SHAPING NEXT-GENERATION SMART CLASSROOMS FROM CORNELL STUDENT'S PERSPECTIVE

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Arts

by

Yudi Chen

August 2024

ABSTRACT

This thesis explores the concept of shaping the next generation of smart classrooms through the lens of student perspectives, aiming to bridge the gap between current educational environments and the evolving needs of learners. Drawing on a comprehensive dataset comprising online surveys, one-on-one interviews, and a review of existing literature, this study identifies key factors that influence student satisfaction and educational outcomes in contemporary learning spaces. The research underscores the significant role of technological integration, such as virtual reality (VR), artificial intelligence (AI), and advanced connectivity solutions, in crafting interactive and immersive educational experiences. Recommendations for future research include exploring the balance between technology and personal interaction, ensuring data privacy, and continuously updating spaces based on student feedback. Overall, this thesis offers insights and practical guidelines for educational institutions aiming to enhance student engagement and learning outcomes through innovative classroom designs.

BIOGRAPHICAL SKETCH

Yudi Chen is a forward-thinking designer specializing in interactive and innovative learning environments. Currently pursuing a Master of Arts in Design and Environment Analysis with a minor in Information Science at Cornell University, Yudi is deeply committed to enhancing the learning experience through cutting-edge design and technological integration.

Yudi's educational journey began at the School of Visual Arts in New York, where she gets a Bachelor of Fine Arts in Interior Design. This program provided a solid foundation preparing she for her future design innovation. Her professional experiences are equally impressive. In 2021, She interned at the Secretariat of China BIM Union in Beijing, where they contributed to a significant research project focusing on Building Information Modeling (BIM) applications for future community projects. Later that year, she served as a researcher for a village reconstruction project in Yuxi, Yunnan. This initiative aimed to promote symbiosis between humans and elephants, leading to a reconstruction design that won the Silver Award by the Chinese Creative Design Annual and earned the membership in the China Designers Association.

This thesis, "Shaping the Next Generation of Smart Classrooms from the Perspectives of Cornell Students," explores the integration of virtual reality (VR), augmented reality (AR), and artificial intelligence (AI) into educational environments. With innovative approach to design, informed by her extensive educational journey, positions them at the forefront of the movement to transform traditional classrooms into smart, adaptable learning environments that meet the evolving needs of students and educators alike.

ACKNOWLEDGMENTS

First and foremost, I extend my deepest gratitude to my advisor, Dr. Ying Hua, whose expertise, understanding, and patience significantly enhanced my graduate experience. Her generous commitment of time has been invaluable. I am also immensely grateful to committee member Dr. Saleh Kalantari, whose insightful comments and the classes he taught on Design Thinking and Ambient Environments inspired me to explore my research from novel academic perspectives.

My sincere thanks also go to the faculty and staff in the Department of Human Centered Design, who supported me throughout my thesis with their knowledge and wisdom. I am equally thankful to my classmates for creating a stimulating and enjoyable learning environment.

A special thanks to my family. Words cannot express how grateful I am to my mother and father for all the sacrifices they have made for me. Their support has been instrumental in my educational journey. I would also like to thank my two beloved dogs, Fu Bao and Cai Bao, who provided comfort and companionship during many late nights.

Lastly, I must acknowledge the contributions of the Cornell students who participated in my study. Without their cooperation, this research could not have been accomplished. I am profoundly thankful for their willingness to share their experiences and thoughts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

The genesis of this thesis lies in a simple, yet profound question: How can we design educational spaces that not only meet the technological standards of the future but also resonate with the needs and aspirations of students? The journey to answer this question began with observations and conversations in various educational environments, leading to a focus on smart classrooms—a concept that promises to redefine educational landscapes.

This research is grounded in the belief that effective learning environments are those shaped by their users at the core. Thus, this thesis emphasizes a student-centered approach to the design of smart classrooms. It seeks to understand the student perspective on what makes an educational space conducive to learning. Throughout the course of this study, I employed qualitative methodologies, including surveys and interviews, to gather insights directly from students. The data collected provided a rich foundation for developing recommendations that align with the actual needs and preferences of students.

The process of crafting this thesis has been both challenging and enlightening. It has stretched my capabilities as a researcher and deepened my understanding of design principles. I am grateful for the guidance received from my advisor and committee members, whose expertise steered this work towards its fruition. It is my hope that this thesis will contribute to the ongoing dialogue about educational innovation and serve as a useful resource for those aiming to design or retrofit classrooms that genuinely support student learning in this digital age.

1. Introduction

Our journey of education often begins in the classroom, which is a crucial space for fostering learning and growth. However, the field of education is on the cusp of a transformative era, propelled not only by rapid technological advancements but also by a profound shift in our perception and interaction with learning environments. Traditional classrooms, once the bedrock of educational systems, are evolving to meet the demands of the digital age. This evolution signifies a pivotal shift, aiming to better align with the needs and expectations of contemporary students.

As society becomes more technologically advanced, students are evolving along with it. Today's university students, known as "digital natives," are not passive recipients of knowledge like their predecessors. They are active learners who grew up in a connected world where information is instantly available, and learning can happen anytime, anywhere. This shift in the way students learn calls for a transformation in teaching methods and learning environments to engage them effectively, making education more interactive, accessible, and personalized. The goal of current educational trends is to adapt more adeptly to student needs, enriching learning experiences and expanding opportunities for the emerging generation (reference for the observation on the trends.). The future of education will be significantly different from its current form due to the advent of new technologies. Consequently, educational institutions—ranging from schools to universities—are at a pivotal point, charged with re-envisioning classroom design to meet the diverse needs of individual learners.

In the evolving landscape of higher education, the shift towards creating more interactive, technologically advanced learning environments represents a pivotal change in how educational content is delivered and experienced. The evolution of education requires more than just the addition of new tools. It necessitates a complete reimagination of the learning environment to align with the digital age and the directions of technology innovations and breakthroughs. While much focus has been placed on the technological and pedagogical aspects of these environments, there remains a critical gap: the perspectives of those at the heart of the educational process—the students.

As we delve into this exploration, it's crucial to acknowledge that the journey toward next-generation smart classrooms is a collective endeavor. The thesis "Shaping Next-Generation Smart Classrooms from Cornell Students' Perspective" aims to bridge the existing knowledge gap on smart classroom design from the viewpoint of its primary beneficiaries: the students. By gathering and analyzing student perspectives on future learning space trends and key features, this research is aiming at putting together a pre-design manual for future designers, educators, university leaders, and policymakers. While predicting the future with absolute certainty is impossible, periods without precedent are prime opportunities for innovation. In doing so, this thesis emphasizes the necessity of designing learning spaces that reflect emerging trends and technologies, ensuring they remain pertinent and effective in addressing the changing needs of students and supporting the desired learning experience and outcomes.

2. Literature Review

2.1 Introduction of Smart Classroom

The concept of the smart classroom has emerged as a transformative force in education, integrating advanced technology with innovative pedagogical strategies. An earlier definition given by Zhu and He (2012) is that “the essence of smarter education is to create intelligent environments by using smart technologies, so that smart pedagogies can be facilitated as to provide personalized learning services and empower learners to develop talents of wisdom that have better value orientation, higher thinking quality, and stronger conduct ability”. Smart classrooms are defined as technologically enhanced learning environments that utilize digital tools and resources to facilitate and improve teaching and learning experiences.

According to Dimitriadou and Lanitis (2023), these environments are designed to be interactive, flexible, and student-centered, offering personalized learning experiences through the integration of various technologies. Zhu, He, and de Pablos (2012) present the concept of smart education as an ecosystem that extends beyond the classroom to encompass a network of interconnected technologies and pedagogical practices. Smart classrooms are foundational to this vision, aiming to equip learners with the skills and knowledge required to navigate a technology-driven world. One of the key aspects highlighted is the role of digital technologies in creating equitable and flexible instructional resources and approaches. In smart learning environments, technologies such as digital cameras, recording equipment, interactive whiteboards, and mobile devices are ubiquitously available. Cheung et al (2021) think these resources ensure all students have access to diverse instructional materials, regardless of their background. Beetham and Sharpe (2019) emphasize the transformative potential of digital resources in creating interactive and engaging learning environments. Technologies such as interactive whiteboards, student response systems, and personal devices not only facilitate access to a vast array of online resources but also promote interactive learning experiences that can cater to diverse learning styles and needs. Barak (2016) provides a foundational perspective by integrating technology within the framework of social constructivism, suggesting that smart classrooms facilitate collaborative learning experiences that are vital for science education in the 21st century. This pedagogical approach emphasizes the importance of leveraging technology to support inquiry-based learning and critical thinking, essential components of the smart classroom concept.

Smart learning environments, sometimes used to refer to smart education. Demir (2021) noticed that smart education is not just about technology. It is also about new teaching and learning approaches. As Shoikova et al. (2018) elucidate, it symbolizes a paradigm shift in educational systems that transcends the mere integration of technology into classrooms. Smart learning environments emphasize the significance of active learning strategies, encouraging learners to engage directly with the material rather than passively absorbing information. These environments represent the effective and efficient integration of pedagogy and technology, aimed at enhancing the learning process.

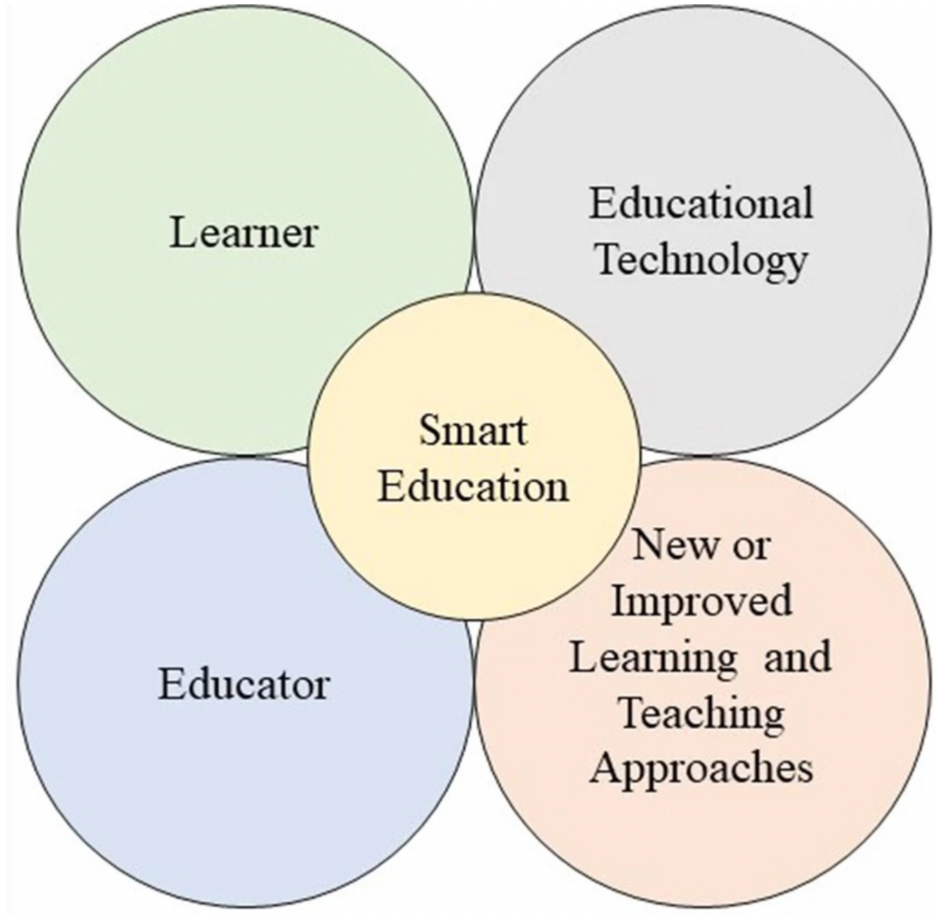

Figure 1: Smart education framework. Smart Learn. Environ. 8, 29 (2021).

Moreover, smart technologies facilitate student-centered instructional approaches, such as inquiry and collaborative learning, by allowing personalized learning plans and making learning activities accessible anytime and anywhere. This flexibility and accessibility contribute to creating a more inclusive and adaptable learning experience. Johnson and Liber (2008) introduce the concept of the Personal Learning Environment (PLE), arguing that smart classrooms should extend beyond physical spaces to include virtual platforms that allow students to control and personalize their learning experiences. Van Harmelen (2008) adds that PLE represents a significant shift towards learner-centered education, facilitated by Information and communication technology (ICT).

The PLE concept is central to the definition of smart classrooms, as it emphasizes the importance of integrating digital tools that support individual learning paths, preferences, and goals. The literature review on Personal Learning Environments (PLEs) emphasizes their crucial role in supporting lifelong learning across formal, informal, and non-formal settings. Studies by Yen et al. (2019), Bodily & Verbert, K. (2017), and Che Ku Nuraini & Shahbodin (2014) highlight PLE management as pivotal for integrating learning experiences and fostering digital literacy, underscoring PLEs not just as technical platforms but as pedagogical processes and social networks. These studies suggest that effective PLE management is key to integrating learning experiences across different platforms and enhancing digital literacy. Far from being mere technological solutions, PLEs are viewed as comprehensive pedagogical frameworks that weave together educational processes and social networking. Together, these works argue for PLEs as instrumental in adapting to the evolving educational landscape, promoting self-regulated learning and digital fluency.

2.2 Traditional Classrooms versus Smart Classrooms

The history of classrooms, dating back to 3,500 B.C. and ancient China, evolved significantly with the advent of modern classroom teaching in the late 16th century. This evolution saw three major periods: the multimedia period focusing on integrating computers and multimedia in classrooms, the network period which combined internet with classroom teaching allowing for dynamic teacher-student interactions, and the current smart classroom period, emerging in the 21st century with technologies like the Internet of Things, Cloud Computing, and Big Data, signifying a new trend in classroom design featuring smart technology applications and management (Song et al. 2014).

Rows of seats, instructor front and center, student eyes trained on the teacher, this classroom model worked well for centuries. Traditional classrooms focus on instructor-led teaching with minimal technology use, primarily relying on textbooks, chalkboards, and lectures. This educational model relies heavily on textbooks, chalkboards, and lectures to convey information, emphasizing a one-directional flow of knowledge from teacher to student. Since the introduction of the chalkboard to classrooms in 1890, a range of technologies including film strips, overhead projectors, desktop computers, interactive whiteboards, and mobile devices like smartphones and tablets have been progressively adopted. This evolution has shifted educational practices from the traditional "chalk and blackboard" approach to more modern "computer and projection" methodologies. Yang et al. (2018) mentioned that a multimedia console was anchored at the classroom's front, restricting instructional flexibility due to the teachers' focus on computer operation over physical interaction with students. Furthermore, standardized classroom arrangements favored traditional teaching methods, limiting the adoption of learner-centered approaches, despite (JISC 2009) studies suggesting alternative layouts like "X-shaped" or circular configurations could support such pedagogies. Additionally, the slides that teachers use in the classroom are usually full of text and devoid of graphics, tables, or multimedia materials. It is easy for students to take their attention away from slides that list what they are learning (Yang et al. 2012).

The phrase smart classroom had been used since 1995 in San Diego State University when they built the first smart classroom with the aim to enhance learning in a big classroom by integrating technologies, like clickers, sympodium, multichannel audio system, etc. (Yang et al. 2018). The classroom environment should be a new type of classroom that can optimize teaching content, facilitate access to learning resources, promote classroom interaction, and have the functions of situational awareness and environmental management - this type of classroom is called a smart classroom. The smart classroom is also a typical smart learning environment that has evolved from the traditional classroom (Yang et al. 2012). Smart classrooms, however, integrate advanced technologies like interactive whiteboards, student response systems, and digital content to facilitate interactive, personalized learning experiences. The standard smart classroom configuration is shown in Figure 2. It includes a multidimensional learning environment, level of integration, technology, innovation and change management.

According to Kaur's (2022) summary, a smart classroom includes a multidimensional learning environment, level of integration, technology, innovation and change management. It has smart whiteboards and projectors for displaying multimedia content, resources for students to easily communicate with peers and teachers, digital assessment tools, cameras for capturing and storing lectures, and smart sensor-enabled surroundings that monitor temperature, humidity, air quality and noise.

Smart classrooms support a variety of innovative teaching and learning methodologies that contrast with the more conventional, often teacher-centered approaches observed in traditional classrooms. The emphasis in smart classrooms is on active learning strategies, personalized learning, and collaborative projects that leverage technology to better engage students and accommodate diverse learning styles and needs.

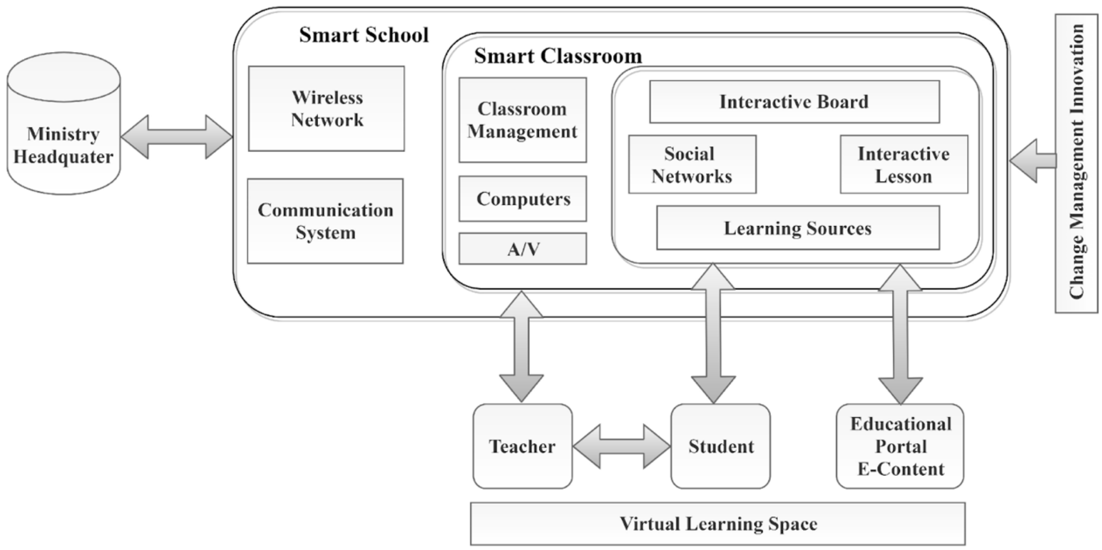

Figure 2: Smart Classroom framework. Kaur, Avneet, Munish Bhatia, and Giovanni Stea. 2022.

2.3 Smart Classrooms Teaching Methods

The evolution of the educational landscape started with Comenius's "classroom-based instruction method." As technology advanced, classrooms witnessed the integration of tech-driven learning, undergoing four significant transitions (Adu and Poo, 2014): a) electronic learning (e-learning), b) mobile learning (m-learning), c) ubiquitous learning (u-learning), and d) Smart Learning (s-learning). Peng & Spector (2019) proposed that smart devices and intelligent technologies are enabling a smart learning environment to effectively promote the development of personalized learning and adaptive learning. Utilizing technologies like the Internet of Things, cloud computing, and artificial intelligence, smart classrooms offer innovative solutions to traditional educational challenges. These technologies facilitate dynamic teaching methods, such as flipped classrooms and blended learning, allowing for real-time feedback, enhanced student engagement, and tailored learning experiences. So far, E-learning, blended learning and flipped classrooms are the three most common models.

2.3.1 E-Learning

E-learning utilizes digital platforms and resources to facilitate education accessible anywhere and anytime via the internet (Zhang et al., 2017). It includes formats such as online courses, virtual classrooms, and digital content that support interactive learning experiences beyond traditional settings. E-learning enhances the learning experience by incorporating multimedia elements and providing real-time feedback. This method offers the flexibility to learn at one's own pace, increasing accessibility for a broader audience. For instance, students can study at their preferred pace and access electronic materials for review at their convenience. It also allows access to a wide range of online resources, supports diverse learning paths, and promotes engagement through interactive content. Smart classrooms equipped with e-learning capabilities enable educators to customize lessons to meet individual needs, monitor progress through learning analytics, and foster collaborative learning environments. E-learning is revolutionizing higher education by leveraging the internet to create interactive, three-dimensional learning experiences, enhancing student-centered learning, and fostering independence. It allows for distance education, accommodates larger class sizes, and facilitates detailed tracking of student progress. Despite the benefits of face-to-face learning in promoting active engagement, the current generation of adolescents shows a preference for the adaptability and collaborative opportunities provided by online learning environments, which prepares them for a technology-driven future (Valdez et al., 2015). E-learning meets modern learners' needs by offering flexibility and incorporating technology they are accustomed to, thus significantly shaping future educational practices.

2.3.2 Flipped Classrooms

One of the simplest definitions of the flipped classroom is the one that comments what is usually done in class, at school, is now done at home and then, in class, the teacher completes it by helping students do what they would normally do at home (Buil-Fabregá et al., 2019). Flipped Classroom- Turning the regular classroom on its head, flipped classrooms reduce lecture time, provide hands-on experience, and help students become more prepared and motivated for learning (Jiang et al., 2022). In the traditional teacher-centered teaching approach, the development of necessary abilities and inspiring students by personalizing learning around their interests are disregarded (Baig & Yadegari 2023). By being outside the classroom, students are encouraged to actively learn new material by reading or watching recorded lectures. It requires students to retain and analyze the knowledge provided in class (Bachiller & Badía, 2020). Students are then asked to utilize what they have learned in class by completing group problem-solving exercises through peer instruction (Huang et al., 2023). This form of learning is more dynamic and student-centered than the traditional lecture method (Karjanto & Acelajado, 2022).

2.3.3 Blended Learning

People have gradually recognized that different learning styles require distinct solutions when using the Internet for educational purposes. Blended learning, an educational strategy that combines traditional face-to-face classroom instruction with online learning. By leveraging technology, blended learning can provide students with access to a wide range of resources and materials, enable them to learn at their own pace, and facilitate more interactive and engaging learning activities. This method enables students to learn at their own pace and facilitates more engaging and interactive learning activities. Initially prominent in corporate training, blended learning combined online and offline training to improve business outcomes and customer satisfaction, gaining attention from educators and researchers (Jokinen & Mikkonen, 2013; Tuncay & Uzunboylu, 2012). Blended learning forces us to consider the characteristics of digital technologies in general and information communication technologies (ICT) more specifically (Dziuban et al., 2018). Students can choose their own classmates, some in face-to-face environments and some in the cloud. Teaching and learning in the smart learning environment will be more flexible than the fixed time and fixed classroom in traditional teaching and learning (Hwang, 2014). Ubiquitous teaching and learning resources in smart learning environments enable students to engage in any learning activity, anytime, anywhere and in their preferred learning style. This approach supports the notion that learning doesn't have to be confined to a traditional classroom setting and can occur anywhere, at any time, provided there is internet access.

2.4 Technology Development Trend

The literature on smart classroom technology trends highlights an evolving landscape where emerging technologies such as artificial intelligence (AI), the Internet of Things (IoT), machine learning, and advanced analytics are making significant impacts. These technologies are transforming traditional educational settings into dynamic, interactive, and personalized learning environments. Additionally, the metaverse, increasingly popular due to advancements in virtual and augmented reality, leverages VR, AR, and blockchain to create immersive, multisensory experiences that enable physical interactions and complex dynamics with virtual objects. In education, the metaverse offers a virtual space where learners can interact socially and educationally, potentially transforming learning methodologies. This revolutionary approach in educational settings promises to make learning more dynamic and accessible, transcending traditional educational barriers.

2.4.1 Virtual Reality (VR)

Smart classrooms increasingly use virtual, augmented, and mixed reality technologies to foster immersive learning environments. Virtual Reality (VR) immerses users in a 3D simulated environment, either imaginary or realistic, that they can explore and interact with (Górski et al., 2016). Virtual Reality (VR) enhances smart classrooms by providing immersive and semi-immersive experiences that significantly enrich learning environments. Sobota et al. (2017) discuss two main VR technologies: CAVE

(Cave Automatic Virtual Environment) and HMDs (Head-Mounted Displays). CAVE systems create a room-sized immersive area with projection walls that users can physically interact with, allowing them to move freely and engage directly with the virtual content. In contrast, HMDs offer individual immersive experiences through personal headsets, making VR accessible on a personal level. To further enhance these experiences, additional VR accessories such as gloves, suits, and controllers can be used with both CAVE systems and HMDs.

2.4.2 Augmented Reality (AR)

Augmented Reality (AR) superimposes digital information onto the physical world, enabling students to engage with both real and virtual elements dynamically (Billinghurst et al., 2015). Dimitriadou and Lanitis (2023) indicate that various types of augmented display devices are used in smart classrooms, including tablets, smartphones, and smartboards. These devices support software that creates augmented scenarios, such as Aurasma, Layar, Augment, and Aumentaty, enhancing the interactive learning environment.

2.4.3 Mix Reality (MR)

Mixed Reality (MR) combines real and virtual elements together within a single display, creating a seamless integration of both worlds. MR worlds achieve high levels of immersion through Head Mounted Displays (HDMs), such as Microsoft HoloLens, HTC Vive, Oculus Rift and Magic Leap One, or AjnaLens (Dimitriadou &Lanitis, 2023). Some examples of Mixed Reality in Smart Classrooms, like allowing students to interact with 3D models of anatomical structures, enhancing their understanding beyond traditional textbook images. Historical lessons come alive as students explore ancient civilizations through immersive experiences. MR also enables safe interaction with virtual simulations of dangerous or expensive science experiments. Additionally, it allows students to virtually traverse global environments like rainforests or polar regions, enriching their geographical and environmental knowledge. These technologies collectively expand the traditional learning space into an interactive, digitally enhanced experience.

2.4.4 Artificial Intelligence (AI)

AI is expected to profoundly impact learning environments through customization, efficiency, and interactivity. Acquisition of multi-source, heterogeneous, and multi-modal big data (e.g., hands raised, facial expressions, body postures, and discussions related to students' learning process can be collected) through artificial intelligence technologies in smart learning environments, such as the Internet of Things (IoT), perceptual technologies, video-recording technologies, image-recognition technologies, and platform-acquisition technologies (Beer, 2019; Chatterjee et al, 2019; Kwet & Prinsloo, 2020). AI will personalize learning experiences by adapting content to meet individual student needs and learning styles, enhancing understanding and retention. It will automate administrative tasks such as grading and attendance, freeing teachers to focus more on teaching than on paperwork. Furthermore, AI will facilitate real-time feedback, allowing students to understand their mistakes and learn from them immediately, making learning more dynamic and continuous. Extracting value from stored data and making predictions from observed patterns for decision making in smart education. AI-driven tools and platforms will provide teachers with detailed analytics on student performance, enabling targeted interventions and fostering a more supportive, effective educational environment.

2.4.5 Internet of Things (IoT)

The Internet of Educational Things (IoEdT) is a sophisticated network integrating both computational and non-computational educational objects through sensors, RFID technology, and the Internet, enhancing various higher education domains including teaching, research, administration, and campus services (Díaz-Parra, et al., 2022). This interconnectivity is exemplified in smart classrooms where the Internet of Things (IoT) significantly elevates the learning environment through wireless communications, personal digital devices, sensors, and a virtual learning platform. It integrates various smart devices and sensors that collaborate to improve classroom management, energy efficiency, and learning experiences. For instance, IoT can adjust lighting and temperature automatically, track attendance through smart IDs, and even monitor and analyze student engagement levels through connected desks and wearables. IoT devices automatically adjust lighting, temperature, and air quality based on the number of students present or the time of day. This not only ensures optimal learning conditions but also conserves energy. This interconnected ecosystem not only optimizes the physical space for comfort and efficiency but also tailors the educational content to individual student needs, fostering a more interactive and adaptive learning environment.

2.4.6 Machine Learning (Robots)

The integration of robots into smart classrooms represents a major leap forward in educational technology, promising to make learning more effective, personalized, and accessible. Chatbots in smart classrooms utilize instant messaging to interact with students, effectively managing large classes and providing real-time assistance with queries and problem-solving, thereby enhancing classroom efficiency. They are particularly valuable for remote education, offering personalized support and educational content, which significantly enriches the learning experience (Colace et al., 2018). Furthermore, chatbots serve as virtual tutors throughout the learning process, demonstrating their potential in educational innovation (Chocarro et al., 2021). Robots will assist in providing guidance and personalized tutoring sessions based on individual student needs. They can manage large classrooms and provide students with real-time help in answering questions and solving problems, thus increasing classroom efficiency. Robots can familiarize themselves with the individual needs of each student and respond accordingly (Jones & Castellano, 2018). Another important feature of the robot is its ability to record students' expressions and emotional changes. Not only will the robot be able to assist students during class, but it will also be able to assess their behavior ahead of time as well as any mood swings that may suggest despair or stress (Werner-Seidler, 2017). Beyond teaching, robots will automate administrative tasks such as tracking attendance and grading assignments. This automation will free up teachers' time, allowing them to focus more on pedagogy and less on paperwork.

2.5 Impact of Smart Classroom of Learning Experiences

The introduction of smart classrooms has transformed traditional learning environments by incorporating advanced technology to significantly improve the educational experience. This integration has made a considerable impact on student learning across multiple aspects. Smart classrooms enrich the learning environment with technologies that support innovative teaching methods and increase student engagement, understanding, and interaction. The interactive nature of these classrooms allows students to participate actively in their learning processes, which helps deepen their understanding of the material and retain information more effectively.

2.5.1 Enhancing Student Engagement

Smart classrooms significantly impact student engagement. Martyn (2007) discusses the use of "clickers," which help maintain student attention and foster a two-way communication channel between students and teachers. Al-Zahrani (2015) extends this by highlighting the role of social learning platforms, which support creative thinking and collaborative learning by allowing students to interact, discuss, and problem solve together in real-time. This technological empowerment leads to higher levels of student engagement and a more inclusive learning environment (Christensen et al., 2008).

2.5.2 Collaborative Learning

The ability to share and edit documents in real-time, as facilitated by smart classroom technologies, encourages a collaborative learning environment. Eguchi (2016) supports this claim by noting that educational robotics, a common tool in smart classrooms, promotes essential 21st-century skills including teamwork and problem-solving. This collaborative approach is reinforced by Zhu, Valcke, and Schellens (2009), who highlight that online collaborative learning environments are conducive to improving multicultural relations among students, thereby preparing them for a globalized world.

2.5.3 Personalized Learning Environment

Smart classrooms support personalized learning where technology such as AI-driven analytics is used to tailor education to individual student's learning speeds, styles, and preferences. Adaptive learning technologies can analyze student data to customize lessons and exercises to fit the needs of each student, thus improving the efficacy of learning significantly (Hwang & Chang, 2011).

2.5.4 Remote Learning Capabilities

With high-speed internet and cloud-based applications, smart classrooms offer the flexibility of remote learning, which is crucial for providing continuous education during emergencies like the COVID-19 pandemic (Bao, 2020). Furthermore, smart technologies connect students with peers and experts around the world, offering global perspectives and networking opportunities that enrich the learning experience (Rosen & Beck-Hill, 2012). Students can participate in virtual exchanges, collaborate on international projects, and attend guest lectures from overseas experts, all from their classrooms or homes. This exposure not only enhances cultural understanding but also helps students develop a global network, which can be invaluable in their future professional lives.

2.5.5 Going Forward

According to (Díaz-Parra et al., 2022), we can summarize the tendency of technology development：

Smart Learning: Educational technology (PowerPoint Presentation), Learning Management System LMS Platform (model, blackboard), Chat Room, E-Mail, Internet Connection, Multimedia Technology, Online Activity (online teaching, online discussion, online information searching), Video Conference

Smart Classroom: Students face recognition, a digital archive of courses, Instant messages to teachers, voice recognition, virtual reality learning, Class activity database, interactive whiteboard system, Automatic learning assessment systems, Virtual classroom, Distance education, Mobile Learning

Smart Campus: The smart campus is the educational institutions or universities that use technology to manage transport, waste, water, electricity, maintenance facilities, gardens and parks, even, the mobility of people and the parking of cars, the management integral of activities of the campus, and thus find the sustainability and efficiency of the university or educational institution. Management of the Education Physical infrastructure is the planning, organization, direction and control of the material and technological resources (windows or air conditioning, intelligent energy management of classrooms and offices, physical security and the perimeter of the facilities security, detection of earthquakes, fires, and humidity, management of visitors to the University campus, optimisation of the use of water through intelligent irrigation of gardens and green areas and the control systems of the water consumption in buildings) of educational institutions.

Despite these benefits, the integration of smart classrooms comes with challenges. Technical issues, such as hardware malfunctions and software glitches, can disrupt learning (Hew & Brush, 2006). For example, a malfunctioning interactive whiteboard can halt a lesson entirely, requiring time-consuming troubleshooting that disrupts the educational flow. Additionally, the high cost of setting up and maintaining smart classroom technologies can be a significant barrier for many institutions (Gabriel & Kaufield, 2008). There is also the concern of digital distraction, where the availability of multiple digital tools might lead students to lose focus.

3. Research Question

In the exploration detailed within "Shaping Next-Generation Smart Classrooms from Student's Perspective," a profound emphasis is placed on understanding and incorporating student perspectives. The emphasis on student perspectives is driven by the understanding that the effectiveness of learning is profoundly shaped by the environment in which it occurs. There is a consensus that educational spaces, when aligned with students' learning preferences, are instrumental in maximizing engagement and facilitating an effective learning experience. In the realm of contemporary education, smart classrooms emerge as avant-garde spaces endowed with technological flexibility and adaptability. These environments offer great potential to customize learning experiences to meet individual needs, which can significantly improve student engagement and understanding. However, without a clear understanding of what students want, there's a risk that these spaces may not live up to their potential.

A noticeable gap in understanding student preferences presents a challenge that could potentially hinder the transformative potential of smart classrooms. To navigate this challenge and bridge the gap, the central research question was formulated: "What aspects of smart classrooms do students value most for supporting their learning experiences and outcomes, guiding the design of future educational spaces?" This question is pivotal as it serves a dual purpose: firstly, to assess the current efficacy of smart classrooms by identifying the features and components students find most beneficial for their learning, and secondly, to look forward, aiming to gather insights into students' visions and expectations for the evolution of learning environments.

Q1: "Which features of current smart classrooms do students find most beneficial in supporting their learning experiences and outcomes?"

This question aims to explore and identify the specific aspects of today's smart classrooms that students perceive as most valuable for their learning. It focuses on understanding the effectiveness of current educational technologies and configurations.

Q2: "What are students' visions for the future of learning environments at Cornell?"

This question seeks to gather student insights and predictions about the evolution of learning environments. It aims to understand students' expectations and aspirations for future educational technologies and space designs, guiding the development of innovative and responsive educational settings.

The primary objective of this thesis is to explore and articulate the specific preferences and needs of students regard to smart classroom design. The aspiration is to unravel the attributes that render smart classrooms genuinely efficacious from the students' vantage point, thereby ensuring that the evolution of educational spaces is both underpinned by empirical evidence and profoundly student centric.

Key areas of investigation include:

- Investigating the types of technology and digital tools that enhance learning from the student perspective.
- Understanding the physical and environmental attributes of learning spaces that contribute to student engagement and satisfaction.

- Identifying the challenges and limitations students face in current learning environments and how they envision the future of smart classrooms.

Furthermore, the significance of Student-Centered Design is highlighted as paramount. The need for student-centered design in smart classrooms is emphasized, highlighting participatory design approaches that involve students in creating their learning spaces. This ensures the final designs are not only functional but also directly relevant to their users. The paper 'Shaping Next-Generation Smart Classrooms from Students' Perspective' aims to guide the development of educational spaces towards being more evidence-based and focused on students. By investigating what students truly value in their learning environments, this research aims to contribute to the field of educational design, ensuring that smart classrooms are developed based on solid evidence and centered around student needs. This approach not only prioritizes student preferences but also aids in designing future educational spaces that truly enhance learning experiences, ensuring smart classroom technologies achieve their intended impact.

4. Methodology

4.1 Research Design

This thesis, "Shaping Next-Generation Smart Classrooms from Cornell Students' Perspective," adopts a mixed-methods research design to comprehensively understand student perceptions, preferences, and expectations regarding smart classrooms. This approach combines quantitative data from online surveys with qualitative insights from one-on-one interviews, ensuring a robust analysis of students' views on current and future learning environments.

4.2 Participant Selection and Recruitment

Recognizing the diversity within Cornell University's student body, the study aims to include voices from a broad spectrum of academic disciplines and backgrounds. The study targets both undergraduate and graduate students enrolled in the College of Architecture, Art, and Planning, the College of Arts & Sciences, the College of Engineering, the College of Human Ecology, the Cornell SC Johnson College of Business at Cornell University. This sample ensures that a wide range of academic disciplines is represented, from the sciences and engineering to the humanities and arts. The goal is to capture varied perspectives on learning environments that reflect the multi-disciplinary nature of the university. The recruitment strategy is designed to be inclusive and accessible, employing multiple channels to reach potential participants:

- Random Offline Recruitment: Conducted within common lounge areas of selected colleges to engage a broad spectrum of students across different majors and age groups.
- Online Recruitment: Utilizes social media platforms and student forums to widen the recruitment net, reaching students who may not be as easily accessible through offline methods.
- Campus Posters: Strategically placed in high-traffic areas like libraries, cafeterias, and academic buildings, these posters detail participation instructions, study objectives, and contact information, alongside a QR code for easy access to the study's sign-up page.

4.3 Stratified Random Sampling

To ensure the study encompasses a broad spectrum of academic disciplines and experiences, a stratified random sampling technique will be employed. Cornell University's student body will be divided into strata based on the seven colleges, with the aim to include participants from four to five of these colleges. 12-15 students will be recruited within each of the selected colleges, totaling a sample of 60, which will be further stratified based on the following factors:

- Major/Department: This ensures representation across different fields of study, from the humanities and social sciences to engineering and natural sciences.

- Year of Study: Including students from various stages of their academic journey, from freshmen to seniors, and including graduate students, allows for insights into how needs and preferences might evolve over time.
- Course Type: Students will be grouped based on the type of courses they are currently enrolled in—lecture-based, studio-based, or laboratory-based—to understand how different learning environments impact their experiences and preferences.

This stratification ensures that the sample reflects the university's diversity student body and learning needs, capturing a wide range of insights into smart classroom design preferences.

4.4 Ethical and Practical Considerations

Throughout the recruitment and sampling process, ethical considerations will be of utmost importance. Participants will be informed of their rights, including privacy, confidentiality, and the voluntary nature of their participation. Efforts will be made to minimize any potential inconvenience to participants, and incentives will be provided as a token of appreciation for their valuable contributions.

4.5 Data Collection Methods

Before participation, students will be briefed on the study's purpose, their involvement, and their rights, including privacy and data protection measures. Consent will be explicitly obtained for collecting data on their major, age, and current course types. This project has undergone an IRB review and has been granted an exemption, signifying that it meets ethical standards and potentially poses minimal risk to participants.

Participants will then complete a detailed online survey, tailored to the type of course they are enrolled in—whether lecture-based, studio-based, or laboratory-based. This design ensures that the survey is relevant and sensitive to the diverse educational contexts of the participants.

Additionally, interested participants can opt for in-depth interviews to further discuss their visions for future learning environments on the Cornell campus. These interviews, like the survey, will adhere to the ethical guidelines approved by the IRB, reinforcing our commitment to ethical research practices and the protection of participant rights.

4.6 Quantitative Component

The quantitative aspect of this thesis relies on a comprehensive online survey designed to capture a wide range of student responses regarding their current experiences and future expectations of smart classrooms. The survey is distributed widely across the student population, aiming for a representative sample that includes diverse majors, age groups, and a type of course.

Likert-scale questions are employed to gauge students' levels of agreement or satisfaction with various aspects of their current learning environments, such as the adequacy of technological tools, the comfort and adaptability of physical spaces, and the effectiveness of learning methodologies. Multiple-choice Questions (MCQs) are utilized to collect demographic information and specific preferences, allowing for the segmentation of data according to variables such as major, year of study, and type of courses enrolled. MCQs help in identifying patterns in students' technology usage and preferences for different classroom configurations. To understand priorities among the student body, ranking scales are included to determine which features of smart classrooms (e.g., interactive whiteboards, VR/AR technologies, flexible seating arrangements) students value most. Statistical analysis tools will be employed to analyze the data, identifying prevalent trends, correlations, and potential disparities in student responses.

Based on questionnaires from these articles (Akhrif et al. 2020, Dai et al.2023, Huang et al. 2015, Wuet et al. 2021, Yu et al. 2022), My survey is divided into several sections, each designed to explore different aspects of student interaction with their learning environment:

4.6.1 Demographic Information

Major: Identifies the academic discipline of the respondent, providing insights into department-specific needs.

Year: Determines the respondent's academic standing to assess how needs may vary across different stages of university education.

Course Type: Asks respondents to choose the type of course (lecture-based, studio-based, laboratory-based) for which they are answering the survey, tailoring subsequent questions to that context.

4.6.2 Current Learning Space Satisfaction

Overall Satisfaction: Rates satisfaction with current learning spaces on a 1-5 scale.

Seating Arrangement Satisfaction: Assesses comfort and support for extended study periods.

Layout Adaptability: Evaluates how well spaces accommodate various learning activities.

Technology Support: Gauges satisfaction with available technology for study needs.

Workspace Sufficiency: Measures adequacy of space for resources.

Personal Device Connectivity: Examines ease of integrating personal devices with classroom tech infrastructure.

Challenges and Limitations: An open-ended question to identify other issues not previously covered.

4.6.3 Smart Classroom Features Preferences

Participants are asked to select the five features they deem most crucial in a smart classroom from a list that includes: Reliable wireless connectivity/User-friendly new learning devices and software/Device and software compatibility across various systems/Hybrid instruction support/Interactive simulation and visualization technologies/Engaging learning devices (gesture-based inputs)/ Automated administrative tasks (check-in, grouping, resource distribution)/Ergonomic, adaptable furniture/Easily controlled environmental settings.

The quantitative component is designed to provide empirical evidence on:

- Current levels of student satisfaction with learning environments at Cornell.
- Specific features students prioritize for future smart classrooms.
- Potential areas of improvement in current classrooms based on student feedback.

This data will not only enrich the understanding of student needs but also guide the development of recommendations for designing next-generation smart classrooms that align with student preferences and enhance the learning experience.

4.7 Qualitative Component

The qualitative component of this thesis, centers around gaining in-depth insights into students' visions for the future of educational environments. Complementing the survey, the qualitative aspect of the research involves conducting semi-structured one-on-one interviews with a selected subset of participants. During the interview, they will be encouraged to discuss the topic: 'What do you envision the learning experience on the Cornell campus will be like in ten years?' The interviews are guided by a series of open-ended questions designed to elicit detailed responses and facilitate a deep exploration of students' perspectives on and expectations for smart classroom design. These areas include envisioned technologies and features, personal learning styles, engagement and interaction, and student-centered learning environments.

Additionally, it creates an opportunity for open-ended feedback, allowing students to share any additional thoughts on the evolution of learning spaces at Cornell University. The interviews are designed to provide students the opportunity to share in-depth personal experiences, reflections, and visions for the future of learning environments. The aim is to capture the richness and diversity of student perspectives and delve into the reasons behind their preferences and expectations.

4.7.1 Interview Question and Objectives

- Envisioned Features or Technologies: This question seeks to understand what innovations students anticipate or desire in the learning environments of the future. It aims to identify specific technologies or design features that students believe will play a crucial role in enhancing educational experiences.

- Personal Learning Styles and Recommended Changes: By asking students to reflect on their own learning styles, this question aims to gather personalized recommendations for adapting classroom designs to support diverse ways of learning. This insight is critical for creating spaces that are flexible and accommodating to individual needs.

- Enhancing Engagement and Interactive Learning: This question explores students' ideas on how future classrooms can foster greater engagement and support interactive learning methods. Responses will highlight students' preferences for collaborative and experiential learning activities facilitated by smart classroom technologies.

- Student-Centered Learning Environment Suggestions: Through this inquiry, the research aims to uncover students' concepts of a student-centered learning environment and gather suggestions for achieving such a setting. This includes understanding the roles of autonomy, technology, and space design in empowering students to take charge of their learning.

- Concerns About Transitioning: Recognizing that change can elicit apprehension, this question addresses any concerns students might have regarding the shift towards futuristic classrooms. Understanding these concerns is essential for addressing potential barriers to the successful implementation of smart classroom designs.

- Open-ended Feedback: Finally, this section provides students with the freedom to share additional comments or suggestions, offering a space for reflections or ideas that may not have been covered by the previous questions. This feedback can reveal new insights and considerations for the evolution of learning spaces at Cornell.

Interviews will be conducted in settings that ensure privacy and comfort, encouraging candid and thoughtful responses. Each interview will be recorded with consent, transcribed verbatim. The insights gained from this qualitative component will complement the quantitative survey data, providing a comprehensive understanding of student perspectives on the future of smart classrooms. This integrated approach ensures that the development of next generation learning environments is grounded in the real needs and aspirations of students, paving the way for more effective, engaging, and student-centered educational experiences.

In conclusion, the methodology for "Shaping Next-Generation Smart Classrooms from Students' Perspective" is thoughtfully crafted to explore the complex landscape of educational environments from the lens of those it aims to serve— the students. The integration of quantitative data from online surveys with qualitative insights from semi-structured interviews provides a robust framework for analysis. Quantitative analysis will identify prevalent trends and correlations, while qualitative analysis will delve into the reasons behind these trends and uncover the deeper meanings and contexts of student responses. By centering student voices in the conversation about the future of learning spaces, this study aims to provide actionable insights that can guide the design and implementation of smart classrooms.

5. Result

The survey titled 'Envisioning the Classroom of the Future' garnered 115 responses from students across different disciplines and academic years. In addition, in-depth interviews were conducted with 30 of these students. The respondents were enrolled in different types of courses, providing a broad perspective on the learning environment needs from across the academic spectrum. The survey data provides a valuable snapshot of current student satisfaction with learning environments and their aspirations for future smart classrooms. The diverse academic standings of the respondents help underline the different expectations and requirements that students at various stages of their educational journey might have regarding the integration of technology and design in learning spaces.

5.1 Key Demographic Insights

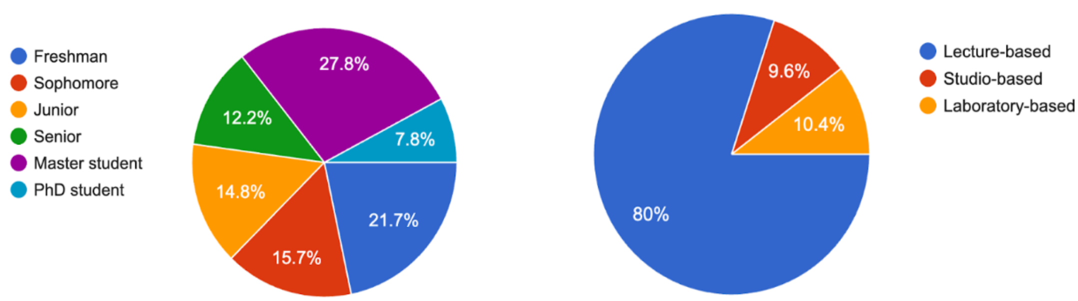

Table 1: Distribution of the number of respondents by year of study and type of course

A total of 115 students from 5 different colleges, The College of Architecture, Art, and Planning, The College of Arts & Sciences, The College of Engineering, The College of Human Ecology, The Cornell SC Johnson College of Business, participated in the online survey. The most common majors included Economics, Computer Science, and Design and Environmental Analysis, each reflecting distinct academic interests and potentially varying needs for smart classroom features. Graduate students (Master and PhD) constituted the largest group of respondents, with Master students alone making up approximately 27.83% of responses, indicating significant interest and perhaps a greater perceived impact of smart classroom features at higher levels of study. Undergraduates (from Freshman to Senior) collectively contributed to over 64% of the responses, with Freshmen being the most represented undergraduate class at 21.74%. The majority of responses (80%) came from students in lecture-based courses, suggesting that students from these courses are either more numerous or possibly more impacted by the current and future state of classroom environments. Laboratory-based and studio-based courses were also represented, at 10.43% and 9.57% respectively.

5.2 Student Satisfaction with Current Learning Space

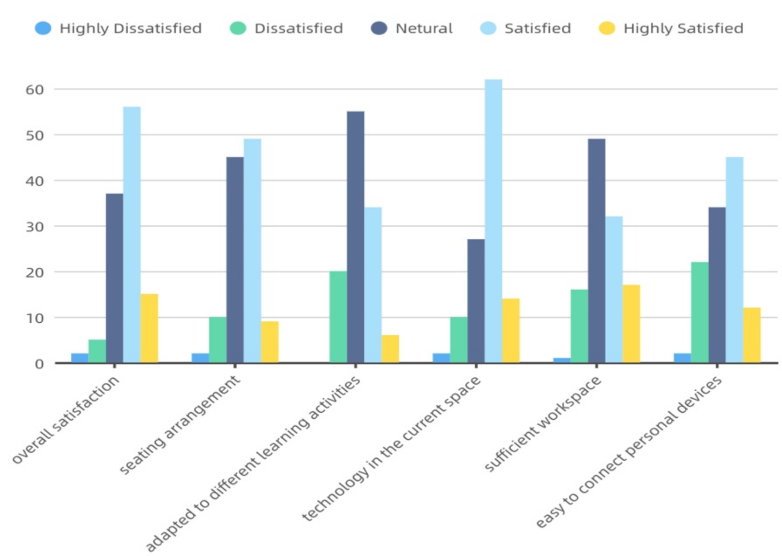

Table 2 : From the survey related to satisfaction rates with the current learning spaces at Cornell.

A significant majority (71 responses, approx. 62%) rated their satisfaction at levels 4 and 5, highlighting a generally favorable perception of the learning spaces. This implies that the fundamental aspects of the current learning environments—space, basic amenities, and accessibility—are meeting the expectations of most students. The neutrality (37 responses, approx. 32%) suggests that while the spaces are adequately serving their purpose, there might be lingering issues that stop short of causing dissatisfaction but prevent a higher satisfaction rating. The highest satisfaction seems to be with the technology available in learning spaces, particularly noting a higher number of "Satisfied" responses. Device connectivity and Seating support have a higher number of dissatisfied responses, indicating potential areas for improvement in smart classrooms.

5.2.1 Current Challenges

Students have expressed various challenges and limitations they encounter in their current classroom spaces. These issues range from physical infrastructure inadequacies to technological shortcomings, impacting their overall learning experience.

Space and Layout Concerns:

- Cramped and Inflexible Seating: Many students find the seating arrangements cramped and uncomfortable, particularly in lecture halls where narrow rows make it difficult to enter or leave once seated.

- Insufficient Desk Space: The small size of desks, particularly armrest tables in lecture halls, hampers the ability to take notes comfortably and keeps the space from being used effectively for group work or using multiple devices.
- Limited or Inflexible Work Areas: Specific complaints include the lack of backrests on chairs in labs, tables being too low or too small, and generally uncomfortable chairs that are not conducive to long periods of sitting.

Technological Limitations:

- Poor Connectivity Options: A frequent concern is the scarcity of power outlets for charging devices, alongside inconsistent Wi-Fi which can hinder the use of electronic learning tools.
- Inadequate Integration with Personal Devices: Students also noted difficulties in connecting personal devices to classroom technologies, due to either a lack of necessary adapters or incompatible infrastructure.
- Visibility and Auditory Issues: Complaints about dim projector screens, obstructed views of blackboards or screens, and inadequate audio in large classrooms suggest that visual and sound technologies need enhancement to be effective.

Environmental Factors:

- Lighting and Temperature Control Issues: Classrooms are often either too cold or poorly lit, which not only affects comfort but also strains eyesight during lectures.

- Noise Distractions: Noise from HVAC systems, other students, or external sources frequently disrupts concentration, which is compounded in open floor plans like those in Milstein Hall.

Accessibility and Privacy Concerns:

- Limited Private Spaces: Students noted a lack of private spaces for taking calls, participating in online interviews, or engaging in quiet study, which are essential for accommodating diverse learning and communication needs.
- Constrained Resource Availability: There's a call for more IT appliances like chargers and adapters, suggesting that the provision of these resources is currently below the requirements of the student body.

Other Issues:

- Many students reported physical discomfort from using the furniture provided, which could lead to long-term health issues if not addressed. And there is an inadequate provision of spaces designed for group work or meetings, which limits students' ability to collaborate effectively on projects.

5.3 Desired Features for Smart Classrooms

In the survey, students were asked to pick the five most important features that define a smart classroom for them. Here's a detailed breakdown of the features that were most frequently mentioned, illustrating the key preferences and priorities of the students regarding the development of smart classroom environments.

Feature	Mentions
Adjustable (height) desks and chairs	89
Lightweight and freely combinable desks and chairs	89
Comfortable seating options	89
Provides reliable wireless connectivity	82
Easily adjustable lights, air-conditioning, and ventilation	81
Supports face-to-face and virtual instruction modes	72
Interactive learning tools (smart boards, touch screens)	72
Encourages collaboration (movable walls, modular spaces)	52
Infrastructure supports students with disabilities	50
New and engaging learning devices and software	45
Real-time access to digital content	44
Modular components for various activities	44

Table 3 : Ranking of future smart classroom features valued by students.

The data clearly shows a strong preference for classrooms that are technologically advanced, ergonomically designed, and adaptable to a variety of learning styles and needs. The emphasis on reliable connectivity and versatile, comfortable furniture indicates that students value a learning environment that promotes both digital integration and physical comfort.

5.4 Hypothesis Statement for Results

To assess the impact of seating arrangements on student satisfaction within different classroom settings, we conducted a two-sample t-test comparing satisfaction levels in Lecture settings versus Studio and Lab settings.

Null Hypothesis (H_0): There is no difference in student satisfaction with seating arrangements between Lecture settings and Studio/Lab settings.

Alternative Hypothesis (H_1): Student satisfaction with seating arrangements in Lecture settings is significantly lower than in Studio and Lab settings.

Group	Group 1	Group 2
Mean	3.55	4.18
SD	0.76	0.75
SEM	0.17	0.23
N	20	11

Table 4 : Two Sample T-Tests Results

Statistical Significance: The two-tailed P value is 0.0340, which is below the alpha level of 0.05, indicating statistically significant differences. Therefore, the null hypothesis is rejected in favor of the alternative hypothesis.

Confidence Interval: The 95% confidence interval for the mean difference in satisfaction scores between Lecture (Group One) and Studio and Lab (Group Two) is from -1.21 to -0.05. This interval excludes zero, further confirming that the mean satisfaction is significantly lower in Studio and Lab settings compared to Lecture settings.

Mean Difference: The mean satisfaction score for Studio and Lab settings (3.55 ± 0.17 SEM) is lower than that for Lecture settings (4.18 ± 0.23 SEM), with a mean difference of -0.63 points on the satisfaction scale. This significant difference substantiates the complaints from students regarding the Studio and Lab classroom experience.

5.5 One-on-One Interviews

Based on the extensive responses provided by the students about their visions for the future learning experiences at Cornell, I've extracted and analyzed the most frequently occurring relevant keywords to highlight common themes and technological expectations.

5.5.1 Top Keywords and Their Occurrences

Key Words	Mentions
Virtual Reality (VR) / Augmented Reality (AR)	24
AI (Artificial Intelligence)	19
Interactive / Interactivity	15
Hybrid Learning	13
Customization / Personalization	12
Technology-Enhanced	11
Smart Classroom	9
Ergonomics	8
Connectivity	6
Engagement	6

Table 5 : Ten high-frequency word occurrence statistics

- Virtual Reality (VR) / Augmented Reality (AR): Includes terms related to immersive technology such as "holographic," "3D environments," and specific mentions of "VR" and "AR."

- AI (Artificial Intelligence): Encompasses AI personal assistants, AI integration in classrooms, AI tutors, and AI for administrative tasks.
- Interactive / Interactivity: Refers to interactive projectors, smart boards(touch screen), and technology-enhanced interactivity within the classroom.
- Hybrid Learning: Combines online and in-person learning modalities, emphasizing flexibility and student choice in attendance.
- Customization / Personalization: Customizable learning experiences tailored to individual student needs, including adjustable classroom environments and personalized learning paths.
- Technology-Enhanced: General references to classrooms enhanced with modern technology to facilitate better learning experiences.
- Smart Classroom: Classrooms equipped with integrated technologies that support a wide array of functionalities to boost learning efficiency and engagement.
- Ergonomics: Comfortable, adjustable furniture designed to improve posture and reduce physical strain during long periods of study.
- Connectivity: High-speed internet, reliable Wi-Fi, and seamless connectivity as crucial features for modern learning environments.
- Engagement: Methods and tools suggested to increase student engagement through interactive and practical applications of course content.

5.5.2 Learning Experiences in Ten Years

Students envision a diverse range of experiences characterized by heavy reliance on technology such as virtual reality (VR) and artificial intelligence (AI) to create immersive and interactive learning environments. They anticipate a shift towards more hybrid and flexible learning models allowing for both physical and remote attendance facilitated by advanced infrastructural adaptations.

5.5.3 Key Features Anticipated by Students

- Virtual Reality and Augmented Reality: Extensive use of VR and AR to simulate real-world and theoretical scenarios, providing hands-on experience in a virtual format.
- AI Integration: AI assistants and smart systems to personalize the learning experience, streamline administrative tasks, and potentially replace some traditional teaching methods.
- Enhanced Interactivity: Utilization of interactive boards, holographic projections, and configurable classrooms to foster a dynamic learning environment.
- Physical and Virtual Integration: A seamless blend of physical presence and virtual tools, maintaining traditional classroom elements alongside modern technological advancements.

5.5.4 Students Advocate for Changes and Improvements

- Flexibility in Learning Choices: Allowing students to choose what, how, and when they learn, potentially through modular courses and a choice-driven approach to education.

- Decentralized Control: Reducing the rigid professor-led model and increasing student autonomy in choosing learning paths.
- Customization of Learning Materials: Using AI to help tailor the content to meet the needs of individual students based on their learning habits and performance.
- Gamification and Interactive Learning: Incorporating game-like elements and scenario-based learning to maintain student interest and participation.

5.5.5 Students Concern Regarding Transformation

- Depersonalization: Over-reliance on technology could lead to a lack of personal interaction between students and teachers.
- Privacy and Data Security: The increase in data-driven technologies raises concerns about the protection of personal information.
- Technological Disparities: There is worry that the gap between students without access to the latest technologies and those without could widen, leading to unequal learning opportunities.

6. Discussion

This study combined online surveys and detailed interviews with students to uncover important information about the design and functionality of future classrooms. The results show a clear link between student satisfaction and the use of advanced technology, ergonomic design, and overall comfort in learning spaces. This connection highlights how important it is to include these elements in educational environments to make them effective and supportive of student well-being and success.

In this research, students are categorized based on the type of courses they are enrolled in—lecture-based, studio-based, or laboratory-based—to understand how different learning environments impact their experiences and preferences. This analysis enabled us to pinpoint specific areas of concern and highlight distinct differences in student experiences across these varied settings. By focusing on each type of classroom individually, this research able to gather targeted feedback that reflects the unique needs and challenges faced by students depending on the course format and the corresponding physical and technological setup of their learning spaces. This approach is crucial for developing tailored solutions that enhance educational outcomes and student satisfaction in each specific classroom type.

6.1 Lecture Classrooms

Satisfaction Level: Neutral to Low

Students often express dissatisfaction with the traditional lecture format, citing it as less engaging and less conducive to personalized learning. Another significant area of dissatisfaction highlighted by the survey results is the seating support. Ergonomics seem to be lacking, which could lead to physical strain and a decreased ability to focus during lectures and study times.

The main concerns include:

- Large Class Sizes: Impersonal and makes interaction difficult.
- Seating and Visibility: Widespread dissatisfaction with uncomfortable lecture hall seating, unsuitable for long lectures. Visibility issues, with students at the back or off to the sides struggling to see presentations and lecturers clearly due to poor hall design.
- Acoustic Issues: Sound quality in lecture halls is often inadequate, making it difficult for students, especially those seated further away, to hear clearly.
- Physical Environment: Inadequate air quality and poor lighting conditions contribute to an uncomfortable learning environment.
- Passive Learning: Traditional lectures emphasize passive reception of information, which students find less stimulating and less effective compared to interactive methods.
- Limited Technological Integration: Although some foresee the use of advanced tech like AI, the current use is minimal, leading to a lack of engagement.

6.2 Lab & Studio Classrooms

Satisfaction Level: Higher Satisfaction Generally

Students express a higher level of satisfaction with lab and studio settings due to their interactive and hands-on nature. But students complain about issues with the limited size and cluttered nature of studios, restricting the ability to spread out necessary materials for projects. And students need more permanent, personal workstations to avoid the frequent disruption of having to relocate or share spaces.

Key satisfaction drivers include:

- Engagement and Interaction: These settings naturally encourage more engagement through hands-on activities and experiments.
- Small Class Sizes: Typically smaller, which allows for more personalized attention and interaction with instructors.
- Relevance to Real-World Applications: Labs and studios offer practical experiences that are often seen as more directly applicable to professional fields.

6.3 Different Learning Behavior

The physical layout of classrooms, including seating arrangements and overall design, substantially affects student satisfaction. Students report dissatisfaction with physical infrastructure and technological provisions in existing classrooms. Key issues include cramped and inflexible seating arrangements, insufficient desk space, and limited or uncomfortable work areas. These problems are particularly pronounced in lecture halls and labs, impacting students' ability to engage effectively with the learning material and participate in extended study periods. Technological limitations are also a major concern, with students facing poor connectivity options, inadequate integration with personal devices, and subpar visibility and auditory experiences in large classrooms. Environmental factors like inappropriate lighting and temperature control further diminish the learning experience, while noise distractions from various sources disrupt concentration. Accessibility and privacy concerns also emerge as critical areas for improvement, with a noticeable lack of private spaces for quiet study or online engagement, and constrained availability of essential IT resources like chargers and adapters. The current classroom design does not adequately support group work or collaborative projects, which are increasingly important in academic settings.

Although lecture-style teaching has remained the favored teaching method for millennia, an increasing number of scientists question its efficacy due to low levels of engagement. Student engagement is an important topic in education as engagement is associated with positive outcomes along academic, social, and emotional lines (Klem and Connell 2004). A recurrent theme across the surveys and interviews was the demand for more student-centered learning environments. This includes greater autonomy over one's learning pace and style, more interactive and participatory class formats, and the systemic incorporation of feedback loops through technology. The necessity for ongoing dialogue between students and educational facility planners, students appreciated when their feedback led to tangible changes in their learning environments, suggesting a dynamic approach to classroom design that evolves with student needs and technological advancements.

Students foresee an educational landscape heavily augmented by technologies such as virtual reality (VR) and artificial intelligence (AI). VR can simulate realistic scenarios for practical applications in fields such as architecture, engineering, and design, providing hands-on experience in a controlled, replicable environment. AI can facilitate personalized learning experiences, adapt content delivery to individual pace and understanding, and provide real-time feedback, which is particularly lacking in large lecture formats. Reflecting a growing trend across educational institutions, Cornell students also favor a hybrid model that effectively integrates in-person and remote learning capabilities. There is a strong preference for classrooms equipped to support both in-person and remote participants simultaneously. Technologies that integrate seamless live streaming, high-quality video conferencing, and real-time collaboration tools (like digital whiteboards) will become standard expectations.

These technologies are perceived not just as enhancements to the learning environment but as essential components that can provide more interactive and immersive learning experiences. The preference for VR and AI supports the transition towards more interactive modules, which can simulate real-world environments and offer hands-on experiences that traditional learning environments cannot. This is particularly evident in the high satisfaction ratings for labs and studios where such technologies are already partially implemented. Students are enthusiastic about the extensive use of Virtual Reality (VR) and Augmented Reality (AR) to simulate real-world and theoretical scenarios, which enhances their hands-on learning experiences. Artificial Intelligence (AI) assistants and smart systems are anticipated to personalize learning experiences, streamline administrative tasks, and introduce new teaching methodologies. The use of AI as a personal assistant or tutor in these future smart classrooms could further personalize learning, adapting in real-time to the needs of individual students. This could address some of the current dissatisfaction expressed with the one-size-fits-all approach of traditional lectures, as noted in the interviews. Additionally, the use of interactive boards, holographic projections, and configurable classrooms is seen as vital in creating a dynamic and adaptable learning environment. The preference for VR and AI supports the transition towards more interactive modules, which can simulate real-world environments and offer hands-on experiences that traditional learning environments cannot. This is particularly evident in the high satisfaction ratings for labs and studios where such technologies are already partially implemented.

The integration of student feedback is crucial for addressing current educational needs and preferences, ensuring that new classroom technologies are user-friendly and directly relevant to the learning environment they serve. However, the design of future smart classrooms presents a unique challenge in leveraging student input effectively. One of the principal reasons is that students, like all users, can only provide feedback or generate ideas within the realm of their experiences. According to studies like those discussed regarding AI systems and digital museums, user expectations and comfort with technology are significantly shaped by what they have already encountered (Wu et al., 2021, Maruping et al., 2016). This inherently limits their ability to conceive of or desire new functionalities or educational strategies that they haven't experienced or seen in action, underscoring the need for input from those who can envision the broader potential of emerging technologies. The pace at which technology evolves means that new capabilities can quickly surpass the current understanding and expectations derived from existing systems. As observed in studies on user acceptance of digital platforms, users often evaluate new technologies based on their prior experiences with older technologies, which may not necessarily translate well to newer, more advanced systems (Straub, 2009). This can lead to a gap between what can be envisioned based on past and present technologies and what future technologies might offer. Future smart classrooms are likely to integrate advanced technologies like AI, machine learning, and IoT to create more personalized and adaptive learning experiences. Designing these environments requires a forward-thinking approach that anticipates educational needs and technological capabilities that current students might not be aware of or value due to their current educational context.

Therefore, while the student perspective is invaluable for understanding current needs and immediate improvements, the design of future smart classrooms also requires input from technologists, educators, and designers who can envision the broader potential of emerging technologies beyond the current user experience. This approach can help create educational environments that not only address immediate learning preferences but are also robust and flexible enough to adapt to future educational challenges and technological advancements.

7. Design Proposal

7.1 Key Elements for smart Classroom

Based on the analysis of high-frequency terms from previous student interviews and a thorough review of existing literature, the design requirements for a smart classroom can be categorized into four main areas: Technology Integration, Learning and Teaching Methods, Physical Environment, and Infrastructure.

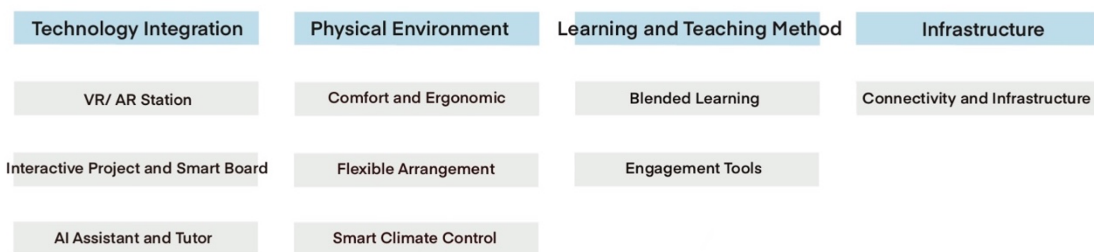

Figure 3 : Key Elements for Smart Classroom Design

Technology Integration: The smart classroom should incorporate advanced technologies to facilitate immersive and interactive learning experiences. This includes VR/AR Stations for virtual and augmented reality learning, Interactive Projectors and Smart Boards for dynamic presentations and digital whiteboarding, and AI Personal Assistants and Tutors to provide personalized learning support and automated feedback.

Learning and Teaching Methods: The design must support diverse pedagogical approaches, including Blended Learning that integrates online and in-person teaching methods. Additionally, Engagement Tools such as quizzes, polls, and interactive discussion platforms should be implemented to enhance student participation and involvement in the learning process.

Physical Environment: The classroom should be designed to maximize comfort and adaptability. This involves the use of ergonomic and adjustable furniture to support long periods of learning and teaching, Flexible Seating Arrangements that can be easily reconfigured to accommodate various teaching styles and group activities, and Smart Climate Control systems to maintain an optimal environment （Lighting / HVAC / Sound / temperature）for learning.

Infrastructure: Essential infrastructure must be in place to support the technological and physical needs of the smart classroom. This includes reliable high-speed internet connectivity and robust power supply systems to ensure the seamless operation of all digital tools and devices.

7.2 Different Type of Class Focus

In my previous research, I compared the classroom space requirements of different types of courses, finding that distinct course settings correspond to varying learning behavior patterns. Lecture classes are typically designed for the delivery of theoretical content to a larger group of students. The focus in this setting is primarily on the dissemination of information from the instructor to the students, operating within a one-to-many communication model. This format necessitates a classroom design that supports the instructor being relatively fixed in a specific location, usually at the front of the room. This setup allows the instructor to effectively use presentation tools like projectors and smart boards to communicate information clearly to all students as the primary setting, while allowing space and flexibility to facilitate instructor-student, TA-student, and student-student interaction in disseminated setting in the room for certain part of the class time.

In contrast, studio courses emphasize a more hands-on, project-based learning approach, and more student-driven, which inherently requires a different classroom dynamic. Here, the instructor is not at a fixed location or area but is mobile, moving around the space to interact with students individually or in groups. This mobility is essential for providing guidance, feedback, and support during the creative and practical work that characterizes studio classes. The instructor's movement facilitates a more personalized interaction, catering to the specific needs of each student's project or learning process. The types of behaviors therefore their supportive settings are more diverse than classrooms primarily for lecture use.

These differing behavioral patterns necessitate distinct design foci for the two types of classroom settings. Therefore, when designing the Smart classroom, the focus of lecture and studio design is not the same. Based on the key elements for the smart classroom, I have subdivided the design requirements according to the different learning experiences of lecture and studio.

7.2.1 Key design focus fot smart class room for lecture use

Based on the understanding of the learning mode and main behavior types, as well as. Student needs and expectation based on the data collected in this study, key design focus for smart class room for lecture usen are outlined in Figure 4, with more elaboration following it.

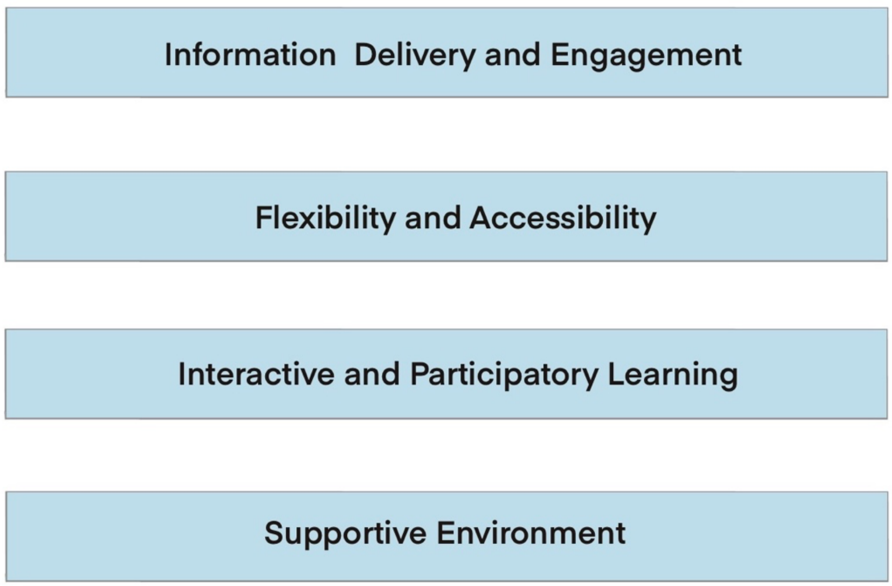

Figure 4 : Lecture Design Focus

Information Delivery and Engagement

Advanced Presentation Tools: Use interactive projectors, smart boards, and other digital tools to enhance the delivery of lectures. These tools allow for dynamic presentations that can include multimedia, live annotations, and interactive elements.

Multi-modal Delivery: Integrate systems that support both in-person and remote learning, such as high-quality cameras, microphones, and streaming capabilities, ensuring that remote students have an equivalent experience.

Flexibility and Accessibility

Flexible Seating and Layout: Design the space to accommodate different teaching methods, from traditional lectures to small group discussions. This could involve movable chairs and tables, tiered seating, or open spaces.

Interactive and Participatory Learning

Real-time Feedback Tools: Implement systems like clickers, polling software, and digital Q&A platforms to engage students actively during lectures, allowing them to participate and provide feedback in real time.

Collaboration Spaces: Designate areas within the lecture hall or nearby spaces for group work and discussions, enabling students to collaborate on projects and study together.

Supportive Environment

Ergonomic Seating: Ensure seating is comfortable and supports good posture to enhance concentration and reduce discomfort during long lectures.

Optimal Environmental Controls: Manage lighting, acoustics, and climate to provide a conducive learning environment. This includes proper lighting for reading and note-taking, acoustic panels to reduce noise, and climate control for comfort.

7.2.2 Key design focus for smart class room for studio use

With a similar approach but focusing on unique learning modes and interation types in studio, key design focus for smart class room for studio use are outlined in Figure 5.

Figure 5 : Studio Design Focus

Support for Creative Collaboration

Flexible Space Design: The studio should include movable walls, modular furniture, and adjustable lighting to create various configurations that support brainstorming, presentations, and group projects.

Technology Integration: Incorporate VR/AR tools, interactive displays, and other advanced technologies to facilitate immersive and collaborative work experiences.

Fluid Transition between Individual and Teamwork

Personal Workstations: Equip the studio with workstations that offer advanced computing capabilities, access to specialized software, and ergonomic design. These workstations should support both solo and collaborative tasks.

Access to Tools and Resources: Include facilities for prototyping, such as 3D printers, laser cutters, and a range of materials and tools that students can use for hands-on projects.

Interactive and Immersive Learning

Digital Platforms: Use digital tools for project management, collaboration, and communication. This can include platforms for sharing work, receiving feedback, and coordinating team efforts.

Experiential Learning Spaces: Design areas for immersive experiences, such as VR environments, where students can test designs, conduct simulations, and explore concepts in a 3D space.

Comfort and Ergonomics

Ergonomic Furniture: Provide chairs and desks that can be adjusted for height and support various postures, helping to reduce fatigue and increase productivity.

Ambient Environment: Control lighting, acoustics, and climate to create a comfortable environment that supports extended work periods. This includes soundproofing, adjustable lighting, and proper ventilation.

7.3 Lecture Classroom Design Proposals

In this section, I would like to propose one approach for designing classroom for the primary use of lecture and studio, respectively; and provide an example for each to illustrate the possible layout and design using such approach.

7.3.1 Lecture Classroom Design Proposals

In lecture classes, the design is centered around optimizing visibility and acoustics for the instructor's presentations, ensuring that every student can see and hear the material being delivered. The technology setup supports the delivery of information, with emphasis on presentation capabilities and, potentially, the recording or streaming of lectures.

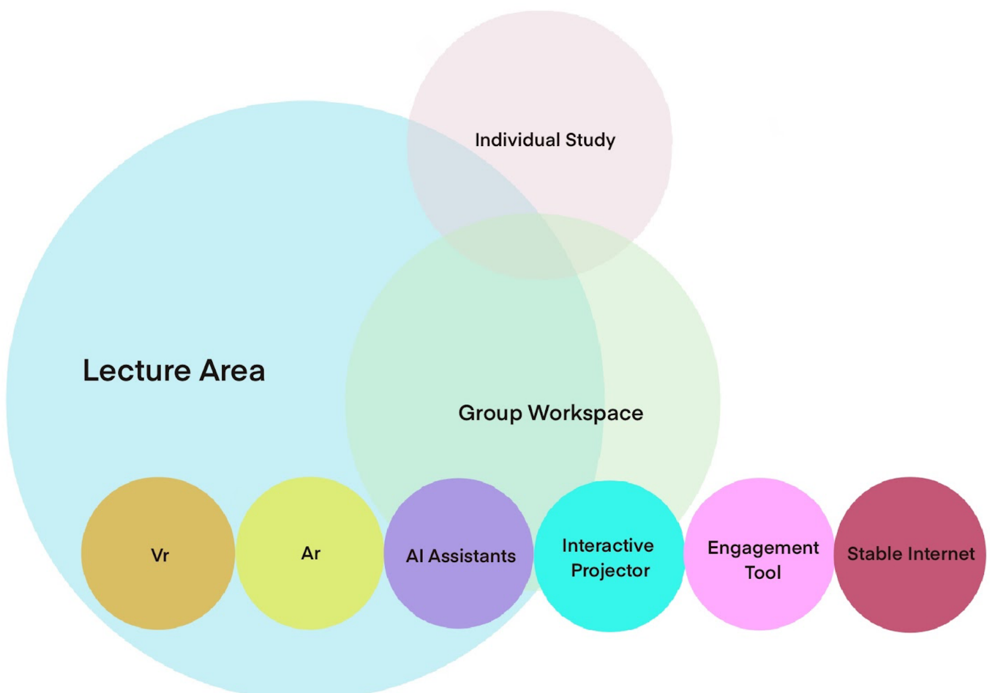

Figure 6 : Lecture Classroom Bubble Diagram

Lecture Area (Light Blue Circle)：

This is the primary zone for traditional instruction, where the focus is on delivering lectures and presentations to students.

Group Workspace (Green Circle):

A dedicated space for collaborative activities, the group workspace is designed to facilitate teamwork and group projects. It overlaps with the lecture area, suggesting that students can easily transition from listening to active collaboration.

Individual Study (Pink Circle):

This zone is designated for individual work, allowing students to focus on personal tasks or study independently. The individual study area overlaps slightly with the group workspace, indicating flexibility in how the space can be used.

Technological and Support Tools:

VR (Virtual Reality): VR technology is integrated into the classroom to provide immersive learning experiences. It allows students to explore virtual environments and interact with 3D models, which can be particularly beneficial for subjects requiring visualization of complex concepts.

AR (Augmented Reality): AR tools can be used for interactive learning experiences, such as augmented reality simulations and enhanced presentations.

AI Assistants: AI assistants are designed to provide personalized learning support, offering guidance, answering questions, and helping with administrative tasks.

Interactive Projector: The interactive projector is a key tool for engaging students during lectures and group activities. It allows for interactive presentations, enabling both the instructor and students to interact with the displayed content directly.

Engagement Tool: Engagement tools, such as clickers, polling systems, and digital Q&A platforms, are included to actively involve students in the learning process. These tools help to keep students engaged and facilitate interactive participation during lectures and discussions.

Stable Internet: It is crucial for maintaining the functionality of AI assistants, VR/AR applications, and interactive projectors.

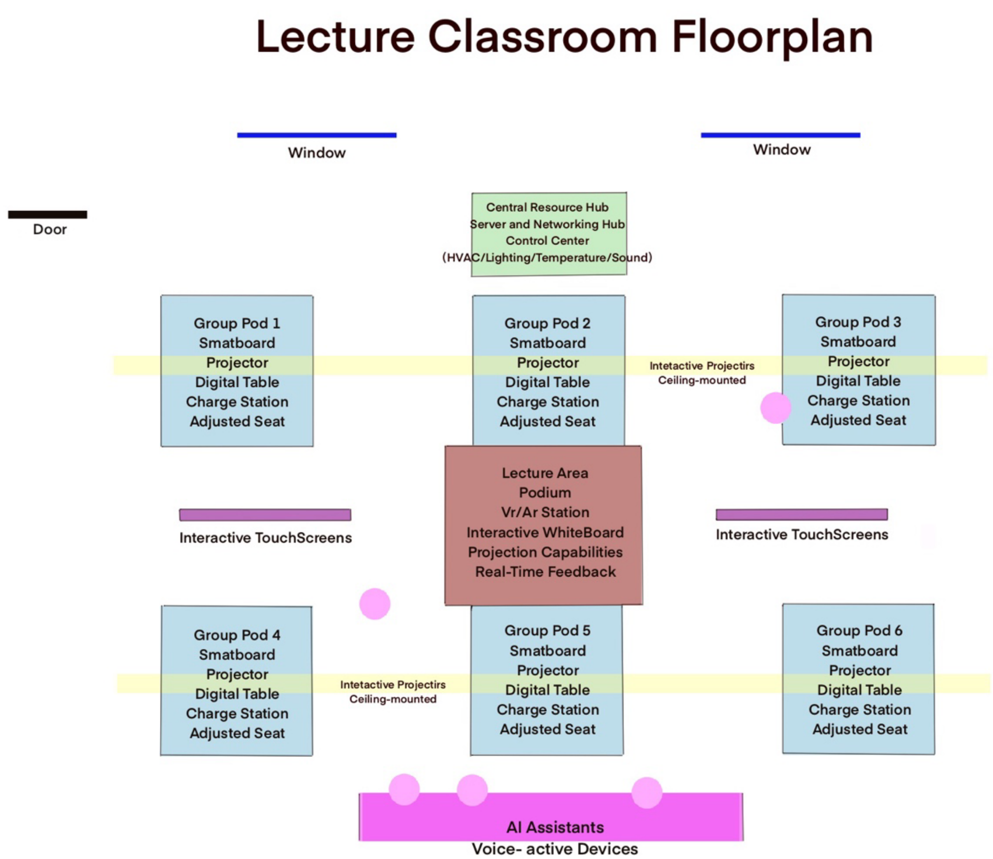

Figure 7 : Lecture Classroom Floorplan Diagram

Lecture Area (Red):

Podium: For the instructor to deliver lectures.

VR/AR Station: Integrated for immersive learning experiences.

Interactive Whiteboard: For real-time note-taking and presentations.

Projection Capabilities: To display visual aids and presentations.

Real-Time Feedback: Systems for immediate student-instructor interaction and engagement.

Group Pods (Blue):

There are six Group Pods arranged around the Lecture Area, each designed for collaborative work and equipped with the following features:

Smartboards: Interactive displays for group work and presentations.

Projectors: Ceiling-mounted projectors serving multiple pods.

Digital Tables: For students to use digital devices and tools.

Charge Stations: For powering devices.

Adjusted Seats: Ergonomically designed for comfort and flexibility.

Peripheral Engagement Zones:

Interactive Touch-Screens (Purple)

Positioned along the sides, these are likely large, interactive displays used for group activities, additional resources, or student interaction.

AI Assistants (Pink)

Voice-activated Devices: Positioned at the front, these devices assist with lecture delivery, answering student queries, or controlling classroom technology.

Infrastructure and Additional Elements

Central Resource Hub (Light Green)

Server and Networking Hub: Manages the classroom's technological infrastructure.

Control Center: For HVAC, lighting, temperature, and sound control.

Entrances: Clear access points for easy movement.

Windows: Positioned to provide natural light.

Clear Circulation Paths: Designed for smooth movement between zones and easy access to all areas.

Simple Illustrations

Figure 8 : Illustration for Arrange Layout, AI tool-assisted generation

Figure 9 : Illustration for Pod, AI tool-assisted generation

The future smart lecture classroom is a modern, technologically advanced space designed to enhance learning and interaction. The central area features a podium equipped with control panels for managing various technological tools, surrounded by an interactive whiteboard and projection screen. The room includes six group pods arranged in a circular pattern around the central lecture area, each pod furnished with smartboards, projectors, digital tables, and ergonomic seating for collaborative learning. Along the sides of the room, large interactive touchscreens and VR/AR stations offer immersive experiences and interactive tools. The space is further equipped with AI assistants, strategically placed to aid in presentations and student engagement. Lighting options include adjustable LED lighting for customizable brightness and color temperature, task lighting for specific areas, ambient lighting for a comfortable overall glow, and accent lighting to highlight key features like the podium and group pods.

7.3.2 Studio Classroom Design Proposals

The design focus for studio classes prioritizes flexibility and adaptability to accommodate various activities. The classroom must be spacious enough to allow for different configurations, such as individual workstations, collaborative group areas, and spaces for project displays or critiques. Movable furniture and modular setups are key, allowing the space to be reconfigured as needed. Additionally, the provision of specialized tools and equipment is crucial to support the hands-on nature of the coursework. The instructor's mobility is supported by a layout that allows easy movement and access to all students, fostering a more dynamic and interactive learning environment.

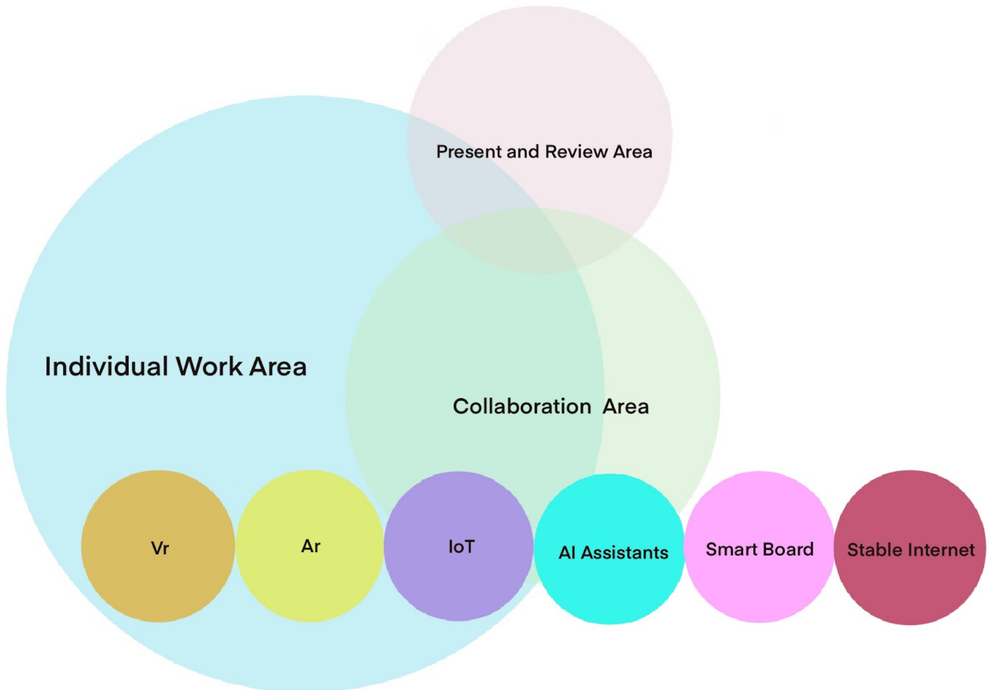

Figure 10 : Studio Classroom Bubble Diagram

Individual Work Area (Light Blue Circle):

This is the primary zone for studio behavior, allowing students to focus on personal projects and activities. It provides a space where students can engage in detailed work, research, or study independently.

Collaboration Area (Green Circle):

The collaboration area is designed to facilitate group work and teamwork, enabling students to share ideas, work on joint projects, and engage in discussions. The overlap between the Individual Work Area and the Collaboration Area suggests a flexible space where students can easily switch between solo and group activities.

Present and Review Area (Pink Circle):

This zone is designated for presenting and reviewing work. It serves as a space for students to showcase their projects, receive feedback, and participate in critiques or presentations. The positioning of this area, overlapping with the Collaboration Area, indicates that it is an integral part of the collaborative process, allowing for immediate feedback and discussion.

Technological and Support Tools:

VR (Virtual Reality): VR technology is integrated to provide immersive experiences, allowing students to explore virtual environments and interact with 3D models, enhancing their creative and technical skills.

AR (Augmented Reality): AR tools are used to overlay digital information on the physical world, supporting activities like prototyping, design visualization, and interactive learning.

IoT (Internet of Things): IoT devices are included to create a connected and intelligent studio environment. These devices can automate environmental controls, provide real-time data, and support various applications that enhance the learning experience.

AI Assistants: AI assistants offer personalized support, helping students with queries, providing learning resources, and facilitating project management. They enhance the learning experience by offering tailored assistance and automating routine tasks.

Smart Board: The smart board is a versatile tool for interactive presentations, drawing, and brainstorming sessions. It supports both individual and collaborative activities by allowing digital interaction with content.

Stable Internet: A reliable internet connection is fundamental, supporting all the digital tools and ensuring seamless access to online resources, cloud-based applications, and collaborative platforms.

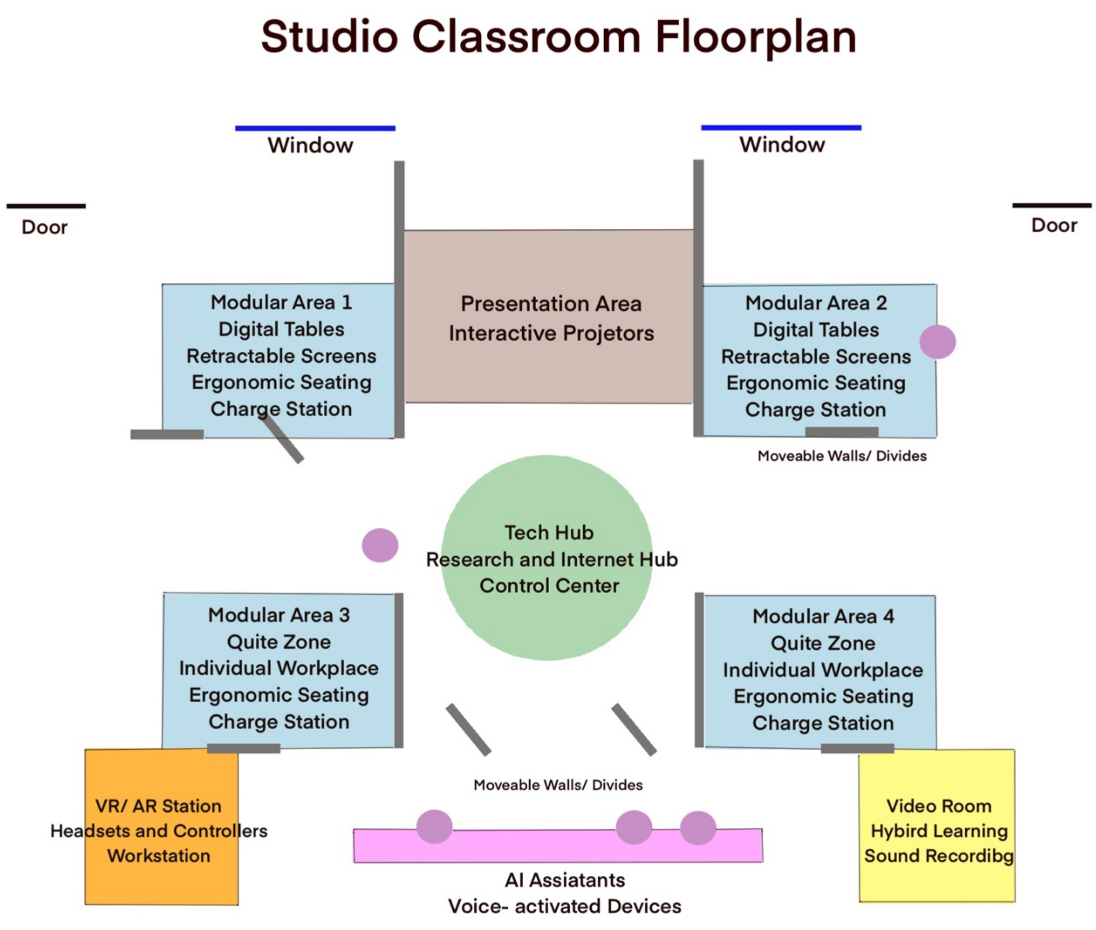

Figure 11 : Studio Classroom Floorplan Diagram

Tech Hub

Situated at the center of the classroom, serves as a pivotal point for all technological and networking activities. It functions as an information sharing center, facilitating the distribution and exchange of digital resources, data, and content among students and instructors. Additionally, the Tech Hub operates as a network control center, managing the classroom's connectivity infrastructure, ensuring stable internet access, and overseeing the integration of various digital tools and systems within the classroom.

Presentation Area with Interactive Projector

This area is equipped with interactive projectors for presentations and demonstrations. It serves as the main focal point for the dissemination of information and group activities.

Modular Areas (1, 2, 3, and 4)

Modular Area 1 & 2 (Digital Tables, Retractable Screens, Ergonomic Seating, Charge Station): These areas are designed for flexible learning setups, featuring digital tables and retractable screens. They are equipped with ergonomic seating and charging stations, supporting both group work and individual tasks.

Modular Area 3 & 4 (Quiet Zone, Individual Workplace, Ergonomic Seating, Charge Station): These zones provide a quieter environment for individual work, with ergonomic seating and charging stations.

Moveable Walls/ Divides

The floor plan includes moveable walls and dividers, providing flexibility in configuring the space according to the needs of different activities. This feature allows the classroom to be easily adapted for various teaching and learning scenarios.

VR/AR Station

This area is dedicated to virtual and augmented reality activities. It includes headsets, controllers, and a workstation, enabling immersive learning experiences and practical applications of VR/AR technologies.

AI Assistants (Voice-activated Devices)

These devices provide voice-activated support, helping students and instructors with tasks such as accessing information, managing schedules, and facilitating interactive learning.

Video Room (Hybrid Learning, Sound Recording)

The Video Room supports hybrid learning setups, allowing for sound recording and the creation of multimedia content. This space is essential for activities such as recording lectures, creating educational videos, and conducting remote sessions.

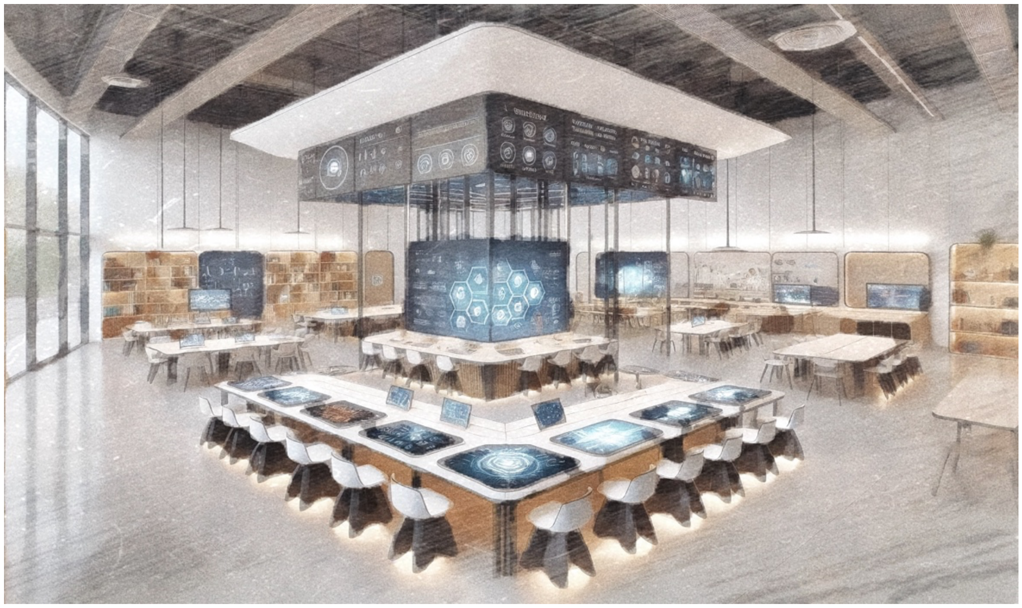

Figure 12 : Illustration for Studio Classroom, AI tool-assisted generation

The future Smart Studio classroom is a cutting-edge educational space designed to foster creativity, collaboration, and technological integration. Upon entering, one is greeted by a versatile layout featuring modular areas equipped with digital tables, retractable screens, and ergonomic seating, all tailored to accommodate both group and individual work. The central feature of the studio is the Tech Hub, an information-sharing center and network control hub that ensures seamless connectivity and access to digital resources. Surrounding the Tech Hub are various specialized zones, including a VR/AR station equipped with headsets and controllers for immersive learning experiences, and a quiet zone for focused individual tasks. Moveable walls and dividers add flexibility, allowing the space to be reconfigured to meet the needs of different activities. The studio is further enhanced by voice-activated AI assistants that provide real-time support, and a video room designed for hybrid learning and multimedia production.

8. Suggestion for Future Research

To effectively shape the next generation of smart classrooms from a student perspective, ongoing exploration of diverse student needs and preferences across different disciplines and learning environments is crucial. Future research should prioritize longitudinal studies that meticulously track the evolution of student interactions with both technology and space over extended periods. This approach could offer insights into the enduring impacts of new technologies and designs on the learning environment, highlighting trends and shifts that may not be immediately apparent.

Comparative studies between different educational institutions and across various cultural contexts could also yield significant insights into how environmental and cultural factors play a role in the effectiveness of smart classroom designs. Such studies would help identify universal design principles as well as culturally specific adaptations that could inform more effective educational environments globally.

Incorporating students more directly in the design process, through participatory design workshops or student-led research initiatives, is another promising avenue. Such involvement ensures that the resulting educational spaces are not only technically advanced but also resonate with the user base, potentially leading to higher satisfaction and better educational outcomes. Moreover, the importance of feedback cannot be overstated. Regularly collecting and incorporating feedback from users—students, faculty, and administrative staff—is crucial for continuously improving the functionality and comfort of educational environments. This feedback loop ensures that the changes made are responsive to the actual needs and preferences of the users, thereby enhancing student satisfaction and educational outcomes.

In this era of data-driven education, addressing privacy concerns is paramount. As classrooms increasingly integrate technology, issues surrounding data privacy become more prominent. There is a pressing need for robust cybersecurity measures to safeguard student information. This includes protecting data from external threats and managing how data is collected, used, and stored. Institutions should develop transparent policies regarding data usage and privacy and communicate them clearly to all stakeholders. This ensures that students and parents understand what data is collected and how it is used. Although technology can provide powerful tools for learning, maintaining a classroom environment conducive to personal interactions remains essential for effective education.

Additionally, investigating the financial implications of adopting advanced technologies and redesigning educational spaces is critical. Cost-benefit analyses would provide educational planners and administrators with a clearer picture of the financial commitments involved, helping to strike a balance between innovative educational technologies and practical, accessible solutions.

By addressing these key areas, future research can help develop smart classrooms that are secure, user-focused, and adapted to the diverse needs of students across the globe.

9. Appendix

9.1 Survey Question

Envisioning Future Classrooms: A Survey of Cornell Students' Learning Space Experiences

Section 1: Demographics

1.1 What is your major?

1.2 What year are you in?

- Freshman
- Sophomore
- Junior
- Senior
- Graduate Student

1.3 Choose a type of course you're taking this semester as the basis for answering the rest of this survey.

- Lecture-based
- Studio-based
- Laboratory-based

Section 2: General Preferences

2.1 On a scale of 1-5, how would you rate your satisfaction with the current learning spaces at Cornell? (1 = Very Dissatisfied, 5 = Very Satisfied)

- 1
- 2
- 3
- 4
- 5

Base on your choice for Q1.3 answer the following questions (Q2.2-Q2.6)

2.2 To what extent are you satisfied with the support from the seating arrangement in the current space for extended periods of study or work?

- Highly satisfied

- Satisfied
- Neutral
- Dissatisfied
- Highly Dissatisfied

2.3 To what extent are you satisfied with how well the layout is adapted to different learning activities (e.g., group work, individual study, presentations)??

- Highly satisfied
- Satisfied
- Neutral
- Dissatisfied
- Highly Dissatisfied

2.4 To what extent are you satisfied that the technology in the space is sufficient for supporting your study and work needs?

- Highly satisfied
- Satisfied
- Neutral
- Dissatisfied
- Highly Dissatisfied

2.5 To what extent are you satisfied that there is sufficient workspace for textbooks, tablets, and other resources?

- Highly satisfied
- Satisfied
- Neutral
- Dissatisfied
- Highly Dissatisfied

2.6 To what extent are you satisfied that it is easy to connect personal devices (e.g. laptops, tablets) to the classroom's technical infrastructure?

- Highly satisfied
- Satisfied
- Neutral
- Dissatisfied
- Highly Dissatisfied

2.7 What other challenges or limitations do you experience in your current classroom space?

Section 3: Technological latitude of the learning environment

3.1 In your definition of a smart classroom, pick the five most important features

- Provides reliable wireless connectivity
- New learning devices and software that you can learn how to use in a short period of time
- Software can support cell phones and computers with different resolutions and systems
- Provides a combination of face-to-face and digital instruction
- Simulation and visualization technologies enable interaction with 3D models and scenarios
- Have learning devices and software that are more fun to use, such as using gestures and movements rather than traditional input devices such as keyboards and mice
- Realize intelligent check-in, intelligent grouping, and intelligent pushing of information resources for students
- The desks and chairs are lightweight, comfortable, adjustable (height), and can be freely combined according to the requirements of different teaching activities
- Lights, curtains, air-conditioning and ventilation systems can be easily turned on and off
- Other (____)

9.2 Interview Question

Envisioning Future Classrooms: A Interview of Cornell Students' Learning Space Experiences

Section 4: Designing for the future

4.1 Ten years from now, what do you envision the learning experiences on the Cornell campus will be like?

4.2 What features or technologies do you envision in the classroom of the future?

4.3 Given your personal learning style, what changes would you recommend to make the classroom more conducive to your learning?

4.4 What are some of the changes necessary to enhance engagement and interactive learning?

4.5 What suggestions do you have for creating a more student-centered learning environment?

4.6 What concerns, if any, do you have about the transition to the classroom of the future?

Section 5: Open-ended feedback

5.1 Please provide any additional comments or suggestions regarding the evolution of learning spaces at Cornell.

10. Reference

Al-Zahrani, A. M. (2015). From passive to active: The impact of the flipped classroom through social learning platforms on Higher Education Students' Creative thinking. *British Journal of Educational Technology*, *46*(6), 1133–1148. https://doi.org/10.1111/bjet.12353

Akhrif, O., Benfares, C., Idrissi, Y., & Hmina, N. (2020). Collaborative approaches in smart learning environment: A case study. *Procedia Computer Science*, 175, 710–715.

Bachiller, P., & Badía, G. (2020). The flip teaching as tool to improving students' sustainable learning performance in a financial course. *Sustainability*, *12*(23), 9998. https://doi.org/10.3390/su12239998

Baig, M. I., & Yadegaridehkordi, E. (2023). Flipped classroom in higher education: A systematic literature review and research challenges. *International Journal of Educational Technology in Higher Education*, *20*(1). https://doi.org/10.1186/s41239-023-00430-5

Bao W. COVID-19 and online teaching in higher education: A case study of Peking University. *Human Behavior and Emerging Technologies.* 2020;2(2):113–115. doi: 10.1002/hbe2.191.

Barak, M. (2016). Science teacher education in the twenty-first century: A pedagogical framework for technology-integrated social constructivism. *Research in Science Education*, *47*(2), 283–303. https://doi.org/10.1007/s11165-015-9501-y

Beer, D. (2019). *The Data Gaze: Capitalism, Power and Perception*. https://doi.org/10.4135/9781526463210

Beetham, H., & Sharpe, R. (2019, July 11). *Rethinking pedagogy for a Digital age: Principles and practices of design*. Routledge & CRC Press. https://www.routledge.com/Rethinking-Pedagogy-for-a-Digital-Age-Principles-and-Practices-of-Design/Beetham-Sharpe/p/book/9780815369264

Billinghurst, M., Clark, A., & Lee, G. (2015). A survey of Augmented Reality. *Foundations and Trends® in Human–Computer Interaction*, *8*(2–3), 73–272. https://doi.org/10.1561/1100000049

Bodily, R., & Verbert, K. (2017). Review of research on student-facing learning analytics dashboards and Educational Recommender Systems. *IEEE Transactions on Learning Technologies*, *10*(4), 405–418. https://doi.org/10.1109/tlt.2017.2740172

Chatterjee, A., Gupta, U., Chinnakotla, M. K., Srikanth, R., Galley, M., & Agrawal, P. (2019). Understanding emotions in text using Deep Learning and Big Data. *Computers in Human Behavior*, *93*, 309–317. https://doi.org/10.1016/j.chb.2018.12.029

Cheung, S. K., Kwok, L. F., Phusavat, K., & Yang, H. H. (2021). Shaping the future learning environments with smart elements: Challenges and opportunities. *International Journal of Educational Technology in Higher Education*, *18*(1). https://doi.org/10.1186/s41239-021-00254-1

Chocarro, R., Cortiñas, M., & Marcos-Matás, G. (2021). Teachers' attitudes towards Chatbots in education: A technology acceptance model approach considering the effect of social language, bot proactiveness, and users' characteristics. *Educational Studies*, *49*(2), 295–313. https://doi.org/10.1080/03055698.2020.1850426

Colace, F., Santo, M. D., Lombardi, M., Pascale, F., Pietrosanto, A., & Lemma, S. (2018). Chatbot for e-learning: A case of study. *International Journal of Mechanical Engineering and Robotics Research*, 528–533. https://doi.org/10.18178/ijmerr.7.5.528-533

Dai, Z., Sun, C., Zhao, L. *et al.* The Effect of Smart Classrooms on Project-Based Learning: A Study Based on Video Interaction Analysis. *J Sci Educ Technol* **32**, 858–871 (2023). https://doi.org/10.1007/s10956-023-10056-x

Díaz-Parra, O., Alejandro, F. P., Ricardo A, B. C., Francisco Rafael, T. M., & Jorge, R. V. (2022). *2022 International Conference on Future Trends in Smart Communities (ICFTSC)*. https://doi.org/10.1109/icftsc57269.2022

Dimitriadou, E., & Lanitis, A. (2023). A critical evaluation, challenges, and future perspectives of using artificial intelligence and emerging technologies in Smart Classrooms. *Smart Learning Environments*, *10*(1). https://doi.org/10.1186/s40561-023-00231-3

Demir, K. A. (2021). Smart education framework. *Smart Learning Environments*, *8*(1). https://doi.org/10.1186/s40561-021-00170-x

Dziuban, C., Graham, C. R., Moskal, P. D., Norberg, A., & Sicilia, N. (2018). Blended learning: The new normal and emerging technologies. *International Journal of Educational Technology in Higher Education*, *15*(1). https://doi.org/10.1186/s41239-017-0087-5

Eguchi, A. (2014). Educational Robotics for promoting 21st Century skills. *Journal of Automation, Mobile Robotics and Intelligent Systems*, 5–11. https://doi.org/10.14313/jamris_1-2014/1

Gabriel, M. A., & Kaufield, K. J. (2008). Reciprocal mentorship: An effective support for online instructors. *Mentoring & Tutoring: Partnership in Learning*, *16*(3), 311–327. https://doi.org/10.1080/13611260802233480

Górski, F., Buń, P., Wichniarek, R., Zawadzki, P., & Hamrol, A. (2016). Effective design of educational virtual reality applications for medicine using knowledge-engineering techniques. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(2). https://doi.org/10.12973/eurasia.2017.00623a

EL Adu, & DCC Poo (2014). Smart learning: A new paradigm of learning in the smart age. *Paper presented at TLHE 204: International conference on teaching and learning in higher education.*e.

Hanımoğlu, E. (2018). The impact technology has had on high school education over the years. *World Journal of Education*, *8*(6), 96. https://doi.org/10.5430/wje.v8n6p96

Hew, K. F., & Brush, T. (2006). Integrating technology into K-12 teaching and learning: Current knowledge gaps and recommendations for future research. *Educational Technology Research and Development*, *55*(3), 223–252. https://doi.org/10.1007/s11423-006-9022-5

Huang, A. Y. Q., Lu, O. H. T., & Yang, S. J. H. (2023). Effects of artificial intelligence–enabled personalized recommendations on learners' learning engagement, motivation, and outcomes in a flipped classroom. *Computers & Education*, *194*, 104684. https://doi.org/10.1016/j.compedu.2022.104684

Huang, R., Yang, J., Hu, Y., Wang, X. (2015). Development and Use of a Questionnaire for Evaluating K-12 Smart Classroom. In: Cheung, S., Kwok, Lf., Yang, H., Fong, J., Kwan, R. (eds) Hybrid Learning: Innovation in Educational Practices. *ICHL 2015. Lecture Notes in Computer Science(), vol 9167. Springer, Cham*. https://doi.org/10.1007/978-3-319-20621-9_18

Hwang, G.-J. (2014). Definition, framework and research issues of Smart Learning Environments - a context-aware ubiquitous learning perspective. *Smart Learning Environments*, *1*(1). https://doi.org/10.1186/s40561-014-0004-5

Hwang, G.-J., & Chang, H.-F. (2011). A formative assessment-based mobile learning approach to improving the learning attitudes and achievements of students. *Computers & Education*, *56*(4), 1023–1031. https://doi.org/10.1016/j.compedu.2010.12.002

Jiang, M.Y.-C., Jong, M.S.-Y., Lau, W.W.-F., Chai, C.-S., Liu, K.S.-X., & Park, M. (2022). A scoping review on flipped classroom approach in language education: Challenges, implications and an interaction model. *Computer Assisted Language Learning, 35(5–6), 1218–124*9.

Johnson, M., & Liber, O. (2008). The Personal Learning Environment and the human condition: From theory to teaching practice. *Interactive Learning Environments*, *16*(1), 3–15. https://doi.org/10.1080/10494820701772652

Jones, R. H. (2022). 4 how trends in Public Higher Education Can Support Sustainability Education and research. *The Future of Sustainability Education at North American Universities*, 65–74. https://doi.org/10.1515/9781772126679-007

Karjanto, N., & Acelajado, M. J. (2022). Sustainable learning, cognitive gains, and improved attitudes in college algebra flipped classrooms. *Sustainability*, *14*(19), 12500. https://doi.org/10.3390/su141912500

Kaur, A., Bhatia, M., & Stea, G. (2022). A survey of Smart Classroom literature. *Education Sciences*, *12*(2), 86. https://doi.org/10.3390/educsci12020086

Kwet, M., & Prinsloo, P. (2020). The 'smart' classroom: A new frontier in the age of the smart university. *Teaching in Higher Education*, *25*(4), 510–526. https://doi.org/10.1080/13562517.2020.1734922

Maruping, L. M., Bala, H., Venkatesh, V., & Brown, S. A. (2016). Going beyond intention: Integrating behavioral expectation into the unified theory of acceptance and use of

Technology. *Journal of the Association for Information Science and Technology*, *68*(3), 623–637. https://doi.org/10.1002/asi.23699

Nuraini, C. K., Mohd, C. K., & Shahbodin, F. (2014). Learning approach for personalized learning environment (PLE): Preliminary analysis. *Information and Communication Technology for Education*. https://doi.org/10.2495/icte130481

Peng, H., Ma, S., & Spector, J. M. (2019). Personalized adaptive learning: An emerging pedagogical approach enabled by a smart learning environment. *Smart Learning Environments*, *6*(1). https://doi.org/10.1186/s40561-019-0089-y

Rosen,Y., & Beck-Hill, D. (2012). Intertwining digital content and a one-to-one laptop environment in teaching and learning: Lessons from the time to know program. *Journal of Research on Technology in Education, 44(3), 225-241.* Retrieved from http://argo.library.okstate.edu/login?url=http://search.proquest.com.argo.library.okstate.edu/docview/1140129679?accountid=4117

Shoikova, E., Nikolov, R., & Kovatcheva, E. (2018). Smart Digital Education enhanced by AR and IOT Data. *INTED Proceedings*. https://doi.org/10.21125/inted.2018.1392

Sobota, B., Korecko, S., Jacho, L., Pastornicky, P., Hudak, M., & Sivy, M. (2017). Virtual-reality technologies and smart environments in the process of disabled people education. *2017 15th International Conference on Emerging eLearning Technologies and Applications (ICETA)*. https://doi.org/10.1109/iceta.2017.8102528

Song, S., Zhong, X., Li, H., Du, J., & Nie, F. (2014). Smart classroom: From conceptualization to construction. *2014 International Conference on Intelligent Environments*.

Straub, E. T. (2009). Understanding technology adoption: Theory and future directions for informal learning. *Review of Educational Research*, *79*(2), 625–649. https://doi.org/10.3102/0034654308325896

Tuncay, N., & Uzunboylu, H. (2012). English language teachers' success in blended and online e-learning. *Procedia - Social and Behavioral Sciences*, *47*, 131–137. https://doi.org/10.1016/j.sbspro.2012.06.626

Valdez, M. T., Ferreira, C. M., Martins, M. J., & Barbosa, F. P. (2015). 3D virtual reality experiments to promote electrical engineering education. *2015 International Conference on Information Technology Based Higher Education and Training (ITHET)*. https://doi.org/10.1109/ithet.2015.7217957

van Harmelen, M. (2008). Design trajectories: Four experiments in PLE implementation. *Interactive Learning Environments*, *16*(1), 35–46. https://doi.org/10.1080/10494820701772686

Jokinen, P., & Mikkonen, I. (2013). Teachers' experiences of teaching in a blended learning environment. *Nurse Education in Practice*, *13*(6), 524–528. https://doi.org/10.1016/j.nepr.2013.03.014

Jones, A., & Castellano, G. (2018). Adaptive robotic tutors that support self-regulated learning: A longer-term investigation with primary school children. *International Journal of Social Robotics*, *10*(3), 357–370. https://doi.org/10.1007/s12369-017-0458-z

J. infoNetFollow this. (2009, August 6). *Designing spaces for effective learning (2006)*. Issuu. https://issuu.com/jiscinfonet/docs/jisc_designing_spaces_for_effective_learning_2006_

Werner-Seidler, A., Perry, Y., Calear, A. L., Newby, J. M., & Christensen, H. (2017). School-based depression and anxiety prevention programs for young people: A systematic review and meta-analysis. *Clinical Psychology Review*, *51*, 30–47. https://doi.org/10.1016/j.cpr.2016.10.005

Wonseok Yang. (2012). Chinese characters education utilizing results of characters sources studies. *Journal of Korean Classical Chinese Literature*, *25*(1), 495–514.

Wu, Y., Jiang, Q., Ni, S., & Liang, H. (2021). Critical factors for predicting users' acceptance of digital museums for experience-influenced environments. *Information*, *12*(10), 426. https://doi.org/10.3390/info12100426

Yang, J., Pan, H., Zhou, W., & Huang, R. (2018). Evaluation of smart classrooms from the perspective of infusing technology into pedagogy. *Smart Learning Environments*, *5*(1). https://doi.org/10.1186/s40561-018-0070-1

Yen, C.-J., Tu, C.-H., Sujo-Montes, L. E., Harati, H., & Rodas, C. R. (2019). Using personal learning environment (PLE) management to support Digital Lifelong Learning. *International Journal of Online Pedagogy and Course Design*, *9*(3), 13–31. https://doi.org/10.4018/ijopcd.2019070102

Yu, Huiju, Gaojun Shi, Jiaping Li, and Junfeng Yang. 2022. "Analyzing the Differences of Interaction and Engagement in a Smart Classroom and a Traditional Classroom" *Sustainability 14, no. 13: 8184.* https://doi.org/10.3390/su14138184

Zhu, C., Valcke, M., & Schellens, T. (2009). A cross-cultural study of online collaborative learning. *Multicultural Education & Technology Journal*, *3*(1), 33–46. https://doi.org/10.1108/17504970910951138

Zhu, Z. T., & Bin, H. (2012). Smart education: A new paradigm in educational technology. *Telecommunication Education*, *12*, 3-15.

Z. Zhang, T. Cao, J. Shu, M. Zhi, H. Liu and Z. Li, "Exploration of Blended Teaching Pattern Based on Hstar and Smart Classroom," *2017 International Symposium on Educational Technology (ISET)*, Hong Kong, China, 2017, pp. 3-7, doi: 10.1109/ISET.2017.10.