these topics. It was observed that students framed conceptual questions and questions which tested the understanding on those topics which were well understood by them. While they either left out or framed basic questions on those topics in which their understanding was poor. This helped in understanding the weak areas of the students and accordingly they were helped in developing an understanding of the given topic.

3.3 Student Mentors and Tutors

In order to improve the conceptual knowledge of a topic along with the communication skills, the final year students were allotted to take tutorial classes of the first-year students under the supervision of the concerned teacher. Apart from improving the fundamental understanding of the student meeting such tutorial, this allowed the tutees to ask questions more freely with the student tutor which perhaps they could not have asked their teacher. The above pedagogy also enabled us to make formative assessments of the final year students, who were acting as tutors.

3.4 Demonstration and Application Driven Pedagogy

Laboratory experiments are far more valuable tools in developing a better understanding of the fundamentals of science through practical skills and enhancing scientific reasoning ability including the analysis and visualisation of data and modelling skills for interested students (Wei et al., 2019). However, most often the students fail to correlate the purpose of investigation with the objectives of designing the experiment and hence get confused while explaining the real-life phenomena based on the principles of science particularly for Physics (Chang et al., 2022).

On being asked whether the experiments performed in Physics laboratory were related to real-life applications, 51.4% of the students felt that the experiments were only partially related or not related at all. Further 64.5% of the students said that experiments should be based on real-life applications and such linkages will be beneficial to them. In order to fix this gap of the existing experiments in the curriculum, these should be replaced by new experiments having such linkages. A portable kit containing Arduino, different ICs, LEDs, resistors, capacitors, breadboard, piezoelectric crystals, springs, weights and many other relevant components were provided to the students to design application-based experiments according to the learning outcomes. This provided flexibility to the students to design such experiments at any time irrespective of their scheduled period or place. In the process they displayed a good deal of dedication and enthusiasm. It has been found that the number of students who wanted to pursue an experimental project in a practical class increased gradually from 75.3% for the students in their first year in 2020 to 92.4% in their final year in 2023. Out of these, the percentage of students who finally submitted the project also increased from 52.3% when they were in their first year to 83.7% when they were in their final year as shown in figure 3(a). Therefore, it is suggested that in designing experiments a flexible approach should be adopted. Learning outcomes should be defined instead of fixing a list of experiments. Based on these learning outcomes, the teachers and students may design and implement the experiments. This is in consonance with the survey where 56.1% learners said that this approach will enable better understanding and clarity of concepts and others said that this approach will improve the understanding to a great extent. To inculcate the designing ability among the UG students it is imperative for the institutes to have a full-fledged workshop where the students can contribute by repairing faulty equipment and maintenance of the apparatus used in the laboratories in addition to designing them. In this study it has been found that students who were involved in designing and repair and maintenance of apparatus not only developed the necessary experimental skills but also got an insight into the working of the apparatus used.

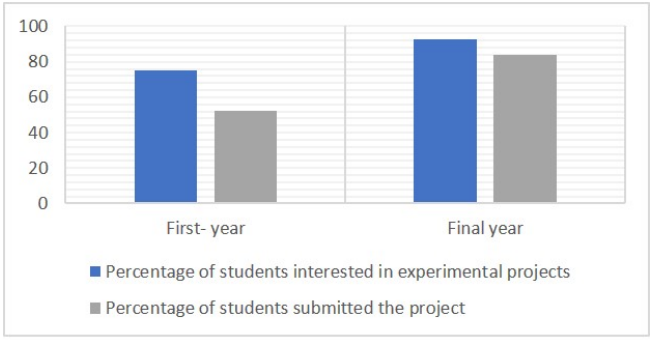
New pedagogical concepts are laying greater emphasis on promoting research at college level, especially in the final year of the program. Thus, some recent good quality research papers are given to the students according to their area of interests and asked them to write their comprehension of these papers. Every student was motivated to write their laboratory records in the style of reputed journal publications. As a consequence of this activity, some of the final year students wrote articles in newspapers and presented their research work and reviews in various conferences.

3.5 ICT integration for teaching-learning process

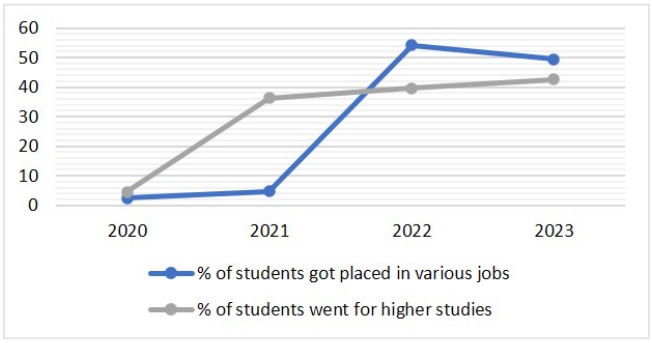
To enhance and augment the efficacy of higher education, new online technology including Massive Open Online Courses (MOOCs) has been globally recognized (Almatrafi and Johri, 2018). MOOCs offer a flexible learning platform, which is a valued addition to classroom learning with some challenges (de Moura et al., 2021; Mohamed and Hammond, 2018). In view of the importance and significance of MOOCs and other ICT tools student's feedback was sought on specific points as given in supporting information. The study performed was pertaining to their awareness about the MOOCs platform and other such platforms developed by various government and academic agencies, led to some startling revelations. Data shows that many students had no knowledge about these courses. It was found that only 29% of students knew about these courses and platforms. A much more serious problem is that out of these students who knew about these courses and platforms only 7.5% of students had undertaken them. Amongst the students who undertook the MOOCs courses, 71.9% of students said that they were not related to their course of study. Further regarding awareness of the various platforms and initiatives regarding ICT and MOOCs by government and other academic agencies a good number of 42.1% students said that they were not aware of such initiatives and platforms.

Therefore, it is extremely important to make this section of students aware about this form of learning. To achieve this, the advantages of these platforms was highlighted and relevant MOOCs were incorporated in the classroom lectures. The MOOCs related to the course/paper should be mentioned in the references of the curricula of every HEI. Amalgamating the

feedback from the students from time to time with the innovative pedagogical strategies extending to more than three years, desired results have been obtained in shaping the career of the students in terms of their furtherance in higher education and securing employment after graduation. The suggested pedagogy is applied from year 2020 onwards. It was implemented for only one year with respect to batch of 2021, two years for batch of 2022 and three years for batch of 2023. Analysis of the results demonstrate year-wise steady growth in percentage of students in terms of placement, from 2.5% in 2020 to 49.33% in 2023, and selection of students in higher education programmes, from 4.5% in 2020 to 42.54% in 2023, with respect to the students passing out in each year as is evident from figure 3(b).



(a)



(b)

Figure 3:(a)Percentage of students interested and submitted the experimental projects, (b)Percentage of science students who went for higher studies and got placements

3.6 Blended approach in teaching-learning pedagogies

To develop the critical, qualitative thinking skills and quantitative working skills among science students, the traditional teaching learning pedagogy should be supplemented with ICT mediated resources i.e., the blended approach (figure 4). This suggestion is also backed by the responses that were received from the students where nearly half of the students said that they preferred the blended mode of teaching, 1/3rd of the students said that they still preferred the traditional classroom teaching.

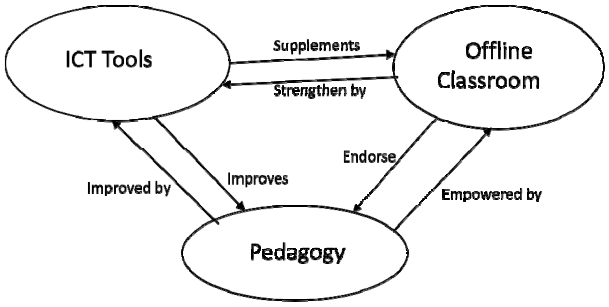


Figure 4: Figurative description of cross linkages between ICT tools, offline classroom and pedagogy

Hence, students expressed their confidence in blended learning (BL) for the effectiveness of their learning environment. The impact of BL on teaching pedagogy (Castro, 2019; Islam et al., 2022) and on learning outcomes and student performance (Dziuban et al., 2018; Sankar et al.) have been investigated. However, if we combine the percentage of students preferring blended mode and online mode then this comes out to be around 66%. As mentioned above, roughly half of the total number of students belong to the rural background and financial constraints may be a significant factor for them to achieve higher education in offline mode from a reputed University located in an urban area. In order to cater to the needs of this group of students, the HEIs should start the highly subsidized online courses. Through the blended approach, students can be transformed from passive learners to active participants in the transaction, delivery, and creation of knowledge, especially in situations like Covid-pandemic where face-to-face interaction with students was non-existent.

The number of students present and their engagement levels in both online and offline mode has been examined. The findings revealed that student's strength in offline classes was 50-70% of online classes. While, their engagement was more in offline mode than online mode despite conducting many interactive activities during online classes. However, it has been observed that by holding various interesting activities (e.g., time bound quizzes, short videos), students become more engaged in online classes. Effect of inclusion of blended learning also reflected in the pass-out percentage of science students as it increased from 95.65% to 97.26% from year 2020 to 2023.Therefore, Blended learning with proper strategy (e.g., various modes of teaching, content delivery, technologies) by the teachers is required to optimize the learning outcomes.

4. Conclusion

The entire study reported above was conducted on a group of students right from the day of admission to the day they passed out from the college i.e., for a period of three years. According to the responses of the students, some points are suggested to the higher education policymakers and science teachers.

5. To Policymakers:

There should be proper facility for the relevant industries, companies, employers, alumni and research institutions to offer internships to every student.

University-Industry-Research institution interaction in curriculum designing.

Each curriculum should contain detailed prerequisites for the course of study.

Formative evaluation process should be made more rigorous with at least the same weightage as summative evaluation.

6. For Teachers:

Teachers should ascertain that all the students admitted to a course of study must be familiarised with the learning objectives.

Student assessment on the prerequisites of all courses and greater emphasis on formative assessment to identify their weaknesses.

A proper continuous evaluation technique should be developed to assess and assist the students in overcoming their problem areas.

Promoting problem-based and designing-based laboratory activities and motivating the students to take up an application-oriented curriculum.

The ultimate aim of all these innovative teaching-learning methods is to ensure that all science students acquire knowledge and skills required to work as professionals. The concluding purpose of this study is to help students become autonomous learners.

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