Scholarly Research Journal for Interdisciplinary Studies
Online ISSN 2278-8808, SJIF 2026 = 8.727
https://www.srjis.com/issues_data/290
Peer Reviewed & Refereed Journal, MAR-APRIL 2026, Vol- 14/94
https://doi.org/10.5281/zenodo.20084271

EXPLORING POLICY TRAJECTORIES FROM CHALKBOARD TO SIMULATION: A ROADMAP IN THE EVOLUTION OF VIRTUAL LABORATORIES IN SCHOOL EDUCATION IN INDIA

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Paper Received On: 20 MAR 2026

Peer Reviewed On: 24 APRIL 2026

Published On: 01 MAY 2026

Abstract

Since Independence India has consistently emphasized on scientific temper, and science laboratories play a significant role in achieving it. However there is a lack of science laboratories in the Indian schools as revealed by NCFSE 2023 and therefore virtual laboratories act as an alternative to develop scientific temper by providing opportunities to the students to practice experiments that would have been done typically in a physical practical laboratory. Therefore, this study analyses the evolution of National educational policies, curriculum framework, educational reports and initiatives taken by the Government of India which paved the way for the emergence of technology in general and virtual laboratories in specific and to understand how these policies and initiatives support inclusiveness. Finding reveals that the quality of science education has been enhanced by the use of education technology by each of these policies by implementing it for the masses. Finding also reveals that all the policies and initiatives since independence promoted a sustainable development goal for quality education with the judicious use of ICT in education, making education reach the unreachable students across the country. Several ways have been suggested by these policies to catalyse and achieve inclusive education like ICT software and tools to facilitate access to persons with disabilities, like screen readers, Braille printers, etc. as part of the ICT infrastructure in all schools. Each policy and commissions from secondary education commission (1952-53) to NEP 2020 acted as a milestone in the pathway of the emergence of virtual laboratories that we are implementing now and the advancement in the field of technology that will be in pace in the future years. Virtual laboratories are therefore an effort of decades which enable us in the path of achieving SDG4 in terms of equity, access and quality in science education and in other subjects as well.

Keywords: *NCFSE 2023, NEP 2020, Policies, Science Education, Sustainable Development Goal(SDG 4), Virtual Laboratories*

1.Background

In science education laboratory experiments play a significant role. Virtual laboratories emerged as a potential tool in making the learners learn scientific principles through automated and virtual practical activities via computer simulation (El Kharki et al., 2021). NEP 2020 also stresses the use of virtual laboratories in science education (Ministry of Human Resource Development, 2020). As per NCFSE 2023 for good science, science laboratories play an important role and the best way to learn science is "doing science" which is possible through hands-on experiential learning. But "there are no separate rooms for science laboratories in the majority of Middle schools" (Section 4.6.1.4, NCFSE, 2023). "At the Secondary Stage, access to a laboratory is non-negotiable — students must be able to assemble and manipulate apparatus, use materials, and design simple experiments to truly develop important competencies related to Science." (Section 4.3, p- 297 NCFSE 2023). Virtual lab can therefore act as an alternative (El Kharki et al., 2021) or can even be used as a supplement to the traditional labs (Zhang & Liu, 2024).

1.2. Virtual Laboratories

Virtual laboratories also known as virtual labs are interactive computer-based environments that enable them to carry out tasks that would be typically done in a laboratory. These tasks can be carried out with the help of an interface which allows animation, simulation and even remote control of the actual laboratory apparatus (Achuthan et al., 2011). According to Azizah & Aloysius, (2021) virtual laboratories are the laboratory experiments which can be performed without the real laboratory with walls and doors. As per Sellberg et al., (2024) ". Virtual laboratories are simulations of experiments or other hands-on activities that allow students to explore scientific concepts and principles in a virtual environment."

Virtual laboratories are the platforms that enable the users to mimic activities or experiments with the help of simulation aided by devices like computer or laptop or mobile which can otherwise be done in physical laboratories. In India various platforms of virtual laboratories have been developed to provide access to learners for hand-on experience in school as well as higher education.

2. Literature Review

Sharma & Tripathi, (2019) explored five ICT initiatives of central and State government of India related to school education which were ePathshala, Shaala Siddhi, Shala Darpan, Saransh

Portal and School GIS. These initiatives were systematically mapped in order to show its effectiveness and exhaustiveness.

Nayek, (2021) presented various policies and initiative by the Central and State government after independence and mentioned their recommendations but this work is not a systematic covering of all the policies and initiatives brought about by the Indian government

Narayanaswamy B V & Ramesha, (2023) explores the awareness of ICT initiatives such as SWAYAM, National Digital Library of India, ePathshala, IRINS, Shodhaganga, eShodhasindhu, and Virtual Labs etc. and its utilization. With the help of literature analysis this study identifies the research gap between theory and practice i.e. its awareness and its utilization.

3. Research Gap

The policies play a significant role in providing a rationale, setting of goals, and a vision for the introduction of ICT in the education system. These policies when planned strategically can motivate, bring change, and can bring coordination between the disparate efforts in turn advancing the nation and overall educational goals (Kozma, 2008). The existing literature done on policies are either related to teacher education or few initiatives but does not provided whole picture of the policy reforms to bring the technological changes in education therefore this study provides a systematic analysis of how the policies paved the way for emerging technologies like virtual laboratories powered by artificial intelligence as a transformative tool in science education as well as how theses policy reforms aligned with SDG 4 to provide equity, quality and access for all .

4. Research Question

1.How has the Indian educational policies and initiative led to the evolution of educational technology in general and virtual laboratories specifically?

2. How does the policy reforms of virtual laboratories reflect the principle of equity, access and experiential learning to achieve the sustainable development goal 4?

5. Research Objective

1.To identify the key milestones in the policy reforms that implicitly and explicitly formed the route for virtual laboratories at school level.

2. To explore the principles of equity, access and experiential learning in Indian policies to achieve sustainable development goal 4 at school level.

6. Research Methodology

This study employed a qualitative research methodology by systematically analysing the policies, reports and initiative by the government of India after Independence. The study analysed documents from various sources for example NCERT website, CIET website and research articles from secondary sources (various databases).

7. Policy Analysis:

Secondary Commission Report (1952-53): This report emphasized on the hands-on experience by the use of technologies of that time which were audio-visual aids, films and radio talks. It is not only recommended to use but also to produce audio-visual aids as well as educational films for secondary education (P 180, Secondary Education Commission Report). Several measures were given on how to use these technologies to improve the quality of education as well as to reach the masses. For example, All-India broadcast has been recommended to be arranged for school education, appliances to be shared by two to three schools on rotation basis to deal with the lack of resources (P 165, Secondary Education Commission Report), teachers to be trained to be able to use the latest technologies (p 136, Secondary Education Commission Report).

Kothari Commission Report (1964): This report emphasized the importance of science and technology by stating "This close interlocking and interdependence between science and technology is a characteristic of the contemporary world." (Pg 9, Education Commission Report 1964-66). Kothari commission regarded science and technology as a powerful tool for social transformation and economic progress therefore, recommended the use of emerging technologies like radio to be used in education.

ET Scheme 1972: This scheme was an initiative of the Indian Government launched during IV plan for the promotion of educational technology in schools. Under this scheme 100% assistance was given to six State Institute of Educational Technology (SIET) and also assisted State and Union territories to acquire equipment like colour TVs and radio cum cassette players. This scheme is a precursor of the Computer Literacy and Studies in Schools (CLASS) Project (1984) which was again a centrally sponsored scheme adopted during VIII plan and ICT @ Schools scheme (2004).

NCF 1975: In section 8.24 of the document, it states the importance of experiential learning in science by 'Doing' and therefore recommended "the provision of the minimum essential facilities in terms of instruction aid and equipment". It further recommended in section 6.1 that

the programmed instructional material or audio-visual aid should be used as a supplement in teaching, to broaden the concept and arouse the interest among the learners. This report also refers to the financial constraint in providing the latest technology in education (section 6.4, p 40, NCF 1975)

Indian National Satellite (INSAT) was launched in 1980: The first INSAT was launched in 1980, however a series of INSAT was launched. It was not used solely for educational purposes. It was a joint venture of the Department of Space, Posts and Telegraphs, Meteorological Department, Ministry of Information and Broadcasting and Ministry of Education and Culture. In education it was used for educational television programme and distance learning

Computer Literacy and Studies (CLASS) 1984: This was a joint project between the Department of Electronics, MHRD and NCERT and covered 2582 schools and 42 Resource Centres. This project aimed to boost computer literacy by providing the schools with BBC micro-computers.

National Policy of Education (1986) which was modified in 1992, called the Program of Action (POA): This policy recommended the use of media and education technology in education for the improvement of its quality. Broadcast method was emphasized to reach the learners at every corner of India. This policy talked about the use of computer for enhancing the efficiency of teaching learning process for making the children creative and providing them an individualized learning environment (P 169, NPE and PoA 1986, 1992)

NCF 2000: NCF recognizes the revolution brought about by the use of technologies in education. Section 1.4.5. of the document states that the use of technologies will not only change the teaching style but it will influence the learning as well. In section 5.3, the policy proposes the integration of ICT into school by suggesting ways by which it can be integrated within the curriculum that will enhance the learning opportunities for using the potential of computer-based learning and all that resources which are accessible. Recommendations for teachers were made to train them to acquire skills to use ICT in the best way in the process of curriculum transaction. It also talks about an 'electronic environment' for reaching the learners from far flung areas.

EDUSAT (Educational Satellite or GSAT-3) 2004: This satellite is India's first satellite dedicated to education in 2004 launched by Indian Space Research Organization (ISRO). The main purpose of this satellite was to provide satellite based tele-education to school as well as

higher education. This satellite gave the concept of virtual university and gave birth to remote ICT-enabled science classrooms. This is not directly linked to virtual laboratories bur can be seen as its precursor which led to the foundation of remote learning and interactivity.

ICT@ Schools 2004: This scheme is an initiative of Government of India and came into existence in 2004 by merging Educational Technology (1972) and Computer Literacy and Studies in Secondary Schools (CLASS) (1984) to use ICT in secondary and higher secondary schools in teaching and learning. The objective of this scheme was to build IT structures in schools, convert the schools into smart schools. This scheme was revised again in 2010 and implemented.

NCF 2005: It talked about Net enabled computers to enhance the curriculum and to promote two-way interactivity. It appreciated the role of educational technology in science and mathematics and also teaching students with disabilities.

Position Paper National Focus Group on Educational Technology 2006: This position paper stresses that we have enough resources by stating "There also exist production capabilities for audio and video, multimedia, broadcast channels, Internet connectivity, trained manpower, and institutions with these mandates that can be leveraged to address the challenges of education." But the need of the hour is to develop the education system by which these resources can be used in an optimum way in the teaching learning process.

This position paper emphasized on interactivity and interconnectivity by the use of educational technology and suggested various ways by which it can be used to enhance the quality as well as equity and access. It also proposed to transform all the schools into "ICT-rich environments."

eGyanKosh 2008 is a national digital repository "aimed to store, index, preserve, distribute and share the digital learning resources(https://egyankosh.ac.in/) with the facilities of webcasting.

NMEICT (National Mission in Education through ICT) 2009: NMEICT is a centrally sponsored scheme aimed to use the potential of ICT in teaching learning processes in higher education. The three cardinal principles of access, equity and quality were served well through this scheme(https://www.education.gov.in/en/technology-enabled-learning-0).

This scheme proposed several measures to provide the masses, quality and inclusive education like the use of DTH and using EduSAT for educational purposes, improvement in the internet connectivity, empowering the teachers with ICT skills, creation of our own content. It also

proposed setting up a Virtual Reality Lab for the learners for improving the quality of education and developing inquisitiveness and imagination among the students.

National Policy on Information and Communication Technology (ICT) In School Education (2012): This policy came into existence with a clear vision of "preparing youth to participate creatively in the establishment, sustenance and growth of a knowledge society leading to all round socioeconomic development of the nation and global competitiveness." This policy talks about ICT enabled teaching and learning processes with a use of a variety of tools, techniques, content and resources ranging from projecting media to use of multimedia. An important part of this policy is that **it talks about promoting the use of virtual laboratories in the teaching learning process (4.3.1and section 7.2.1). It also talks about the creation and its widespread dissemination of specialised software like simulation and virtual laboratories (Section 6.3.3).**

National Repository of Open Educational Resources (NROER) 2013: It is a joint venture between Department of School Education and Literacy, Central Institute of Educational Technology, NCERT, and Ministry of Education (MoE). It is a web-based platform which aims at the collaborative creation of digital resources. It hosts various types of educational resources which can be accessed through this platform in the form of audio, video, image, document and interactive media for primary, secondary and senior secondary schools in all subjects and all languages.

Digital India 2015: This flagship programme was launched in July 2015 by the government of India with a vision of transforming India into "digitally empowered society" and "Knowledge economy". Education plays an important role in this transformation, and technology helps in this mission. Thus, the relation between education and technology is bidirectional at all levels (NEP, 2020).

OLABS (2015): On Good Governance Day, i.e. Dec, 2015 OLAB for school experiment was launched as part of Digital India. It is a joint venture between CDAC, Mumbai and AmritaCREATE, Amrita University and an initiative of the Ministry of Electronics & Information Technology (MeitY), Government of India.

(https://www.olabs.edu.in/?pg=topMenu&id=129). Olabs are based on the idea that experiments that are learned in physical labs can be easily taught more efficiently and less expensively via the internet breaking the geographical barrier. It can be accessed anytime and anywhere and is free to access thus bridging the digital divide. Olabs consists of labs/activities

for class 9 to 12 for the subjects Physics, Chemistry and Biology, for class 6 and 10 in the subjects Languages (English, Hindi and Sanskrit), Social Science and Mathematics and Computer Science for class 11 and 12 (https://www.olabs.e du.in/).

Fig 1: OLABS Webpage source: (https://www.olabs.edu.in/)

DIKSHA 2017: DIKSHA (Digital Infrastructure for Knowledge Sharing) is a national platform with the tagline "one nation, one digital platform" is an initiative of National Council of Educational Research and Training (NCERT) with Ministry of Education, Government of India launched on 5th September 2017. This platform is available through web-portal as well as mobile application covering school education for grades 1 to 12. It is built on open-source technology with a mission to make education accessible, engaging and as per the need of the learners(https://diksha.gov.in/about/). It can be accessed by the teachers as well as the learners across the country supporting 108 languages. DIKSHA has 1.42 lakh daily active users and 1.96 crore registered users as of 11 September 2025. Among many focus areas of DIKSHA one of the focus areas is dedicated to Virtual Labs.

Figure 2:DIKSHA can be used through diverse interface Source: India_Report_Digital_Education_0.pdf

Samagra Shiksha Abhiyan 2018: It is an overarching programme launched by Ministry of Education, Government of India, formed by merging three existing previous scheme which were Sarva Shiksha Abhiyan, Rashtriya Madhyamic Shiksha Abhiyan and Teacher Education in 2018. This scheme aims to provide inclusive, equitable and quality education for school children from pre-school to class XII in accordance with Sustainable Development Goal for Education(SDG 4). Among the various objectives, one of its objectives is to promote the enhanced use of technology through smart classrooms and support for "operation digital board".

Installation of virtual reality labs in 65 DOE schools for the year 2023-2024 has been approved at secondary level under Rashtriya Aavishkar Abhiyan of the component quality interventions under Samagra Shiksha- Delhi.

(https://www.edudel.nic.in/upload/upload_2023_24/3879_3899_dt_10012024.pdf)

Fig 3: https://samagra.education.gov.in/docs/Samagra%20Brochure.pdf

National Education Policy (NEP) 2020: This policy has come after a gap of 34 years. Since then, a lot of development has been done in the field of use of educational technology in education ranging from print to audio to video to immersive use of technologies in education. The effect of this advancement can be seen in this policy also, as it dedicated its two-chapter titled "Technology Use and Integration" and Online and Digital Education: Ensuring Equitable Use of Technology specifically, to the use of technologies in education. In both of these chapters virtual laboratories have been emphasised for fulfilling the various objectives in education.

- Para 23.8 of the policy talks about the emerging technologies like artificial intelligence3D/7D Virtual Reality that needs to be adopted in education on the basis of its effectiveness.
- Section 24.4.d of the policy proposed "A digital repository of content including creation of coursework, Learning Games & Simulations, Augmented Reality and Virtual Reality will be developed, with a clear public system for ratings by users on effectiveness and quality."
- Section 24.4.f states "Virtual Labs: Existing e-learning platforms such as DIKSHA, SWAYAM and SWAYAMPRABHA will also be leveraged for creating virtual labs so that all students have equal access to quality practical and hands-on experiment-based learning experiences. The possibility of providing adequate access to SEDG students and teachers through suitable digital devices, such as tablets with pre-loaded content, will be considered and developed."

This shows the importance of virtual laboratories in this policy as well as the potential of this emerging tool to cater the need of the students in providing equal access and providing quality practical in science education.

Virtual Labs on DIKSHA Platform (29 July 2022) It is a joint venture of CDAC, AMRITA Vishwa Vidyapeetham and NCERT launched on DIKSHA platform on 29th July 2022 as per the recommendation of NEP 2020. Virtual labs have been developed on the idea that the experiments that are performed in the traditional lab can be taught efficiently and, in a cost effective manner with the use of the internet. This will increase accessibility to school students where physical labs are not available or where there is lack of equipment. This platform not only consists of virtual experiments of science but experiments from other subjects are also included like maths, English and Social science also. Currently it is available in English and Hindi language covering class 6 to 12. It is based on the idea that it can be accessed by the learners anytime and anywhere.

National Curriculum Framework for School Education (NCFSE) 2023: NCFSE refers to the National Curriculum Framework for School Education that has been developed to implement NEP 2020. This curriculum recognizes the potential of technology in making the teaching and learning process more effective.

- Section 6.1.1 of the policy talks about the enormous possibilities of the use of the emerging technologies like artificial intelligence, machine learning, data science and immersive technologies such as AR/VR/virtual labs and gamification in the education process.
- Section 6.3.6 essentially deals with virtual labs and simulations. It states that ICT facilitates democratising access to experiential learning via virtual labs and simulation which should be used with physical teaching methods. Even if the students use the basic physical labs, it will enhance the ability of the students to use the virtual labs more effectively and in a better way.
- Section 6.3.6.1 states the importance of virtual labs in deep learning not only in maths and science but also in other subjects like languages.
- Section 6.3.6.2. states the benefits of virtual labs like access anytime and anywhere, better quality of lab experience without challenges of funding or acquisition of equipment and materials, immersive learning experience for complex theoretical concepts, repeatability and flexibility option, faster feedback, **and equitable access.**

Fig 4: Key milestone in the policy reforms that implicitly and explicitly paved the way for virtual laboratories

8. Findings

Findings for Objective 1: The quality of education has been enhanced by the use of educational technology by each of the policies that try to implement it on the masses. From the secondary commission which focused on audio, visual, latest technology of that time to NEP

2020 which emphasized the use of artificial intelligence have contributed in the enhancement in education with the help of technology. Thus, the evolution of virtual laboratories does not occur suddenly but a gradual, systematic transformation shaped by each of the commission, policies and national initiatives by the government of India.

Findings for objective 2 : All the policies of India since Independence promoted sustainable development goal 4 for quality education with the judicious use of ICT in education by making the education to reach the unreachable students across the country. From the first policy of education, it can be seen that the government of India has tried to use educational technology to the masses. Even the National Policy on Information and Communication Technology (ICT) in School Education (2012) has mentioned in its mission "To devise, catalyse, support and sustain ICT and ICT enabled activities and processes in order to improve access, quality and efficiency in the school system". Several ways have been suggested by these policies to catalyse and achieve inclusive education like "ICT software and tools to facilitate access to persons with disabilities, like screen readers, Braille printers, etc. will be part of the ICT infrastructure in all schools. Special care will be taken to ensure appropriate ICT access to students and teachers with special needs."(Section 4.6.2), teachers to be sensitised for the potential use of ICT for children with special need, and ICT to be used for Open and Distance Learning. Provision of internet connection in the school

NCFSE also states "With the spreading network access to the internet and the ubiquity of digital devices that can connect to the internet, access to educationally valuable content has become more equitable and democratised, thereby enabling learning anytime and anywhere." Virtual laboratories is one of the milestone in the history of ICT in education which align with SDG 4 promoting access, quality and equity.

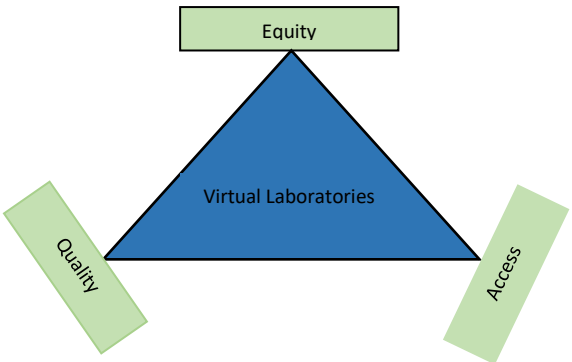

Fig 5 : Virtual Laboratories as a Tool to achieve SDG 4

9. Conclusion

The emergence of virtual laboratories in India has not occurred suddenly but is an effort of decades of pedagogical reforms, investments, ICT policies and framework and initiatives. Each policy and commissions from secondary education commission (1952-53) to NEP 2020 acted as a milestone in the pathway of the emergence of virtual laboratories that we are implementing now and the advancement in the field of technology that will be in pace in the future years. Virtual laboratories are therefore an effort of decades which enable us in the path of achieving SDG4 in terms of equity, access and quality in science education and in other subjects as well. This has been strengthened by other studies which also state that virtual laboratories could play an important role in achieving SDG 4-quality education.(Raman et al., 2022)Thus, the policy trajectory of India demonstrates a sustained commitment to SDG 4: "inclusive, equitable and quality education for all" and virtual laboratories are one of the tools to achieve it.

10. Educational Implication

1. **For policy makers:** A significant advancement in introducing the virtual laboratories in the Indian education system can be seen in the form of NEP 2020, the only change needed in this regard is its effective implementation.
2. **For curriculum makers:** The finding shows that virtual laboratory aligns strongly with the constructivist approach, inquiry based and experiential learning as outlined by NEP 2020 and NCFSE 2023. Therefore, the curriculum developer should integrate virtual laboratories particularly in science curricula in which hand on experience is needed.
3. **For teacher education:** Teachers are the medium to translate policy into practice. Therefore, virtual laboratories should be integrated in the teacher curricula for its effective implementation.
4. **National level platforms :** National level platforms such as DIKSHA, SWAYAM, and SWAYAMPRABHA should create highly interactive simulation for virtual laboratories as outlined by NEP 2020 and a quality control mechanism should be devised to check its quality control.

11. Future Direction

1. Future research should move beyond the policy to practice at classroom level. It has been five years since the NEP 2020 has been introduced in the Indian education

system, therefore there is a scope for further research to examine the impact of virtual laboratory related provision outlined by NEP 2020 at classroom level.

2. Future research should explore the teachers readiness towards the integration of virtual laboratories.
3. Longitudinal study on critical analysis of policy in terms of digital divide and accessibility can be explored in further research.

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Cite Your Article as
Sehar Nigar & Prof. Jasim Ahmad. (2026). EXPLORING POLICY TRAJECTORIES FROM CHALKBOARD TO SIMULATION: A ROADMAP IN THE EVOLUTION OF VIRTUAL LABORATORIES IN SCHOOL EDUCATION IN INDIA. Scholarly Research Journal for Interdisciplinary Studies, 14(94), 92–106. https://doi.org/10.5281/zenodo.20084271