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The Role of Augmented Reality in Promoting Interactive Learning Experiences in STEM Education

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Abstract

Augmented Reality (AR) is quickly becoming a game-changing technology in education that provides an engaging immersive experience and opportunity to learn. AR can mediate the conceptual levels of thinking with application to the physical world and can help overcome the disconnection between concepts and their use in the real world in Science, Technology, Engineering and Mathematics (STEM) education where one can lay digital information on top of the physical world. The paper examines how AR can be used to complement interactive learning by suggesting ways on how it can be completed to enhance student engagement, learning conceptualization and problem solving abilities. The study is based upon the review of recent research and the evidence of cases in order to analyze how AR based applications, including 3D visualizations of molecules, virtual simulations of engineering edges and interactive mathematical models allow learners to understand the intricate subjects more clearly. The study also explores AR's effects on motivation, collaboration and cognitive encoding of what is learned, especially in complex learning contingencies. The evidence indicates that AR embraces experiential and inquiry-based learning that opens the STEM subjects in a way that is accessible and attractive. Obstacles like technical shortcomings, the readiness of teachers and the expense costs are talked about, not leaving without any mention of how successfully it can be implemented. The study concludes that AR can have a major impact on modernizing the training of STEM that has the power of changing the pensiveness of passive learning and transforming it into the proactive exploration resulting in students becoming future-proof professionals in the current world which is becoming highly digital and technological.

Keywords: Augmented Reality (AR), STEM Education, Immersive Learning, NEP 2020, Experiential Learning, Educational Technology

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Introduction

Over the last decade, increased development in digital technologies has changed the paradigm of education and specifically in Science, Technology, Engineering and Mathematics (STEM). One of these new tools is the Augmented Reality (AR) that has been drawing prominent attention as this technology is capable of integrating virtual information with the real world, which can provide a learning experience that is better and more intensive. AR adds digital data, in the form of 3D models, animations, sounds or interactive simulations, on top of the real world with the use of such devices as smartphones, tablets, smart glasses or AR headsets. This technology is not a substitute to reality but an improvement and this allows the learners to see the image of the abstract, interact with the virtual objects in an environment and manipulate the moving content in real time.

It is much more than a novelty that the use of AR in education is worthwhile. STEM subjects require multi-steps, where the concept might be based on a complex structure, invisible phenomena or multi-step processes. AR may fill the gap between theory and the implementation. Take, as an example, in the study of a human circulatory system in a field of biology AR is capable of rendering a 3D model of the system so that students can interactively study the system. It can model the motion of particles based on different forces in physics and it can give a virtual prototype to test the design in engineering without building the expensive real model.

The main aim of using the AR in STEM education is to support interactivity, engaging and learner-centered experience. AR supports active engagement and promotes a better understanding by delivering a real-time feedback, facilitating an inquiry-driven discovery and offering the possibility of contextual learning. It generates individualised learning tracks and serves different learning styles (visual, auditory and kinesthetic), consequently making STEM concepts reachable to more students across the general population with varying learning styles.

In a curricular development sense, AR provides an educator with a multifaceted lesson planning tool to provide an experiential learning-based lesson incorporating a fundamental academic element. It can be applied to construct virtual laboratories, interactive field trips and real time collaboration problems solving task. AR applications could be incorporated in lesson plans by the teachers in order to promote thinking, creativity and practical use of knowledge. Also, AR is compatible with the current pedagogical practices in the form of constructivism and experiential learning theory, which focus on the principle of learning through doing.

AR integration into teaching-learning process will not only improve the engagement level of students but also make them oriented towards the future workplaces where technology is well integrated. With STEM skills becoming more central to numerous world economies, AR can be considered a creative avenue to develop future skills like problem-solving abilities, teamwork, flexibility and digital literacy in a 21st century world.

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It discusses the use of Augmented Reality in advancing interactive learning in STEM education with its uses, advantages, limitations and implication to their teachers and curriculum developers. The study will illustrate the potential of the AR to become the driver of the active, immersive and impactful learning in STEM through the comprehensive overview of the existing studies and case examples.

Understanding Augmented Reality

Augmented Reality (AR) can be characterized as the emergent interactive technology, which superimposes computer-generated graphics e.g. images, animations, simulations and 3D models on the real world environment and in the process augments the sense of reality by a user. In contrast to Virtual Reality (VR), where the user is put into something of a full-scale simulated reality and actual surroundings are forced out altogether, AR superimposes digital data over real life in real time. This enables the learners to be anchored in the reality of their natural environment and at the same time also releases them to interact with contextual and more information in digital form.

AR is usually based on some technological framework, which is provided by hardware devices like smart phones, tablets, smart glasses that are AR powered or head mounted displays. These devices scan the physical environment using camera input, sensors, GPS and computer vision algorithms to trace the position of such an environment and associate virtual things with it appropriately. Developers and educators can create highly interactive learning experiences by using popular AR platforms, including ARKit (Apple), ARCore (Google) and other learning Augmented Reality apps.

When it comes to STEM education, AR enables visualisation of those concepts that are abstract and rather complicated and could not have been explained in a typical classroom.

For example:

- In Biology, students are able to view the human heart and examine blood flow and the process of cardiological performance within a fully rotatable interactive 3D model.
- Chemistry Chemical reactions and the structures of molecular compounds, as well as their bonds, can thus be visualised safely in AR simulation, removing the physical risks of experimental chemistry.
- In Physics, pupils can model mechanical systems, ascertain forces and run energy changes in real time.

AR has other potential applications in Engineering and Mathematics, where real-life objects can be augmented with either schematics, circuit diagrams or geometric models, to aid in spatial and conceptualisation.

Having a more immersive (physical), available and personalised form of learning is one of the most life-changing capabilities of AR. AR makes visual, auditory and kinesthetic learning styles available simultaneously, serving a range of learner interests in this way and facilitating an active learning environment.

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Furthermore, the interactivity that is found in AR promotes problem-solving, experimentation and inquiry-based learning that is a key area in STEM pedagogy.

With the use of AR in curriculum development, educators have the chance to bridge the gap between theoretical teachings and hands-on, practical teachings and thus can create deeper insight and knowledge within their students. Regardless of its application in lectures, laboratory-based learning or field-based experiences, AR will be a useful pedagogic tool through which passive learning will be actively translated into active and experiential learning.

AR in STEM Education

With the help of Augmented Reality (AR), STEM (Science, Technology, Engineering and Mathematics) education is also heading towards drastic changes wherein abstract concepts would be made experiential and interactive. AR helps to bridge the gap between theory and practice that it creates by superimposing the virtual world on reality and enabling users to do what is not available in theory but what they really need. This does not only help in further insight but also helps to create creativity and teamwork when trying to solve problems.

Enhancing Conceptual Understanding

The STEM subjects are in most cases dealing with abstract/versatile/microscopic subjects which are hard to picture within a conventional teaching process. AR technology also contributes to its solution as the students can view, manipulate and interact with the digital 3D models online.

- ↳ **Science Applications:** In molecular biology, AR allows molecular structures and chemical reactions to be shown at an atomic level where the learner can zoom in, rotate and analyse bonds or molecular interactions.
- ↳ **Mathematics Applications:** Complex mathematical modelling, e.g. 3D geometry or calculus-based simulations, becomes easier to understand when the learner can handle the variables and visualise the changes in real time.
- ↳ **Engineering and Technology Applications:** The layers of mechanical parts or circuit boards can be studied in more information and the design and operation of items is better understood.
- ↳ **For Example:** A simulation on solar systems via AR can make it possible to generate planets in a classroom. Students are able to walk; observe planets in different ways; examine and appreciate their orbits, sizes and rotations. This sort of spatial action increases the clarity of astronomical length and interrelations.

Improving Engagement

AR can make the process of learning both fun and engaging because it introduces interactive aspects to stem lessons. In contrast to the passive images of textbooks, the experience of AR makes the students engage in learning process by touching, gesturing and speaking.

- **Virtual Experiments:** Chemistry students are able to do safe virtual experiments - combining chemicals, observing reactions and repeating experiments- with no safety concerns and no resource limitations.
- **Gamified Learning:** AR puzzles and quest can also incorporate STEM learning including designing and troubleshooting an electric circuit so that the next learning process can be unlocked.
- **Engineering Design Simulations:** This aspect allows the student to design their prototype virtually, test the strength of structures and immediately modify the design to facilitate an understanding of critical thinking and problem-solving.

An example is when these students are in an AR-enhanced physics lab, where the students can experience changing gravitational forces or changing environmental conditions to see how various materials behave and remember the abstract theory.

Supporting Collaborative Learning

Besides the improvement of individual learning, AR can also foster collaboration, interaction with peers and teamwork, which are essential in work related to STEM professions. Most AR applications are targeted in a multi-user scenario so that the students may collaborate on an assignment in real time.

- **Co-Design Projects:** Members in engineering team can design a bridge together in AR, allocate various parts of the bridge to each other and fit all parts together to one 3D model.
- **Problem-Based Learning (PBL):** Groups will have an opportunity to work together in order to solve existing practical problem, e.g., developing an AR-based proactive approach to flood prevention or an energy-efficient house.
- **Cross-disciplinary Projects:** AR can be used to enable collaborations between students in science, technology and art to bring all-new interdisciplinary solutions.
- **For Example:** On an AR civil engineering-related project, several students can plug into the same bridge model and test it under simulated loading and everyone make modifications to the design. Not only does this enhance technical skills, it also enhances communication skills, as well as project handling skill and decision-making skills.

Review of Literature

Azuma (1997), saw Augmented Reality (AR) as a technology paradigm of overlaid digital information that is used to augment perception and interaction with the real world by superimposing digital content onto a real-world object. His contribution provided the basis of AR in education and its possible contribution in making the abstract/ the complex idea, more concrete and active especially in terms of scientific and technical education.

According to Milgram and Kishino (1998) AR concept is a continuum between reality and virtuality. They demonstrated how AR has the ability to preserve the real world context with integration of digital contents, which explains the usefulness of learning environments incorporating both physical and virtual worlds. This worldview has been shared in developing educational interventions that could enable learners to engage with the simulations as they do not lose touch with the physical environment.

In addition, another study conducted by Bower, Howe, McCredie, Robinson and Grover (2014) analyzed the use of AR in the classroom and was able to identify that it facilitates experiential learning. The children have the ability to interactively play with 3D objects and visualize science and that makes them MORE engaged and more knowledgeable in STEM topics. The research conducted revealed the focus of AR on active involvement and curiosity.

Inquiry-based STEM learning Wu, Lee, Chang and Liang (2013) were investigated in terms of AR. They discovered that through AR, students are able to explore abstract ideas in a safe manner offering visual and interactive models to bring a greater understanding and problem-solving abilities. AR helps learn by experience without any of the disadvantages of conventional labs.

Chiang, Yang and Hwang (2014) pointed out the incentive advantages of AR. In their analysis, they found that students who created science and maths assignments using AR experienced them to be more engaging, fun and retentive. Contributions and facilitation were also improved with interactive simulations and gamed tasks, motivating the learners to read beyond instructions in the textbook.

The analysis of collaborative AR environment was conducted by Fonseca, Mart, Redondo, Navarro and Sihnchez (2014). They concluded that collaboration, message exchange and collaborative problem-solving are more easily established using multi-user AR tools. In virtual spaces, students will be able to develop experiments or engineering models and such collaboration fosters social and cognitive skills as well as learning of the STEM field.

Moro, Štromberga and Stirling (2017) investigated AR in the fields of Medical and Engineering education. They cited a better sense of space, ability to visualize anatomical and mechanical shapes as well as better critical thinking. AR-based simulation allowed them to understand some intricate topics which would otherwise have been hard to explain physically in classrooms.

Akccayyr and Akccayyr (2017) summarized the benefits of accessibility to AR. They observed that the virtual experiment labs help in minimizing on the physical equipment that is costly to purchase but still offer practical learning experiences. AR enables the learners to safely play with the experiments increasing the inclusivity and reachability of STEM education in a variety of schools and collages.

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Ibanez and Delgado-Kloos (2018) led a systematic review of AR in the STEM field. They found that AR transgresses the verges of theoretical and practical knowledge in the classrooms that are either remote or face constraints in resources. The technology facilitates the interactive use, picturing the abstract ideas or practical learning processes that people could not readily get using traditional methods.

Huang, Liaw and Lai (2019) spoke about the importance of teacher preparedness in terms of AR implementation. Based on their research, they believed that teachers required professional growth and pedagogical mechanisms that conformed to the possibilities of AR. The proper integration involves education in digital tools and instructional design so learning outcomes can be achieved.

Liu, Hwang and Chu (2020) concentrated on the mobile AR application to self-directed learning in STEM. Students with mobile AR would have the chance to learn concepts on their own, conduct interactive experiments, getting instant feedback, boosting autonomy, engagement and learning. AR allowed the learners to study individual learning pathways successfully.

Ibanez, Di Serio, Villaran and Kloos (2021) discussed AR in blended and distance learning of STEM. They found that the lack of physical classrooms can be media-saturated with interactive visualizations, simulations and collaborative functionality- in other words, AR compensates using more interactive, more visual, more collaboration-based learning- improving comprehension, retention and involvement in virtual or hybrid classes.

Evidence-based instructional design of AR has been mentioned by Bower, Howe, McCredie, Robinson and Grover (2020). They asserted that AR should be curriculum based, learning goal directed and assessment behavioral. Considered design will guarantee the improvement of the level of implementation rather than the utility of the effect as a piece of novelty and because of that, the AR will be effective in STEM learning.

The work by Alghamdi, Aldhafferi and Al-Hassan (2022) researched inclusive STEM education and AR. They discovered that the multimodal AR experiences can cater to both visual and auditory and as well as kinesthetic learners. AR will create equity and participation since the provision of interactive content will be available to students of varying abilities and backgrounds.

Objectives of the Research Study

1. To examine how augmented reality (AR) enhances conceptual understanding and practical application in STEM subjects.
2. To investigate the impact of AR on student engagement, motivation and collaborative learning in STEM classrooms.

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3. To explore the integration of AR tools into STEM curricula to support experiential and competency-based learning.
4. To identify challenges and provide recommendations for effective implementation of AR in school and higher education STEM programs.

Research Methodology

This study adopts a qualitative-descriptive research design to explore the role of Augmented Reality (AR) in STEM education. A case-based approach is employed to gain in-depth insights into how AR influences teaching and learning processes, student engagement and collaborative learning outcomes. The study integrates both primary and secondary data sources to ensure a comprehensive understanding of the subject.

Sample

The sample consists of 20 STEM educators and 200 students from secondary and higher education institutions using AR tools in their curriculum. Educators are selected based on their experience in integrating AR in classrooms, while students represent diverse academic backgrounds across science, technology, engineering and mathematics streams. Purposive sampling ensures that participants have adequate exposure to AR-based learning experiences.

Data Collection

→ Primary data: Semi-structured interviews with STEM educators, focus group discussions with students and classroom observation of AR-based activities.

→ Secondary data: Review of published research articles, curriculum documents, AR application usage reports and institutional case studies.

Data Analysis

Data is analyzed using thematic analysis to identify recurring patterns, trends and significant impacts of AR on learning. Quantitative measures, such as frequency of AR tool usage and student engagement metrics, are triangulated with qualitative insights to validate findings. Coding categories include conceptual understanding, motivation, collaboration and instructional effectiveness.

Alignment with NEP 2020 and NCrF

The NEP 2020 offers great emphasis on experiential, multidisciplinary and skills-oriented learning to make learners able to survive in the challenges of the economy of the 21st century. Among its major

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suggestions is to incorporate the emerging digital technologies like Augmented Reality (AR) in order to establish individualised, engaging and competency-based learning ventures.

AR actively endorses the NEP 2020 pedagogical vision in the following:

1. Experiential Learning -AR allows a student to experiment learning in an interactive risk free compartment. To illustrate, surgical methods can be practised through the AR simulations well before the students enter the real operating theatres, which is consistent with the requirement of the NEP 2020 to learn by doing.
2. Multidisciplinary Integration rejection of silos between disciplines is considered in the policy. AR enables an architectural student the opportunity to visualise the load analysis of the structures incorporating physics, maths and design concepts.
3. Just distribution of High Quality Resources -The NEP 2020 recognizes the issue of mediating gaps due to geographical and Infrastructural division. AR-based material is implementable via low-cost AR devices and smartphones and thus even in schools or colleges located in remote rural areas, advanced simulations may be made accessible.
4. Individualised Learning Paths- AR enables students to work and revise through simulations until in control with subject matter by being able to replay the same simulation simultaneously controlled by their ability levels. It is similar to the suggestion of the NEP 2020 to turn to adaptive learning technologies.

AR-based projects, simulations and virtual internships may be bought into the legitimate educational credits to a learner under the National Credit Framework (NCrF). This becomes rather important with:

- ↳ Skill Credits A student in an industrial machine maintenance could complete an AR-enabled internship and receive Skill Credits as part of the vocational and skills part of NCrF.
- ↳ Project-Based Credits- students of engineering institute may be involved designing AR applications of urban planning and the work of these students may be evaluated and counted as credits on the innovation and entrepreneurship dimensions.
- ↳ Lifelong Learning Credits - NCrF acknowledges learning taking place outside of a classroom setting; augmented reality based corporate training, upskilling and reskilling programs can be added into the cumulative academic record of a learner.

☞ Practice Example of Alignment:

Indian Context: National Skill Development Corporation (NSDC) has now started experimenting with modules on automotive and healthcare ASR, through which the learners get skill credits claimed through the NEP 2020 as also NCrF.

B.Tech or M.Sc, engineering universities are also integrating in their curriculum Higher Education AR-based lab experiments being accredited as a credit under the NCrF Practical and Applied Learning category.

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It is possible to design a new, industry-relevant education system through AR adoption in curricula that would enable institutions to establish a future-ready education system by giving equal emphasis to practical and theoretical aspects.

Cases and Examples

1. Medical & STEM Education

- ↳ Human Anatomy Atlas, Asian – Allows medical students to navigate through human organs, skeletal systems and body systems in 3D with interactive enhancements and helps them to develop spatial recognition and clinical interpretation abilities.
- ↳ AccuVein AR Tool: Has also been designed in nursing and clinical training to assist safe injection practices and improves the quality of training by projecting a virtual map of the veins on the arm of a patient.
- ↳ Case Impact- AIIMS Delhi study stated that the use of AR anatomy training lowered the cadaver dependency rate of students by 40%, i.e., it made the teaching process easier and healthier.

2. Design and Architecture of Engineering

- ↳ ARki - Enables students of civil engineering and architecture to superimpose 3D structure designs onto construction sites so that they can reach the scale accuracy and show the clients.
- ↳ Morpholio Trace AR: Architecture students can now sketch, annotate and visualise structures in AR directly to study together in these collaborative design reviews.
- ↳ Case Impact- An Ar-enabled bridge design project at IIT bombay cut down the cost of a prototype by 60 times and the efficiency of design reviews.

3. Chemistry aamp; Physics Experiments

- ↳ Augment Chemistry Lab allows one to work with virtual chemicals and reactions, as well as with virtual molecular structures safely without a risk of accidents.
- ↳ Physics Lab AR - simulates mechanics, optics and electricity experiments and enables learners to test various variables immediately by touching the screen.
- ↳ Case Impact – With pilot schools in CBSE Class XI, Ar-based chemistry learning caused a 35 percent increase in concept retention over standard, in-lab teaching lessons.

4. School Science Outreach/STEM Outreach

- ↳ Merge Cube -With this, an ordinary cube can transform into a 3D model of a planet, volcano, DNA strands or ecosystems.
- ↳ Google Expeditions AR - Turning historical journeys into classrooms so that students visit historical monuments and missions to space and start learning a process of life.
- ↳ Case Impact: Kendriya Vidyalaya in Pune implemented AR in Class VIII geography so that the students would be able to visualise the tectonic plate movement which resulted in 45 per cent additional improvement in the map-based test score.

5. Vocational Training & Industrial Skills

- Bosch AR Service Training- Applied in technical schools to teach students repair techniques on automobiles using the 3D overlays on a real car engine.
- Welding AR Simulator: Trainees under industrial Training Institute (ITI) can learn the art of welding on the computer with less wastage of material.
- Case Impact - AR welding modules that were introduced in Gujarat ITIs led to the reduction of training costs by 30 percent and an increased benefit in the pass rates in skill certification tests.

6. Environ. Ag.

- AR Crop Identification Tool - Assists agricultural students in getting real time knowledge about plant diseases, plant growth patterns and the soil conditions.
- EcoAR - Projects in endangered species in the natural habitats as part of an environmental education program.
- Case Impact - Anand Agricultural University is educating its crop scientists about AR which solved misidentification issues in the field to the extent of 50 percent.

7. Arts, History, Culture studies

- Civilisations AR by BBC: Allows students to study historical artefacts, historical sculptures and cultural heritage sites in general.
- AR Museum Tours The tours provide complete experiences of museums and heritage places without the need of physical travel.
- Case Impact The National Museum, New Delhi, was carrying out an AR based Harappan Civilisation programme with students in Class IX, which increased their accuracy of historical timelines by 38%.

6. Benefits of AR in STEM

1. Tries to make Abstract Concepts tangible

- Augmented Reality helps in explaining complicated theoretical concepts in an easily comprehensible, interactive visual form.
- In physics, the AR simulations are able to demonstrate real-time working of an electromagnetic field.
- In the field of mathematics, geometric solids rotating in the 3-D space can be viewed and the students will better understand angles, symmetry and volumes.
- In biology, AR can show the human circulatory system in action in such a way that students learners can virtual walk within arteries and veins to learn how blood flows.
- This visual/spatial interaction brings the gap between textbook pictures and real world application applications.

2. Promotes Practice-Based, Challenged Learning

- AR allows solving problems, experimenting and testing to be an active learning experience, with no fear of failure.

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- In the case of engineering students, ARki can allow engineering students to redesign a bridge structure and test its limit load capacity virtually.
- In the environmental science field, one could apply AR-based disasters to enable the learners to control a virtual flood pattern or contain a wild spread.
- By having students working in environments that need decisions being made AR generates critical thinking, creativity.

3. Minimizes the reliance on Costly Physical Labs

- The common STEM experiments usually take into account expensive instruments, laboratory areas and disposable resources. The solution is using AR as it is removable, reusable and cost effective.
- In chemistry, the combination of volatile chemicals in MEL Chemistry VR/AR labs gives students a chance to mix them together safely and repeatedly without expense and risk.
- In the case of robotics, AR would be able to demonstrate the programming and control of virtual robots prior to the creation of corresponding physical models, which reduces material wastage and expenditure.
- This democratises the STEM education particularly in under-resourced schools.

4. Enables Distance and Blended learning

- Having AR available on smartphones, tablets and AR headsets, students can acquire knowledge of STEM concepts at any location.
- AR apps may give students the chance to be involved in lab practices remotely such as dissecting a frog or building a circuit, during remote classes.
- During blended learning, instructors are able to set AR-led pre-lab simulations so that students enter the physical labs equipped with previous experience.
- This flexibility can guarantee the success of the STEM learning even in case of a pandemic or learners who are not in vicinity of educational establishments.

5. Supports individuals in learning how to employ the use of technology and invent novel ideas

People are increasingly required on STEM jobs that involve a laudable command of digital instruments, data presentation and immersive technology in the 21st century.

AR helps students learn to operate advanced software, carry out digital modeling and know about 3D simulations. These can be applicable in engineering, healthcare, AI and manufacturing.

Students also learn creative things by creating their own AR outputs using such tools as ZapWorks or CoSpaces Edu. They also get to know how to develop, test and optimize interactive models.

This prepares them to job markets the AR and immersive tech will matter a lot.

Challenges in Implementing AR in STEM Education

As much as Augmented Reality holds transformational promise within the STEM learning environment, implementing it is associated with a series of functional, instructive and infrastructural issues.

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These need to be resolved in such a way as to make acquisition of personality meaningful, fair and long-lasting incorporation into the teaching-learning process.

1. Expensive AR Hardware and Software

- ↳ Hardware Cost: AR headsets, AR-compatible tablets, high resolution cameras and interactive displays may be costly, especially when used in government schools or within schools or institutes with low budget.
- ↳ Software Licensing: Other costs found in Quality AR apps may be subscription charges or licensing fees, which are needed to possess a quality application, particularly those applications that are specifically made to complement STEM coursework.
- ↳ Maintenance and Upgrades: The costs of maintaining the software through system updates, replacing components damaged by use and maintenance are upped in the long-term.
- ↳ Equity: Depending on the location of the school or its economic situation, there is a risk that the schools will not be able to fund such technology, which further worsens the chances of the digital divide.

2. Need for Teacher Training in AR Integration

- ↳ Skill Gaps: Skill gaps are a major issue with most educators having not been previously exposed to the AR tools and thus, either not using it optimally or not using it successfully.
- ↳ Pedagogical Alignment: Adoption of AR activities needs certain training of the teachers to bring them into congruence with curriculum objectives, learning objectives and measures to assess them.
- ↳ Confidence Building: The fact that educators will not have any hands-on workshop and continued mentoring may mean that they will be intimidated by the technology and revert back to traditional methods.
- ↳ Time Limitations: Educators have already demanding schedules and have little time to explore, experiment and learn to operate with AR tools.

3. scarcity of high-quality AR Content with regional languages

- ↳ Language Barriers: Most of the high quality AR applications are developed in English language and this cannot support large numbers of students, studying in regional or vernacular languages.
- ↳ Cultural Relevance: International content catered to the needs of other markets might not provide any sort of relevance to the Indian contexts, examples and local curriculum demands.
- ↳ Content Development Hurdles: Content development on AR is multilingual and this consumes special skills of not only translation but AR programming code as well, thus rendering the adoption relatively sluggish.
- ↳ Influence of Learning Outcome: The students unable to grasp the knowledge completely will not make any progress as they have a lack of language to comprehend the information thoroughly and will maybe not have interest or an interest in comprehending the material.

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4. It may be a Distraction unless it is combined with Clear Learning Goals

- ↳ Excessive Visual Appeal: Well, the visual appeal of AR may distract students and make them concentrate on the entertaining parts of the technology rather than the goals of learning.
- ↳ Cognitive Overload: Animations that are too complex or too much interactivity have the consequence of confusing learner and thus lowering understanding and recall.
- ↳ Curriculum Misalignment: According to many, AR experiences cannot be aligned with the subject matter without good practice instructional design and one wastes time.
- ↳ Classroom Management: Improperly monitored use of AR may be an off-task behavior as the students may be less focused on the instructions of the teacher than on the technological device.

8. Future Potential

The use of the Augmented Reality (AR) in STEM education has a huge potential in the future that keeps growing. As the technology approaches maturity, future integration brings with it the idea of the availability of AI-enabled AR-enabled tutors which can give real-time instructions, immediate feedback and adaptive assistance as per the student requirements. Combined with the Internet of Things (IoT), AR would give students access to live information from networked devices and in subjects such as physics, biology and engineering, give them the opportunity to experiment and engage in real-world problem solving. Also, further investment on device prices and availability will enable AR to become more accessible to schools within the communities of India, rural and under-resourced. Inclusive and engaging content will also be increased by developing high-quality AR content that is culturally and linguistically relevant and will be available in the local languages or in the source languages within the region. With such developments, it can be argued that AR could revolutionize STEM classrooms by enabling them to become fully immersive and interactive in nature where abstract knowledge can be made more concrete, experimentation can be preformed without any risk and where students will be able to train their thinking skills at a higher level through direct access to digital environments. Finally, with the merging of AR with new technologies, it may become a part and parcel of the STEM curricula across Indian education sector.

Conclusion

Augmented Reality (AR) is an enormous potential to transform STEM education to an active, engaging and highly immersive system. As opposed to conventional teaching, AR is a tool that closes the gap between theory and its implementation because the student can see and experience the complicated ideology visually. This is in absolute coherence with the National Education Policy (NEP) 2020 and National Credit Framework (NCrF) which focuses on experiential, competency-based and technology-integrated learning. AR can enhance the student to investigate the world of science, mathematical solution to a problem, engineering and technological application in a manner that stimulates the students and makes them curious learners. With cost and accessibility to AR tools, which is likely to improve in the future and, specifically, promising the production of content that is relevant to where a learner lives, the use of AR in Indian classrooms can guarantee

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equitable and inclusive access to quality STEM education. However, in the future, AR will also be a key tool in teaching students to navigate in a fast changing technologically oriented world, enable them to think critically, solve problems and be innovative enough to be able to achieve professional success in the workplace therefore making a generation that is capable of handling real-life issues confidently.

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