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LEARNING PHYSICS PRACTICALS ONLINE DURING COVID-19: CHALLENGES AND OPPORTUNITIES

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Abstract : Laboratory work is an integral part of learning science subjects and its importance cannot be ignored, especially in undergraduate courses. The practical training through virtual physics laboratories was explored meticulously for the first time in regular undergraduate colleges in India during the Covid pandemic. Although both theory and experiments were carried out in online mode there were some apprehensions regarding effective learning of experiments through online laboratories. The objective of this study is to evaluate the learning achieved by the students in virtual laboratories. In order to check the efficacy of online mode on various parameters we have surveyed only those students who had performed the experiments both in real and virtual laboratories. The questionnaire of our survey covered all pertinent issues related to offline and online modes. The authors noticed that students highlighted a few infrastructural impediments in real laboratory work. The keenness and enthusiasm shown by the students for learning practicals was overwhelming in online mode but the transition was not smooth as expected in learning any novel technique. Although the students adapted to this new set of learning, they complained of missing peer to peer interaction and physical unavailability of mentors.

IndexTerms -.**Online mode, offline mode, virtual laboratory, real laboratory, apparatus, physics practical, experiments.**

I. INTRODUCTION

The pandemic period has been a challenging time for all of us and we have entered a new paradigm in every sphere of our lives due to this. The new challenges also brought exciting opportunities to explore new initiatives as rightly said by the prominent physicist John Archibald Wheeler (1979)

"*In the middle of every difficulty lies the opportunity*".

Although online teaching had gained acceptance with the vast majority of institutions as the only medium of interaction much before the pandemic also (Lundberg, et al, 2008), it became a necessity as it was the only means of imparting education during the lockdown imposed due to the pandemic. All over the world educationists inculcated online teaching as the preferred mode of teaching/ learning process during the pandemic **(**Anna, et al, 2016**)**.

"Science teaching must take place in laboratory; about that at least there is no controversy" (Hudson**,** 1991)

Practical training is a vital and irreplaceable tool in imparting scientific knowledge and achieving intended learning outcomes (Millar, et al, 2002). Many online resources were explored and adopted for performing experiments in the virtual laboratories (Tang et al, 2016).The best possible open software was selected for each experiment to give students a feel of a real laboratory for effective teaching. For this purpose a virtual laboratory source, viz. Virtual Labs -an initiative by the Ministry of Education, Government of India was used. The main purpose of these simulation based laboratories is to provide remote-access and to enthuse students to conduct experiments so that they could learn basic and advanced concepts through remote experimentation. The online mode was adopted so that the students were not devoid of their primary need of education during the pandemic.

The softwares and virtual laboratories were the only options available to give practical training to the students during the pandemic (Kocijancic, 2002). This mode of online teaching which continued for almost two years opened new unchartered territories for teachers and students who were not well versed with the online methods of doing practicals (Tang et al, 2016).This study explores the challenges and opportunities faced by the students while doing online physics practicals and compares the learning of physics practicals by the students in online and offline mode.

Objectives of the Study

The objectives of this study are as follows:

- To compare the experiments performed in online and offline mode from the students' perspective.
- To know whether the student has understood the theory, concepts and procedure of the experiment.
- To check the role of videos related to the experiment in understanding the experiment.
- To check the role of student- teacher interaction in effective learning of Physics practicals.
- To understand the significance of peer group discussion in the learning process.
- To know about the problems faced by the students in the virtual physics laboratory and try to find solutions for the same.

II. RESEARCH METHODOLOGY

As this transformation from offline to online mode was very swift so many apprehensions were created both in the minds of teachers and students. In this study it was planned to do a comparative analysis of online and offline practical classes from the students' perspective.

2.1 **Sample**

In University of Delhi the graduation is for a span of three years comprising six semesters, so the undergraduate students during 2020-2022 had a firsthand experience of doing experiments in both offline and online modes. The hands-on experience of these students became the case study to give comparative feedback for their experience of learning the experiments in dual mode.

2.2 Data

A Google form was circulated amongst this group of students of three prestigious colleges of Delhi University for this survey. About 200 students who had physics as their major subject shared their experiences of doing experiments in physics laboratories and the data collected is analyzed in the present study. The questions in the survey form mainly focussed on the comparisons of understanding of concepts and theory of the experiments, learning experience in virtual and real laboratories. As the students were the real stake holders, their experiences were recorded from the very beginning till the completion of experiments in the virtual laboratories. This novel technique gave us interesting data regarding the advantages and challenges faced by them in the online mode of performing experiments.

III. RESULTS AND DISCUSSION

3.1 Population and Sample

Majority of the students who were chosen for the survey had done physics experiments in both the modes and hence were capable of providing a comparative analysis for both the laboratories (Figure 1).

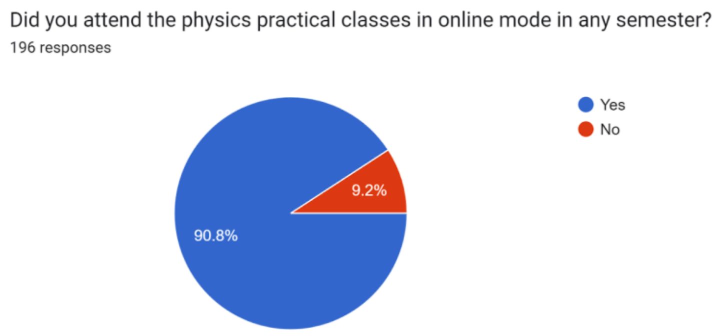

Figure 1. Percentage of the students who attended online physics practical classes

3.1. Transition to Online Mode

Delhi University colleges get students from all parts of the country including students from small towns and villages, where infrastructural obstacles such as irregular connectivity became a major concern in online mode. Also non- availability of computers was a major concern. Our colleges issued the laptops (given by the University of Delhi to its affiliated colleges) to the needy students to facilitate their online learning. Inadequate technology was a common hurdle during Covid-19 pandemic especially among lower income students (Jaggars, et al, 2021) which was overcome by providing extra time to such students. Almost 62% of the students experienced seamless transition towards the online practical training methodology (Figure 2).

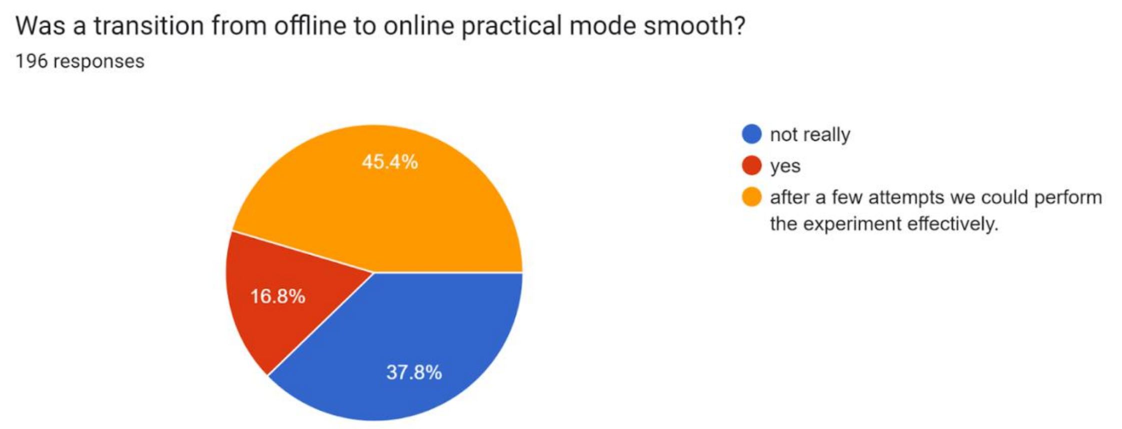

Figure 2. Smoothness of transition from online to offline mode of teaching

3.2. Initiatives to tackle teething Problems

A major apprehension before switching over to online mode of teaching physics experiments was the inability of the students to understand the theory and procedure of the experiment. The task of due diligence was carried out to successfully enable the students to understand the theory and procedure of the experiment (Figures 3 and 4) before attempting it on the virtual lab platform.

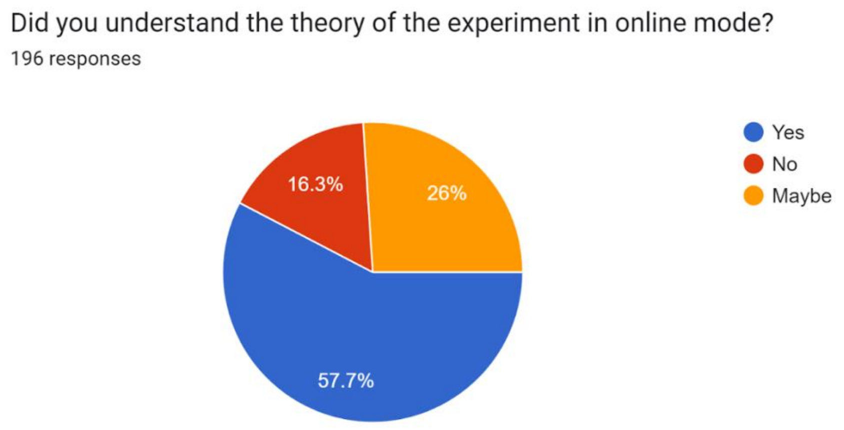

Figure 3. Percentage of students who understood theory of the experiment in online mode

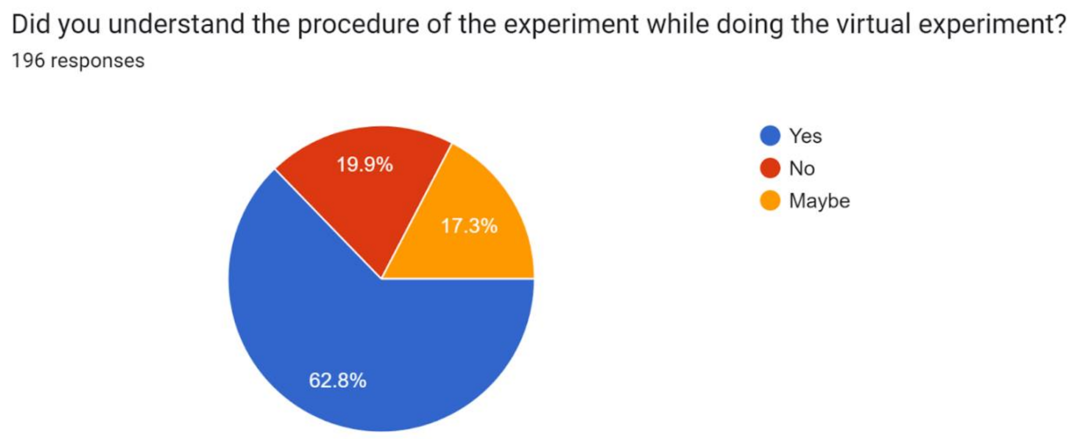

Figure 4. Percentage of students who understood the procedure of the experiment while doing experiments in online mode

Online physics laboratory was a novel experience both for the teachers and the students, which seemed a herculean task in the beginning. The teachers tried their best to make the students at ease with the virtual laboratories. The teachers conducted these online practical classes through Google class rooms and Google meet. The videos and the material (in the pdf form) related to the experiments and were shared with the whole class in the Google classrooms before their practical class, so that they could go through them before joining the class. These videos served as very beneficial audio-visual aids in the online mode of teaching/ learning process (Wong, 2020).

In the practical class, the students were explained the theory, concepts and derivations of the formulae of the experiments, before starting the experiments. Many additional web-resources, video-lectures, animated demonstrations and self-evaluation techniques were used as supplements for effective learning through virtual laboratories.

Online teaching of experiments was also embedded with videos related to the experiments which was keenly observed and used by almost all the students (Figure 5) for a better understanding of the experiments. Students were given ample time to watch and discuss these videos for clarification of their doubts if any. Each step for performing the experiment was demonstrated by the teachers by sharing their screens through Google Meet. Sufficient time was allotted to the students to perform the experiments. If the students faced any problem while performing the experiment, they were asked to share their screen to exactly see their problem and rectify that immediately. The students who could do the experiment without any glitches were also asked to demonstrate their working on their screens to the whole class. Collective efforts were made to ensure the success of this unique method of learning. Students were free to discuss, ask any questions or problems faced by them in virtual laboratories with their teachers through personal texting and calling also.

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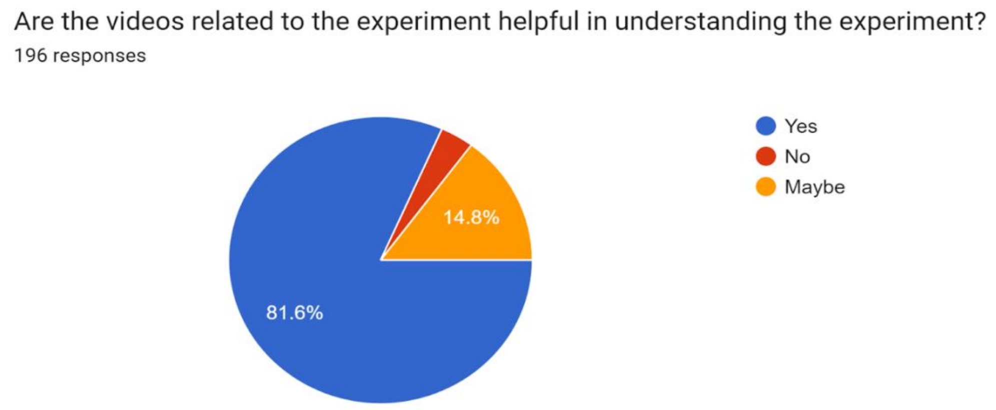

Figure 5. Effectiveness of the videos related to the experiments for students

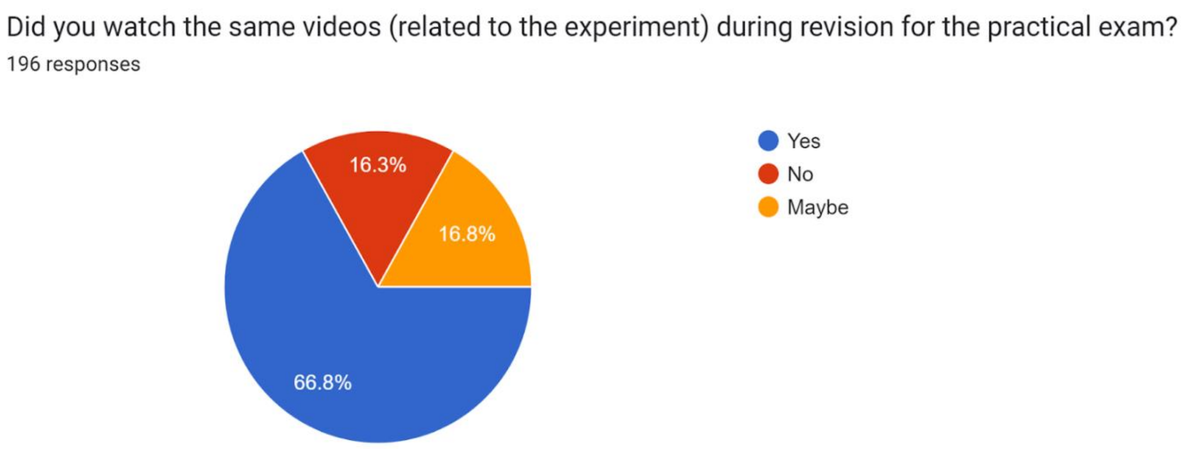

Figure 6. Statistics of the students who watched the videos repeatedly related to the experiments while preparing for exams

It is evident from Figure 6 that 84% of the students revisited these videos before their practical examination.

3.3. Overwhelming response to the new technique of learning

A sizable majority of respondents, approximately 74%, overwhelmingly voted in favor of online mode (Figure 7) as it saves time and energy. It also provides flexibility to the students in accessing the course as per their convenience. (Finch, et al,. 2012).

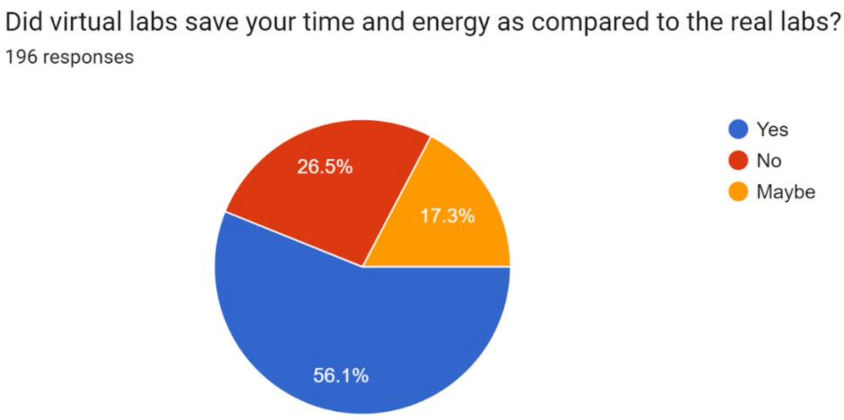

Fig. 7 Data for saving time and energy in online mode of doing practical

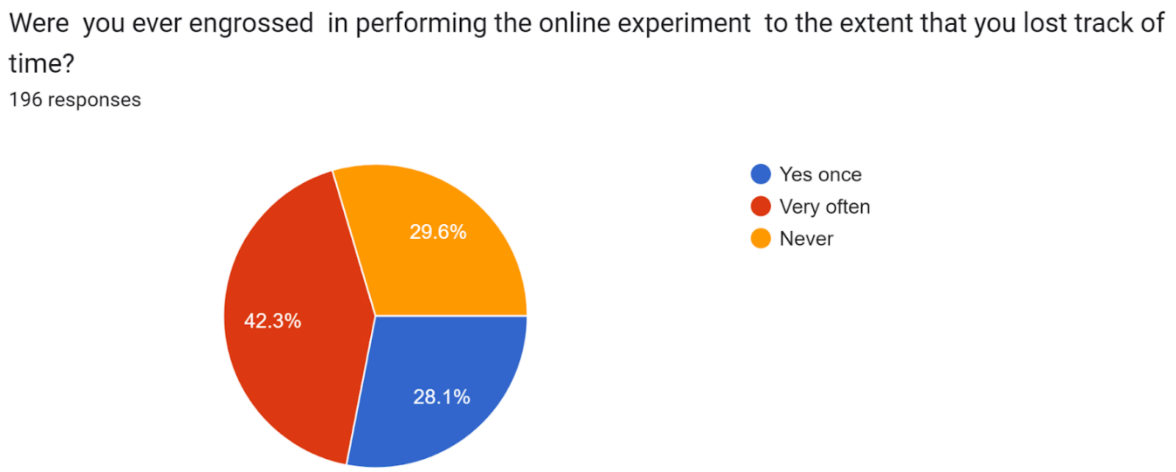

Figure 8. Pie chart showing the percentage of students who were engrossed in online physics laboratories without time constraints

More than 70% of the students were engrossed in online laboratories (Figure 8) as the software was user friendly and physical setting up of apparatus was not required. Their digital knowledge was also enhanced as per this survey (Figure 9). This experience led them to a new paradigm shift in applying digital knowledge in learning which added a new dimension to their overall knowledge **(**Waycott, et al, 2010**)**, but they needed guidance initially to kickstart the process **(**Gurung, B. et al, 2014**)**. The role of mentors was extremely important in providing the database of open softwares available for performing physics experiments alongside equipping them to set up the apparatus and perform the experiment by simulation.

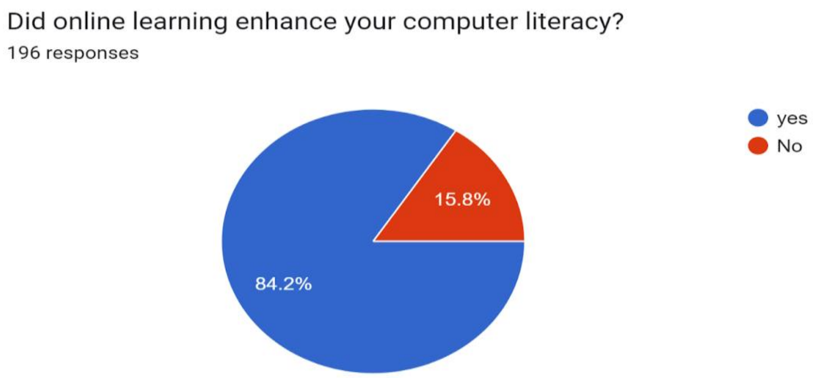

Figure 9. Results of the students who experienced enhancement in their computer literacy while performing experiments in online mode

All the available virtual laboratories are updated as these were built recently and students could suggest a very few experiments like e/m by magnetic focusing, sextant, etc. to be added in a virtual laboratory. The available virtual laboratories are updated regularly so students could find very few experiments such as magnetic focusing, sextant, etc. that were not available in the virtual laboratory.

Students appeared to enjoy virtual laboratory platforms and they had a positive perception of them. They were able to concentrate more on their learning without worrying about the safety risks associated with the traditional laboratories (Marendaz JL, et al., 2011). In fact, according to T. Lynch et al.(2017), students reported better performance in virtual laboratories compared to the traditional laboratories. Additionally, virtual laboratories enable students to conduct experiments that would be risky and difficult to perform in real life, such as studying the function of a nuclear reactor.

The students conducted experiments in virtual laboratories and were asked to share their experiences, which are depicted as a bar chart in Figure 10. The results show that 73% of respondents agreed that in the online mode, they could perform experiments at any time of the day as per their convenience. About 68% of students could independently perform online experiments after virtual training classes. A majority (63%) agreed that they could learn and perform physics experiments at their own pace in virtual laboratories. Similarly, 63% of respondents also agreed that they did not face a dearth of apparatus in online laboratories as they often did in real laboratories. The bar chart shows that half of the students found various options available in virtual laboratories to enhance their inquisitiveness in the subject, and 46% of them pointed out that in online laboratories, slow learners are not left behind.

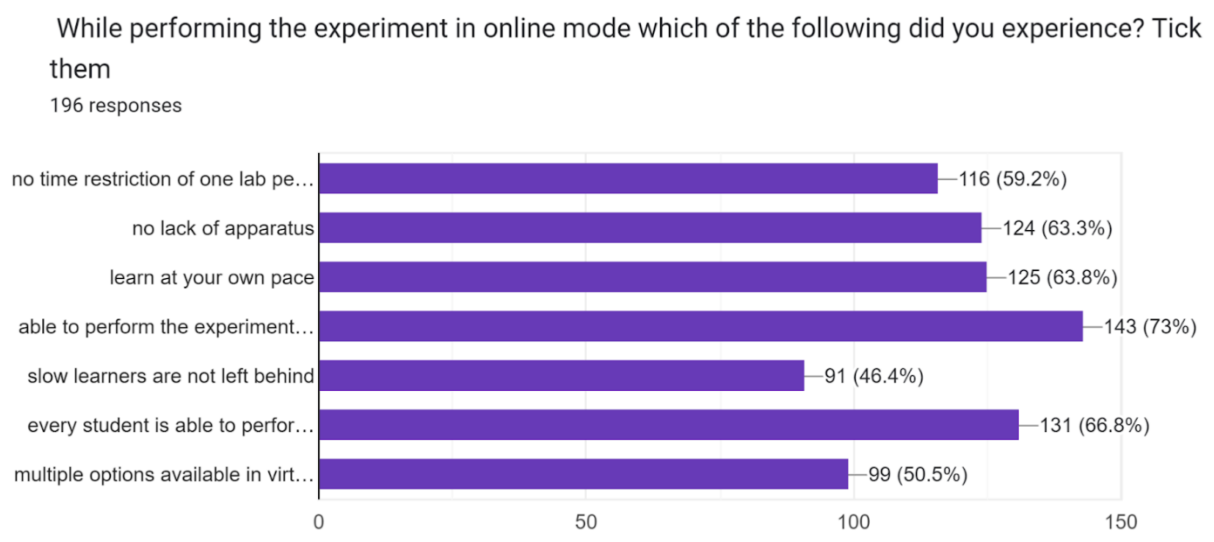

Figure 10. Analysis of good experiences of the students in online mode

To evaluate the understanding of the students an online examination using virtual labs was conducted by the University during lockdown. In a virtual laboratory various parameters could be varied in a single experimental set-up, so different problems could be assigned to the students. This facilitates the proper assessment of their understanding of basic and advanced concepts through remote experimentation.

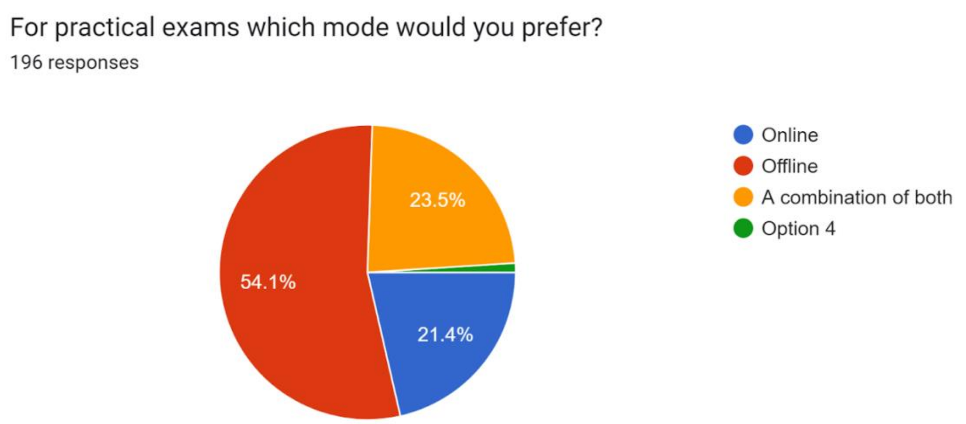

Figure 11. Survey preference for choosing between the two modes while doing the experiments in practical physics exams

Only 21% of the students were in favor of their exams in virtual labs, whereas half of them wanted the exams in real labs and the remaining students voted for a blend of online and offline practical exams as depicted in Figure 11. With proper assessment tools, online examinations can be made student friendly keeping the feedback in mind.

3.5. Few stumbling blocks for seamless adoption of new technique

As per the verbatim of the students, a few common reasons for choosing the option of offline laboratory are cited below:

Give reasons for choosing the above option
196 responses
hands-on experience
Better understanding of theoretical concepts
save time
apparatus not working properly
network issues
constantly look over the screen
aware of digital technology
Interactive
Encounter with true reality of experiments
problems related to devices
Resolve errors
a combination of both would be appropriate no doubt online can never replace offline .

The students expressed their dissatisfaction with the lack of hands-on experience with apparatus in online experiments. They missed the opportunity to physically interact with the apparatus and experience a real laboratory environment. In addition, online experiments posed other challenges such as prolonged screen exposure and extended sitting periods, leading to discomfort and health concerns. Poor network connections also hindered the smooth conduct of online experiments, causing frustration among students. Moreover, some students struggled with the digital literacy required for virtual laboratories and found it challenging to handle virtual apparatus. The absence of interaction was another common factor missed by students, which is a crucial element for creating a congenial learning atmosphere. These challenges highlight the limitations of online learning and emphasize the importance of creating an interactive and immersive learning experience for students.

Conceptual understanding of physics practicals was always a major concern in our minds. The percentage of students who preferred the online mode for better understanding of concepts was abysmally low (Figure 12).

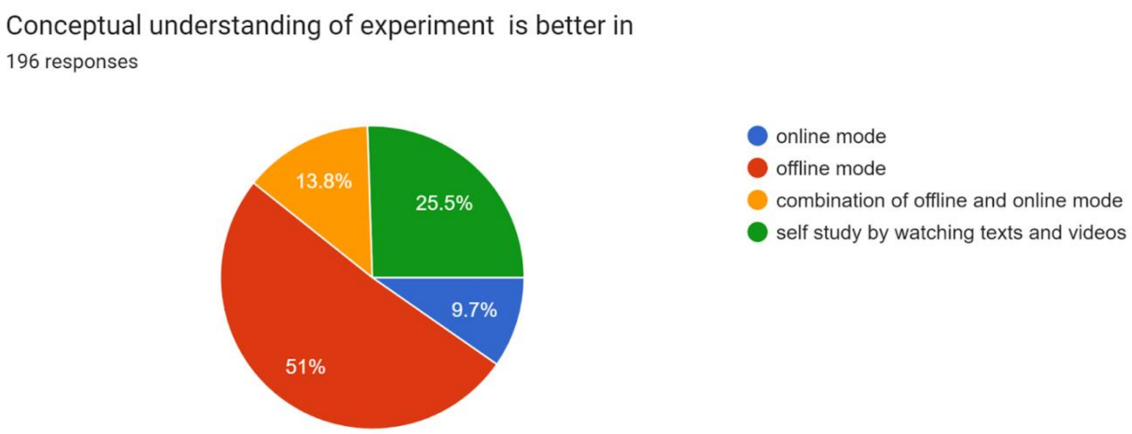

Figure 12. Comparison of conceptual understanding of the students in online and offline modes

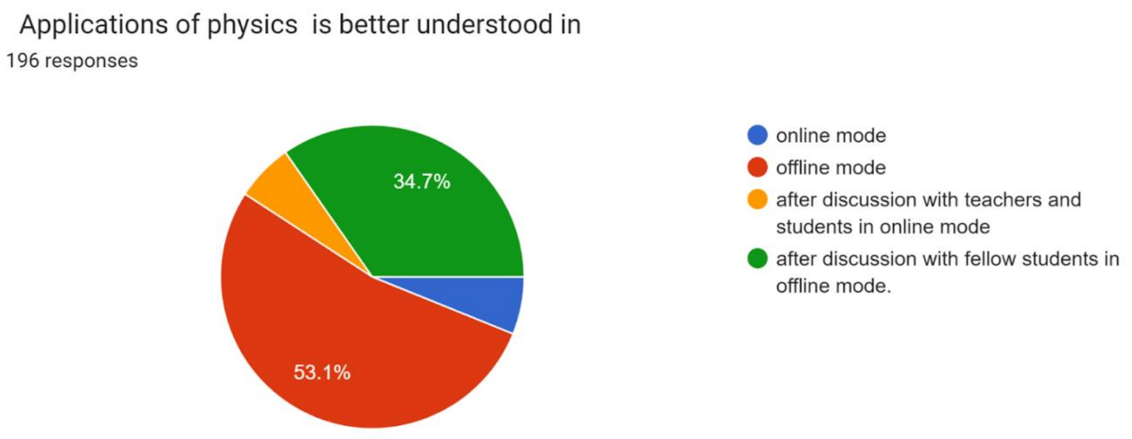

Figure 13. Response of the students in understanding applications of physics through practicals in both modes of learning

The students reported a better understanding and retaining of physics experiments in offline mode as depicted in Figures 13.

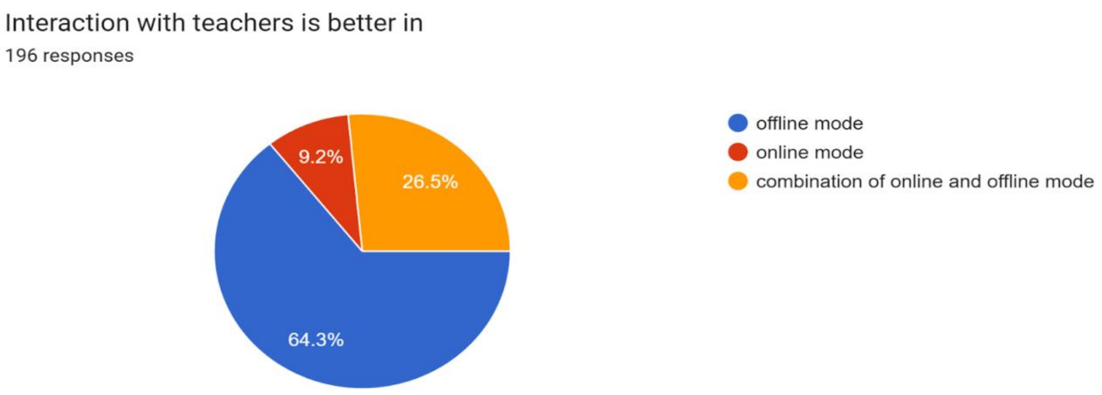

Figure 14. Compiled data figures for student-teacher interaction

According to the survey results presented in Figure 14, students reported that their interaction with teachers was better during offline experiments. They also felt that the lack of interaction in online mode may have contributed to their better conceptual understanding in offline mode. This is because classroom interactions promote active learning, which encourages students to inquire and develop a deeper conceptual understanding through peer and teacher interactions (Abrami et al 2011). Therefore, physics concepts and their practical applications can be better understood through face-to-face interactions with teachers and peers, as suggested by the survey results. The students favoured physical laboratories and discussion with teachers and fellow students for better understanding of applications of physics (Figure 13).Despite having fruitful interactive practical sessions with their teachers, it was apparent that peer interaction among the students was lacking. Peer group discussions play a crucial role in clarifying doubts and comprehending the experiment at hand. In real laboratories, students typically work in small groups of two or three, where they discuss the theory, procedure, and concepts involved, and collectively perform the experiment. However, in online experiments, on-the-spot discussions with teachers and peer groups are major concerns expressed by most students. This is reflected in the survey results, with 97% of students favoring offline mode for a better understanding of experiments (as shown in Figure 15). Therefore, it is evident that peer interaction plays a critical role in facilitating effective learning and should be prioritized in both offline and online modes of learning. Peer interaction definitely plays a vital role in the holistic development of a learner (Henderson, et al, 2009). It leads to active learning and also enhances the students' ability to solve novel problems (Cortright, et al, 2005).

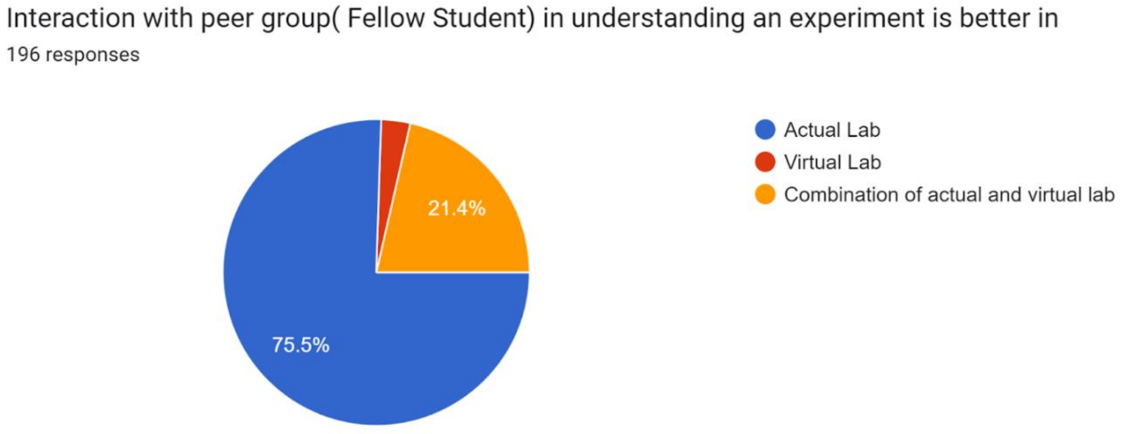

Figure 15. Pie chart depicting the preference of mode for understanding an experiment with peer group interaction by the surveyed sample

Following are the excerpts from the students' experiences in the online laboratory, which again highlights the concern of missing interaction being experienced by the students in virtual laboratories.

Which is the most avoidable component in online practical class learning?
196 responses

Interaction
Network problems
Sometimes it doesn't work properly
No direct interaction

Online physics laboratories were introduced for the first time, and both students and teachers encountered several initial difficulties. However, with continuous and rigorous efforts from both teachers and students, these teething problems were eventually resolved. Both trainers and learners had to devote extra time and perseverance to learning experiments in virtual laboratories.
This study also focuses on the constraints faced by the students in actual laboratories (Figure 16).

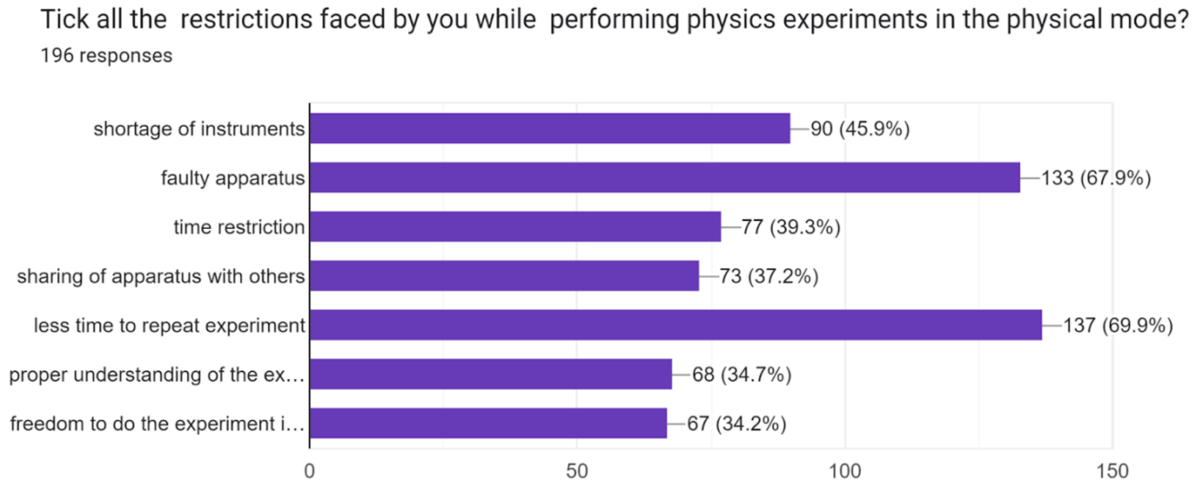

Figure 16. Limitations of the real laboratories

Lack of instruments and time consumed due to the faulty apparatus are the major stumbling blocks while performing the offline experiments whereas these constraints were entirely missing in online methodology **(**Zhao, et al, 2009**)**. Here the students have an independence to perform the experiments at their own pace and convenience. In traditional laboratories the number of available apparatus is limited and must be shared by a group of students typically three or four depending on class size. This sharing of resources often limits a student's ability to conduct experiments independently, and slow learners may sometimes be left behind by faster students. Additionally faulty apparatus may waste students' time and energy causing them to spend entire laboratory sessions without any concrete results. Moreover, due to the limitations of the physical apparatus, desired results may not always be obtained in traditional laboratory settings.

Which is the most undesirable component of offline mode learning?
196 responses
More time
not able to setup the apparatus correctly
Limited time and resources
Limited time and resources

Most of the students pointed out the following undesirable components for real laboratories: Around 60% to 70% (Figure 16) of respondents conveyed that almost all limitations of time, space apparatus, sharing and other parameters of real laboratories are taken care of in the virtual laboratories. These limitations actually distract student's learning enthusiasm and creative ability in physics experiments in physical mode (Zhao et al, 2009).

Online laboratories offer a financially feasible solution for colleges and universities with limited resources to acquire high-quality apparatus in large numbers. They enable students to learn at their own pace and convenience. Part-time employed students can also benefit from these online laboratories as they can manage their time more effectively. Furthermore, virtual laboratories offer more innovation opportunities as various parameters, such as materials, sizes, and dimensions of the apparatus, can be varied, which is not feasible with the fixed physical apparatus available in traditional laboratories. Another advantage of virtual laboratories is that the entire class can perform the same experiment during the same class, as there is no shortage of apparatus. In contrast, in traditional laboratories, each group of students has to perform different experiments due to a lack of experimental setups.

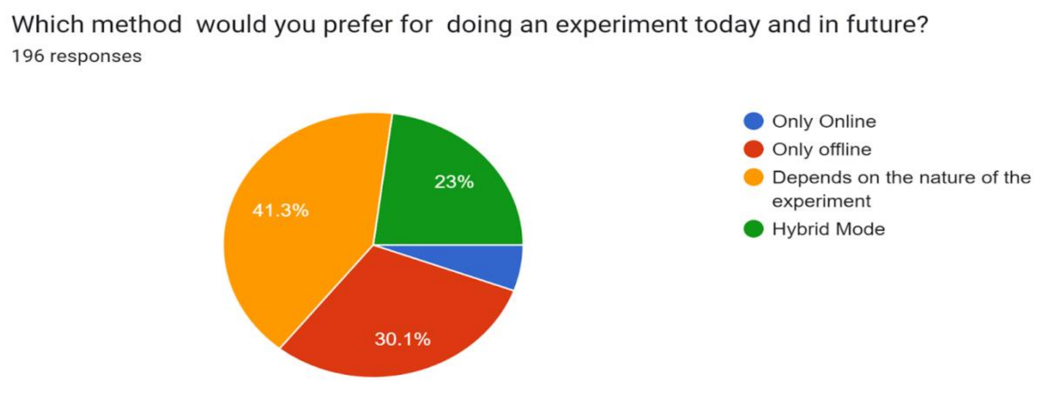

Figure 17. Students' selection of the preferred mode

3.6. Blended Mode emerged as a winner

Most of the students did not approve only online mode, instead strongly advocated for doing the physics practicals in both offline and online mode i.e a blended mode. Blended learning combines e-learning with face to face teaching in the classroom (Sarıtepeci et al, 2015). It is emerging as a modern instructional tool with the advancement of digital technology to maximize educational benefits to the students (Oweis, 2018). Students clearly mentioned that the online learning mode of performing experiments cannot replace the offline ones, For doing physics practicals, just 6% preferred only online mode while 41% of the students preferred to adopt a learning method depending upon the nature of the experiment (Figure17).

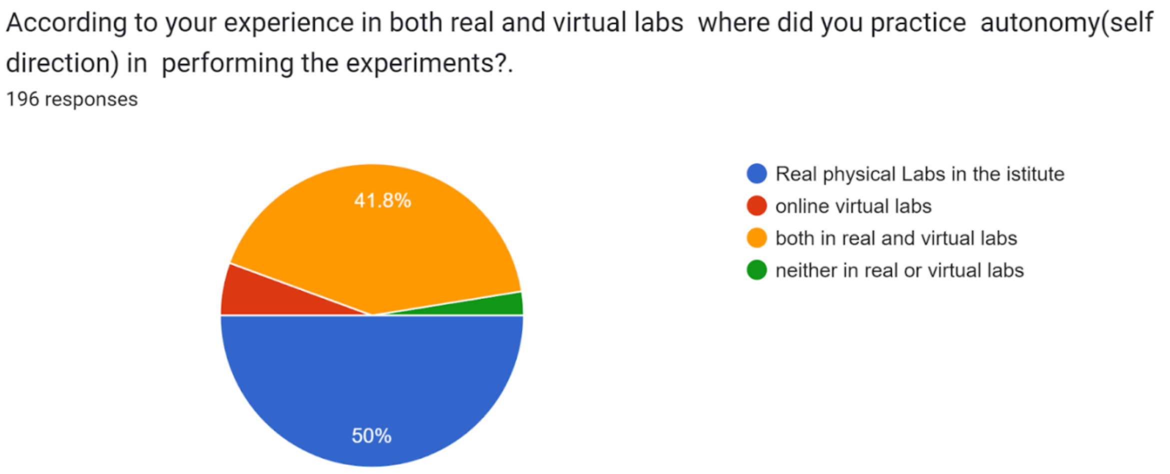

Figure 18. Percentage of students who experienced self directed learning in both online and offline modes

Self directed learning **(**Knowles, M. S. 1990**)** has been experienced by the students in both the real and virtual laboratories. As per the statistics (Figure 18) doing practicals in blended mode will provide them with an autonomy to learn at their own pace and become active learners (Prince, 2004).

Only 8% of the surveyed students recommended exclusively memorizing concepts in online mode while the majority reported that they retained information better through offline methods or a combination of both online and offline modes. (Fig. 19)

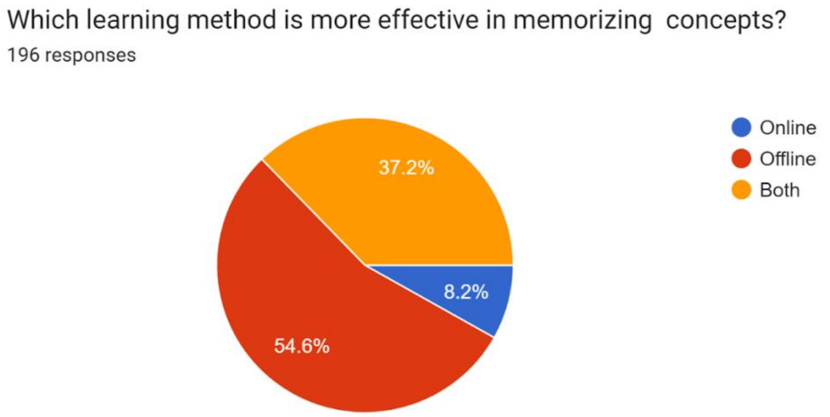

Figure 19. Inefficiency of only online mode for memorizing the concepts of physics

CONCLUSION

The survey results reveal that a significant majority of students (91%) performed physics practicals in online mode. Although this sudden transition to learn this new procedure was not smooth initially but majority of them adapted themselves after many pragmatic attempts. The success of this transition was evident as a very small number of students (about 20%) lacked the proper understanding of the theory and procedure of the experiment. The availability of online videos contributed immensely to enhance the level of understanding amongst the students and a vast majority (81%) has been the testimonial to this fact.

The comparative analysis of the survey highlighted very meaningful insights for both modes of learning as enumerated below.

A sizable number of students (approximately 74%) favored online mode as it saves time and energy and provides flexibility in accessing the course at their convenience. Moreover, students pointed out that online mode efficiently addressed the limitations of time, space, and faulty instruments, which otherwise could weaken their practical ability and enthusiasm. In online mode, students can easily repeat the experiment multiple times, which was not possible in physical mode due to timetable constraints. It is also an academic boon for those students who are living in far flung areas having limited access to the physical laboratories.

The accurate simulated results with error free observations look illogical and distract students from critical thinking. The poor network connectivity, absence of physical handling of the apparatus and continuous exposure to screens are the major bottlenecks in the online mode. However, the survey also highlighted that while students and teachers had productive interactive sessions, the lack of peer interaction negatively impacted learning. Consequently, students were not able to utilize the results of the experiment efficiently to solve real-life problems.

The students have also expressed their apprehensions in understanding the applications of physics and remembering them without hands-on experience. Majority of students consider peer interaction and direct contact with the teachers as a stumbling block in the success of online training of physics practicals.

Learning in actual laboratories has many advantages, such as the ability to conduct hands-on experiments, interact with equipment, and work with other students in real-time. However, there are also limitations to actual laboratories, such as the availability of expensive or dangerous equipment, limited time and resources, and safety concerns.

Virtual laboratories, on the other hand, can provide a safer and more accessible way to conduct certain types of experiments, particularly those that are exploratory in nature, like Michelson Morley experiment. Virtual labs can simulate complex and expensive experiments that may not be feasible in an actual laboratory, allow students to repeat experiments multiple times without using additional resources and provide a controlled environment for students to explore concepts and theories.

In summary, both actual and virtual laboratories have their advantages and limitations, and the choice between the two depends on the learning objectives and the type of experiment being conducted. Hence it is concluded that for the maximum benefit of the real stakeholders we should have a blend of both physical and virtual laboratories so that the best of both the online and offline worlds can be seamlessly blended to learn the physics experiments. In conclusion the findings of this survey clearly indicates students' preference after evaluating on various parameters is hybrid mode of learning practicals in physics.

The hybrid learning model which has gained acceptance by the majority of the students surveyed is also recommended in the National Education Policy of Government of India. Therefore, this study serves as a valuable resource for the effective implementation of blended learning in experimental physics.

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