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Cloud Computing Solutions for Remote Education Infrastructure

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Abstract: The dramatic increase in the adoption of remote education necessitates a corresponding enhancement of the technical infrastructure supporting the process. For this reason, the application of cloud computing technologies in education, such as Software as a Service, Notebooks as a Service, and Infrastructure as Code, increases the quality of the learning experience while reducing the costs of developing and supporting the educational process.
The theoretical foundations of the topic are based on an analysis of 2,885 sources from the Scopus bibliographic database, which were processed using modern digital analysis tools. The material is filtered by key terms in the title, abstract, and keywords. Five main aspects are considered: service models, deployment models, quality assurance, identity management, and data security. The service model Software as a Service is explained in the context of cloud-based educational environments.

Keywords: Cloud-based Learning Management System (LMS),Virtual Classroom Platforms,Education Cloud Infrastructure,Scalable Cloud Hosting for Schools,Remote Learning Cloud Services,Cloud Storage for Educational Content,Video Conferencing for Online Classes,Cloud Security for Education,Identity and Access Management (IAM),EdTech SaaS Solutions,Cloud Collaboration Tools for Students,Content Delivery Network (CDN) for E-Learning,Disaster Recovery & Backup for Schools,Hybrid Cloud for Education Institutions,AI-Powered Cloud Learning Analytics.

1. INTRODUCTION

The rapid, global shift to remote education introduced by the COVID-19 pandemic has catalyzed digitalization across society, raising cloud computing to the forefront of modern information technology and educational innovation. In addition, Web-based educational services have formed the basis of new educational models and environments, evolved and supported by Cloud Computing Paradigm as one of the most rapidly growing branches of Information Technology. The theoretical foundations of cloud computing in education are informed by qualitative and quantitative analysis drawing on documentary evidence. The core construct - a cloud-enabled education ecosystem - integrates all participants, provides integrated and secure delivery of services. Quality of service, security requirements and compliance are key considerations for cloud-based education. A self-service architecture enables corresponding learners to readily manage their own accounts, aliases and access privileges. Interoperability considerations encompass standards, frameworks and educational data exchange. Deployment and migration scenarios for cloud-based infrastructure services in education form a complex risk-driven optimization problem.

A hybrid cloud deployment scenario enables institutions with limited resources to temporarily access additional capacity, while public cloud services support virtual desktops and administrative functions. The Cloud Computing Paradigm has the potential to radically change the provisioning and delivery of educational services through Web-based platforms, particularly in developing countries that have long suffered from pervasive resource constraints. ולהלן הסקירה במצגת וגם בסקירהPresent and Future Trends in the Cloud Computing Paradigm: Implications for Education and Training) International Journal of Information Management, 34(1), 1-9. The COVID-19 pandemic has severely affected education systems worldwide, with widespread closures of schools and universities. Cloud computing solutions for remote education infrastructure have provided critical support. This paper makes a twofold contribution. First, it identifies the key cloud computing resources that should be implemented within an educational institution. Second, it identifies how a public cloud can help educational institutions provide remote education services. The findings are drawn from the literature in a review and synthesis manner: an overview of the core relationships and of how each service can support remote education is presented. The research issues that arise when using public cloud services to support education have also been addressed. The aim is the formulation of a conceptual model of a Cloud-enabled Education Ecosystem, which integrates all actors of the education and training process and provides the integrated and secure delivery of the services required.

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1.1. Background and Significance The COVID-19 pandemic compelled the sudden closure of many educational institutions, resulting in a rapid switch to remote teaching. These subsequent shifts in teaching and learning practices prompted increased interest in easily accessible and cost-effective remote education solutions. Community-managed educational resource-sharing platforms such as MOOCs became widespread during the pandemic, offering resources and live lectures on a subscription basis, while private cloud solutions like Google Classroom emerged as comprehensive remote education solutions. The rush to embrace these platforms has blurred the line between learning and leisure, heightening the need for a reference architecture focusing on quality assurance for education.

Despite a shift in geographical location, online education is fundamentally different from face-to-face and blended learning. The review identifies the core components of a cloud-enabled remote education ecosystem and offers a the implementation of Cloud Computing for education in Higher Education Institutions (HEIs). The cloud computing ecosystem for remote education comprises three architectural layers: service orientation, information storage and management, and data accessibility and security management.

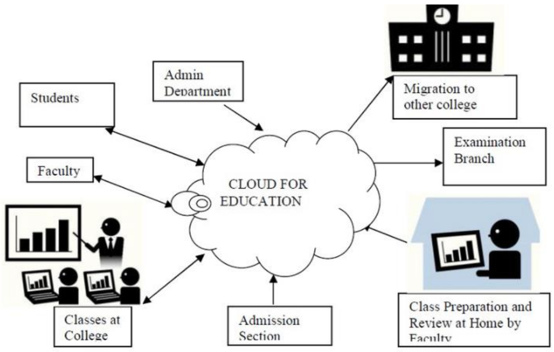

Fig 1: Services attached to Education Cloud

2. THEORETICAL FOUNDATIONS OF CLOUD COMPUTING IN EDUCATION

Cloud Computing as a Diffusion of Innovation in Education

N. F. Kemekhin, M. M. Kuzmin, M. A. Morozov, Yu. Y. Bakhareva, L. G. Galkina In the context of a global pandemic, the share of online education reached an unprecedented level, resulting in significant changes in the mood of educational institutions, teachers, and learners. Nevertheless, cloud solutions have provided certain advantages, especially regarding operational readiness, Fault Tolerance and Scalability. Increasing the share of remote education changes the traditional educational process, determining new roles, goals, and functions of the parties involved in online education. Cloud technology and other digital tools are evolving rapidly, and their integration into the educational system can be viewed as a process of diffusion of innovation on the part of the new generation of educated young people, who, as digital natives, take for granted the use of modern technologies in the learning process and are capable of undertaking voluntary full-time. At the same time, it is no longer sufficient for educational institutions to offer the same standard courses and teaching methods as in the past: new actors are also coming onto the market of educational services, and the offer is diversifying. Those who respond more quickly to the needs of the educational market are usually successful. Cloud adoption brings about an important period of transition and allows institutions that prefer to focus on the educational process rather than on managing complex IT infrastructures to pursue development initiatives. Students and teachers need to use the instruments offered by cloud services, which provide their first novelty in Learning Management Systems as Learning as a Service.

The actual situation and development prospects are being studied, and a Research Design is proposed for the adoption of the "service-oriented" architectural model in educational institutions (universities and other organizations) that prefer to concentrate their resources on the core business: teaching, participating in research, and pursuing student satisfaction. Supervisory/Coordination and Management are not perceived as core business, but more in the vein of service fulfillment. Other companies can undertake all these activities (Server, Platform, Infrastructure as a Service), with the portal being visible and accessible for data entry and visualization, updates, etc. "Software as a Service" provision is currently concentrated in the Learning Management Systems of an independent Application Service Provider (Office in Cloud, Virtual Characters and Instruments, etc.)." Past education was teacher-centered; current education is learner-centered; future education will be managed by learners, with teachers relegated to the role of tutor, supervisor, or consultant." Online education offered by different types of providers differs in many respects and is subject to the same terminology

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and points of evaluation as face-to-face education. The Curriculum-VAT model can also explain why and how students separately evaluate online education. Students are not unconscious interlocutors but are considered an active part of the learning process and process scientists."

Equation 1: QoS as a measurable objective (from "QoS management")

Let:

- A= availability (fraction of time system is usable)
- R= reliability (probability the service does not fail over a time window)
- L= latency (seconds)
- T= throughput (requests/sec or sessions/sec)
- S= security/privacy score (0–1, higher is better)
- C= compliance score (0–1)

To combine them into one "QoS score" (useful for automation), define normalized forms:

- **Normalize "higher is better"** metrics directly:

$$\tilde{A} = A, \tilde{R} = R, \tilde{T} = \frac{T}{T_{\max}}, \tilde{S} = S, \tilde{C} = C$$

- **Normalize "lower is better"** latency:

$$\tilde{L} = \frac{L_{\min}}{L}$$

(where $L_{\min}$is a chosen best-case target; this makes $\tilde{L} \in (0,1]$)

Pick weights $w_A, w_R, w_L, w_T, w_S, w_C$such that:

$$w_A + w_R + w_L + w_T + w_S + w_C = 1, w_i \geq 0$$

Then define:

$$\text{QoS} = w_A\tilde{A} + w_R\tilde{R} + w_L\tilde{L} + w_T\tilde{T} + w_S\tilde{S} + w_C\tilde{C}$$

2.1. Research design The COVID-19 pandemic has accelerated the transition of educational services to remote, hybrid, and blended support. Such an approach allows instruction and curricula to commence through online channels with a focus on cloud technologies. The sudden growth of remote and hybrid education needed prompt technological solutions to enable high-quality services while permitting low-cost and fast deployment. Herein, the cloud-computing architectural model is proposed as the fundamental technological base of an educational service ecosystem. The infrastructure, platform, software, and service models of the cloud paradigm are considered along with the four principal components of a learning ecosystem, namely learners, learning resources, organizations, and service providers. By exploring the perspective of cloud computing in education from these four aspects, specific solutions for remote educational services, particularly for the Software-as-a-Service layer hosting Cloud-based Learning Management Systems, are uncovered.

Cloud computing has to be viewed as an architectural model providing a logical organization of resources and services enabling the convenient provision of on-demand ICT capabilities, facilities, and tools for enabling business activities. Cloud-computing systems must therefore be designed for flexible support of existing business processes while providing automated Quality of Service (QoS) management supporting a maximum degree of process automation and adaptation. With cloud computing as an underpinning architectural model, the deployment architecture must be aimed at providing the most appropriate integration of the services offered and the various supporting infrastructures. Four deployment

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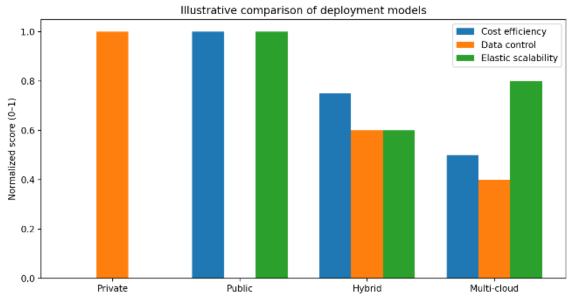
scenarios are evaluated, namely across private, hybrid, public, and multi-cloud environments, with their selection driven by the requirements of the business processes supported.



3. ARCHITECTURAL MODELS FOR REMOTE EDUCATION

Cloud computing makes it possible to provide remote education services interconnected with various information systems. Services of data storage and exchange, digital accounting, identity management, and distribution of training programs via learning platforms provide users with such possibilities through the use of SaaS model as part of cloud services.

Resources of cloud computing are being actively used for distance education in conditions of special quarantine measures. Reliability of the network infrastructure of cloud computing allows the deployment of cloud services used in remote education, which supports elaboration of services of equipment and information centers of higher educational establishments. It is possible to consider the whole system of services for remote education as cloud computing for educational purposes, cloned by federative principles, when all parts of the system are based on separate clouds, unified by a single portal, an identity management system, and common standards of communication and data exchange between services.

Management of cloud services for remote education concentrates on their main functional characteristics and service quality. Using O1cloud services allows students and their tutors to receive almost complete set of cloud-instrument support for remote education without special interactive service of teachers and administrators; they only realize the control of quality and effectiveness of students' training, which is the basic task of teachers. Real-time communication is contained in separate service, and even it can be one additional component of a broader cloud system, if the accounting is realized by other stakeholders of the system.

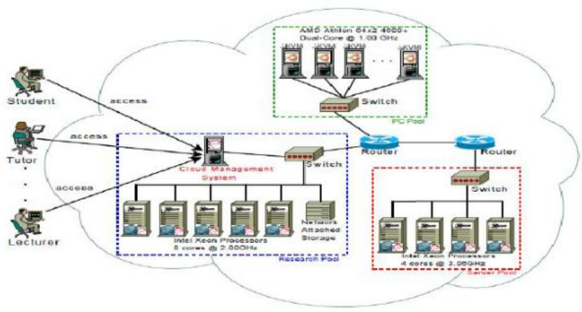


Fig 2: Cloud Computing architecture

3.1. Software as a Service in Learning Platforms Adopting Software as a Service (SaaS) within a cloud-based learning platform allows students and faculty not only to share collaborative content, but also to communicate and interact with one another through forums, group pages, and chat functions. SaaS solutions enable remote teams to manage workflow processes such as assigning work, receiving submitted work, giving feedback, and tracking the status of a task with notes. Most commercial solutions on the market offer services that would allow two or more teams to work on the same document simultaneously, along with real-time versioning.

Examining communication tools as a SaaS model shows its usefulness in sharing and collaborating with others in a fast, efficient, and cost-effective manner. Their success largely correlates with proper use and ongoing access, and with the

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availability of easy-to-use systems within the learning platform. For faculty, having a well-defined workload process with timely information and feedback can improve the overall experience. Working in teams to produce a document not only improves the final product but also allows flexibility in a busy schedule. These tools provide inventive and engaging alternatives to current methods while enabling core competencies to be developed effectively and efficiently.

4. CORE COMPONENTS OF A CLOUD-ENABLED EDUCATION ECOSYSTEM

In addition to learners' access and authentication in cloud environments, successful implementation of remote education based on cloud technologies requires addressing four core components. First, identification and authentication of users as protected entities is increasingly considered a necessity for building cloud applications that ensure appropriate access control and information security. In addition to addressing user access, the second component refers to an ecosystem for the delivery of cloud services. Although education as a defined mean of social development is a global concern, it cannot be dissociated from government, business, and educational institutions, which must periodically review aspects that require modernization, such as curriculum and courses. As a result, educational processes often need to adapt quickly to environmental changes or specific technical demands, requiring temporary platforms for relatively short-term use.

The third component consists of an appropriate cloud architecture model that addresses hosting and handling of educational services, relational databases, Secure File Adaptations, and Web Security Layer. For example, the recent migration of an on-premises learning management system to an external data center operated by a private telecommunications operator motivated the definition of a cognitive model to monitor its environment and verify the effectiveness of control procedures. In addition, quality planning is a key aspect of educational management that contributes to its optimization in any context, including the educational cloud. Quality Indicators—understood to be values associated with characteristics of services, resource use, or infrastructure—and stakeholders' expectations are key aspects of an educational quality framework that support ICT provision in education. Such an ICT provision model connects the in-house developed Electronic College and a commercial learning management system and supports quality control and assurance of the remote education delivery process.

Equation 2: Cost & scalability equations (from "low-cost, fast deployment" + deployment scenarios)

Let:

- N= number of active learners (or concurrent sessions)
- a= baseline monthly cost (admins, base services)
- b= marginal monthly cost per learner (compute+storage+bandwidth allocation)

Then:

$$C_{\text{cloud}}(N) = a + bN$$

Let:

- F= fixed monthly cost (staff, datacenter, amortized capex)
- capacity per "step" = Klearners
- step expansion cost = $s$per step
- number of steps needed beyond baseline:

$$m(N) = \left\lceil \frac{N}{K} \right\rceil - 1, m(N) \geq 0$$

Then:

$$C_{\text{onprem}}(N) = F + s \cdot m(N)$$

Let:

- F_h= private baseline monthly cost

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- threshold N_0 learners served privately
- burst marginal cost b_h for learners beyond N_0

$$C_{\text{hybrid}}(N) = F_h + b_h \max(0, N - N_0)$$

4.1. Learner Access and Identity Management Identity and access management represents one of the fundamental components of a cloud-based educational ecosystem and is critical in regulating access of different users to shared cloud resources. Services supporting user authentication and authorization are needed for remote learning environments in which multiple organizations participate, encompassing users from different institutions and companies.

Federated architectures allow identity management services to be deployed and used within a singular organization, but permit users from third-party institutions to cross identities and access the resources of the home organization. They are particularly useful in the context of education, where particularly institutions such as licensing authorities, consortiums or other self-organizing groups can decide and deploy such resources. Authentication mechanisms such as Shibboleth, Identity Provider of the Internet2 or MFA of the Dial-a-Course consortium, interconnect the deferred installation spaces of different institutions enabling collaboration or course study. The implementation to support those deployments is very costly due to the low number of users relative dimension against an autonomous local solution. Mutual endorsement electronically mines the cost of establishing this mechanism and promotes collaboration within environments that share formal trust and registration. Access control mechanisms consider the different policies in relation to the sensitive information that can be processed by such services.

Whenever sensitive educational information is to be shared on a public cloud deployed by a third party, a data encryption mechanism must be used to guarantee that such data could not be breached. Data classification by data types and users role profiles may automate and speed up such access controls that enclose gateways of privacy policies definitions on user identity monitoring.

5. QUALITY, SECURITY, AND COMPLIANCE CONSIDERATIONS

Quality assurance for cloud-based educational services focuses on both the quality of the delivered service and the quality of the educational service itself. In the first case, it is important to guarantee the reliability, availability, security, and privacy of the platform as a whole. Furthermore, the experience of learners and teachers while using the service often forms the basis for the service being rated and ranked. Security and privacy concerns that arise with the use of cloud computing technologies and services are taken seriously by educational institutions, as sensitive data are frequently processed. Moreover, certain laws or regulations require educational institutions to ensure the protection of personally identifiable data. The European Union's GDPR is one of the most comprehensive legal frameworks in this regard. Topics related to software access security, data protection during transport and storage, and privacy when handling identifiable data have been studied extensively in the literature.

Quality assurance for educational services based in the cloud also involves checking compliance against corporate policies, national laws, and international regulations. This is especially important when the cloud service provider is located in a foreign country. Nonprofit organizations, especially, often depend on public funding and the noncompliance of services with these regulations and laws can have detrimental effects.

5.1. Data Privacy and Protection in Educational Contexts Given the sensitive nature of the information processed by educational institutions, learners' data privacy and legal protection against misuse are critically important. Indeed, cloud computing significantly enhances the risk of data misuse and requires careful consideration of data handling policy, storage location, and access control capabilities. However, measures to mitigate the risk must also be practical to implement and non-intrusive so as not to deter users from the services provided. Therefore, a foundational understanding of data protection issues is desirable for both technical personnel and the rest of the cloud ecosystem, including service developers and users such as instructors, administrators, and learners.

A summary of the privacy and protection principles of the most pertinent data privacy legal frameworks can help ensure that institutions comply with them when deploying services supporting learners' activities. The Cloud Security Alliance's Education Sector Working Group Resource Guide identifies a set of data privacy issues that require specific attention from any educational institution using cloud computing technologies, as well as key considerations for mitigating risks concerning these issues. The considerations make explicit the measures recommended to mitigate a particular risk, allowing institutions to discuss and assess their feasibility. Institutions are also encouraged to conduct risk assessments

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that map the outcome of such discussions to the CSA Data Security Breach Prevention and Response: A Guide for Security & IT Teams document, allowing them to share their conclusions with vendors and developers.

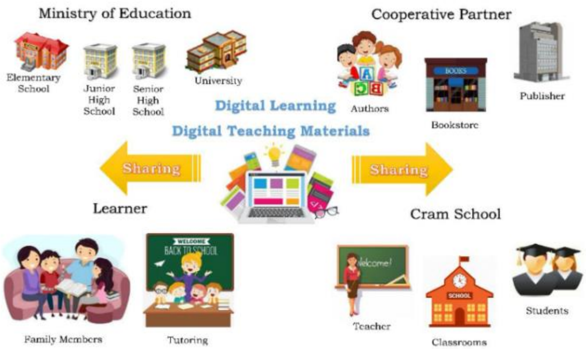

Fig 3: Data Privacy and Protection in Educational

6. INTEROPERABILITY, STANDARDS, AND PORTABILITY

Industry-specific, community-driven interoperability frameworks based on common contexts and vocabularies vastly reduce semantic obstacles inherent to multi-vendor environments and are accepted and respected by many sectors. The IMS Global Learning Consortium, for example, has developed several important specifications in support of data interoperability, including the Learner Information Package, Simple Data Access, and Learning Data Interoperability standards, which together facilitate sharing, transferring, and accessing learning records about degrees, courses, assessments, and competencies. The Sharable Content Object Reference Model and IMS's Question & Test Interoperability specification serve similar purposes for learning content and assessment items respectively, while a family of standards defined by Learning Tools Interoperability establishes computer- and sender-independent paths for the exchange of learning tools between learning management systems and the academic cloud. As these specifications gain acceptance in the education sector, they aggregate considerable political and economic clout, resulting in the increasingly common assertion that only content that conforms to these standards should be deployed in educational institutions.

Interoperability solutions that focus on data exchange rather than service operation continuously inform the development of information services in digital and corporate environments, including those for education. While vendor-neutral data exchange remains economically and politically difficult, a technology able to transform recorded information on demand into a vendor-specific format—either for direct use or for transfer to a payment service—does permit internal interoperability and short-circuiting vendor locks.

Equation 3: Availability improvement via redundancy (reliability/availability focus)

Let each replica have availability a_0.

- Probability a single replica is **down**: $(1-a_0)$
- Assuming independence, probability **all** n**replicas are down**:

$$P(\text{all down}) = (1 - a_0)^n$$

- Therefore, probability **system is up** (at least one is up):

$$A(n) = 1 - (1 - a_0)^n$$

That's the complete derivation.

Graph generated (illustrative):

- Download: availability redundancy plot
- Download: availability table (CSV)

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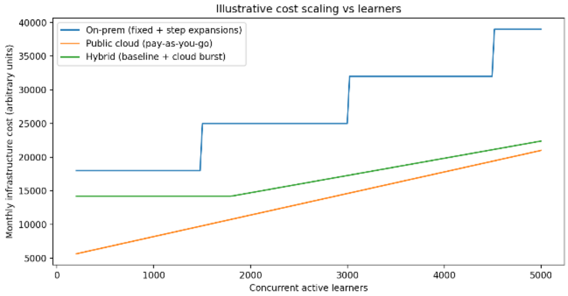
6.1. Interoperability Frameworks for Educational Data One challenge in the fulfillment of the Cloud Computing Solutions for Remote Education Infrastructure is the limited native interoperability between cloud applications. In response, various organizations, both governmental and non-profit, have introduced interoperability frameworks and standards designed to support educational needs.

LTI (Learning Tools Interoperability) is a specification maintained by the IMS Global Consortium that facilitates the integration of web-based learning applications with platforms like Virtual Learning Environments (VLEs) and Learning Management Systems (LMSs). Designed for integration within a hosting environment, LTI supports the exchange of data and services among VLEs/LMSs and links to third-party applications hosted elsewhere.

The IMS Global Quest and Test (QTI) specification enables the exchange of assessment items, item metadata, test metadata, results, and student submission data between learning and assessment entities. It supports interoperability between assessment authors and test takers, as well as assessment providers and their tool providers. QTI enables authors to create assessment items that adhere to a common definition and meta-data structure and can be stored in a source repository.



7. DEPLOYMENT SCENARIOS AND MIGRATION STRATEGIES

Remote education services based on a dedicated cloud computing architecture may be deployed as a hybrid, public, or multi-cloud model. The educational institution focuses on its primary services and uses its cloud environment to meet practical needs. A public-cloud-based service model is an alternative for institutions unprepared to set up their own ecosystem. Multi-cloud solutions avoid vendor lock-in, give greater flexibility, and provide failover capabilities. Dedicated tools and methodologies support the safe migration of legacy systems to cloud infrastructures.

In a hybrid setup, the educational institution deploys several core components within its own environment but offloads secondary functions (e.g. course hosting, learner protection, and identity management) to public clouds. This practical design allows places to mainly rely on customary appliances, preserving an infrastructure that they can openly control while taking advantage of an external service for non-critical—yet demanding—needs. As a result, an appropriate balance can be achieved between privacy and performance. Such approaches see wide acceptance and growth throughout other sectors.

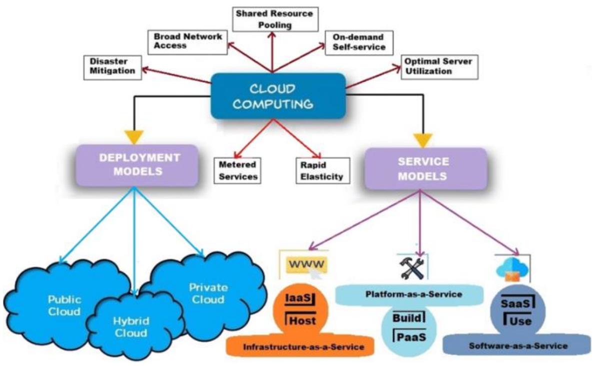


Fig 4: Cloud Computing Deployment and Service model

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7.1. Hybrid, Public, and Multi-Cloud Deployments Selecting an appropriate deployment model is a fundamental aspect of cloud computing. The three principal models are hybrid, public, and multi-cloud. The hybrid model combines public infrastructure with privately operated components connected by secured mechanisms. For example, government services typically incorporate credit card payment solutions offered as a public service. These public external services enable the government services community to attain a degree of maturity at a lower cost or a faster pace. In education, some services are perceived as being better offered privately to fulfill specific needs, while others are unique to a specific institution or country and attract a small number of users. Examples include aspects of the data centers involved in national computational initiatives that satisfy a wide diversity of needs, software management systems for educational institutions, or business intelligence platforms for educational institutions.

Education cloud services can also be offered as a public service. Such services attract users by providing a service free of charge or a more affordable option because the user and service provider agree to distribute the cost of the educational endeavor. An example is the Google services offering. The public cloud deployment in a service mix is frequently mentioned in the literature on Cloud Computing in education. Educational institutions are encouraged to consider the availability of appropriate institution-agnostic services that can safely and transparently integrate mobile and offline capabilities. Security risks might arise in safeguarding data privacy and information ownership when adopting the public cloud model in educational setups, but they are manageable.

8. CONCLUSION

Cloud Computing Solutions for Remote Education Infrastructure leave a legacy of trust in cloud computing-based tele-education, given the raging COVID-19 pandemic, which observed for the first time, the yeoman service provided by numerous commercial and open-source tele-education service providers. Cloud computing is emerging as a panacea for the conduct of remote education, especially in developing and underdeveloped countries. Relying on the principles of tele-education and cloud computing, a model for cloud-computing-based education for remote education to achieve administrative, academic, and IT Service Management for Institutions in a learning environment has been discussed. The deployment of organizational cloud in the education sector was deliberated. The role of Software as a Service in the form of learning management systems & three-tier service-oriented delivery capability of organization of membership-based Cloud computing institutions with SaaS learning management systems during a ready-to-use service application commenced: Learner, Teacher and Administration have helped institutions to bridge the gap effectively during the pandemic. Tele-Education is the technology not to conduct classes but to provide complete Remote Campus Environment in the cloud with resources for faculty and staff.

The variety of software packages integrated into cloud computing-based deployments forms a ready-to-use comprehensive remote campus service for Learning/Department/School inherent with SaaS application capability. The fear of violating data privacy of student and leakage into the dark web are negated with the data privacy framework. Portability of data within higher education under cloud computing helps assignment of foolproof facilities in the form of Cloud Ready Educational Deployment (CRED) in the Cloud Metropolitan area Network. The emergence of artificial intelligence, machine learning, and analytics embedded support help shape the policies for a hybrid model of Cloud computing supporting Virtual/Blended Learning and the TED community with an immaculate design of mobile Apps-Speech2TextCloud.

8.1. Emerging Trends The COVID-19 pandemic accelerated the adoption of technology for remote learning. Cloud computing technology plays a central role in meeting educational demands amid the ongoing uncertainty. Although many educational institutions look to maintain a cloud-enabled infrastructure to support hybrid learning in the future, the rapid transition to an online environment has presented considerable challenges. Unfortunately, many educational deployments are not sufficiently equipped to ensure a high-quality learning experience. Most system administrators lack cloud management experience, while understaffed departments face increased workload and demands on sparse financial resources. Yet, using cloud services enables educational institutions to fulfil needs efficiently and effectively.

Recent developments in the emerging cloud ecosystem for education highlight several areas of architectural design, quality, security, usability, compliance, interoperability, and migration. Over the longer term, a shift from on-premise provisioning to hybrid or multicloud operational models seems inevitable. Such systems provide a multitude of choices—systems can deliver applications as well as services, allowing environments that combine both on-premise and cloud resources. Data remains under institutional control through private facilities, while public and partner clouds satisfy requirements for near-sourcing provisioning. Institutions can also adopt a manageable multicloud strategy, using a tiered approach to address regulatory and compliance considerations.

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