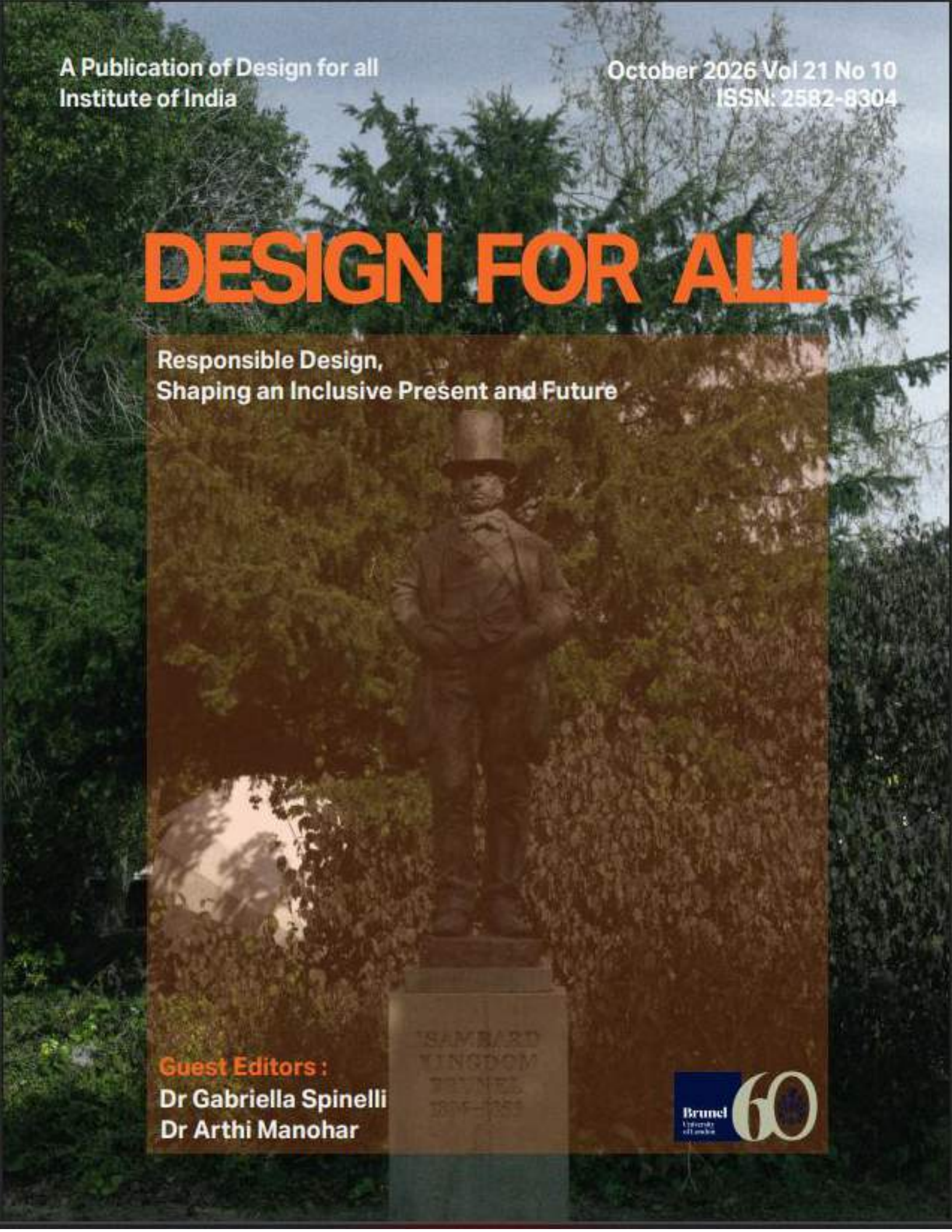
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DESIGN FOR ALL

Responsible Design, Shaping an Inclusive Present and Future



Guest Editors :
Dr Gabriella Spinelli
Dr Arthi Manohar

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GUEST EDITOR(S):



Gabriella Spinelli

Dr Gabriella Spinelli is Reader in Healthcare Design and Innovation and Head of Brunel Design School, with over twenty years of internationally recognised research at the intersection of human-centred design, engineering, digital health and regulatory science. Throughout her career, her work has been driven by a central question: how can healthcare technologies and services be designed around people's needs while ensuring that they are safe, effective and capable of delivering meaningful real-world impact?

This focus has shaped an interdisciplinary research programme that brings together design, engineering and clinical practice. Through strategic partnerships with the NHS, industry, regulators and government, she has developed research programmes that translate human-centred innovation into healthcare practice, generating research income to fund her research programme. She currently leads RADIANT-CERSI, one of seven UKRI national Centres of Excellence in

Regulatory Science and Innovation for human health, and co-directs the Smart Technology Advancements in Health and Rehabilitation (STAHR) Research Centre. These roles reflect her commitment to research that not only advances knowledge, but also addresses the complex organisational, regulatory and societal conditions that shape whether innovation can be safely adopted and sustained.

Her research expertise increasingly informs national policy and the development of emerging approaches to the regulation of healthcare technologies. She is a member of the Home Office Scientific Advisory Council (HOSAC).

She is a committed educator who has introduced and developed challenge-based learning and interdisciplinary, team-based learning opportunities through the Design for Health programme, bringing together students from Design, Computer Science, and Health disciplines.



Arthi Manohar

Dr Arthi Manohar is Course Director, Ethics and EDI Lead in Design at Brunel University London. She trained as an architect before moving into digital and interaction design, and her EPSRC-funded doctoral work at the University of Dundee developed a practice-led Participatory Action Research methodology for telling emotionally meaningful stories — an approach that has stayed with her ever since. With twelve years of experience in design research, her work incorporates participatory design methods that involve stakeholders directly in the design process, rather than studying them from the outside, guided by a central question: how can creative, participatory design methods generate genuine insight and real-world impact for the diverse communities and stakeholders who must live and work alongside disruptive new technologies?

This focus has shaped a research programme that applies the same underlying commitment — user-centred and participatory methods generating design insight with genuine stakeholder impact — across a deliberately wide range of technological contexts, from blockchain and distributed ledger technology to IoT, wearable health technology

and artificial intelligence. Through collaborations spanning Brunel, Glasgow School of Art, the University of Kent, the University of Nottingham, the University of Edinburgh, the University of Sheffield, Northumbria University and SUPSI Switzerland, alongside SME partners, she has secured and led externally funded project grants since 2019, including work on privacy in FemTech applications, wearable technology for wheelchair users with spinal cord injuries, trust in IoT smart-home interfaces, and algorithmic intelligibility.

Her research expertise increasingly shapes the direction and quality assurance of the wider design and HCI field. She holds editorial and chairing roles including Paper Associate Chair for ACM Designing Interactive Systems (DIS), Conference Paper Chair for India HCI, and Workshop and Masterclass Chair for BritCHI.

Beyond these formal roles, she remains a long-standing reviewer for UKRI (AHRC, EPSRC and ESRC) and for ACM and IEEE journals and conferences, and serves as External Examiner for Loughborough University and Domus Academy Milano — work that, together, reflects a sustained commitment to shaping the standards and next generation of the field she researches.

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GUEST EDITORIAL:
Responsible Design: Shaping an Inclusive Present and Future

Gabriella Spinelli, Arthi Manohar

This special issue of *Design for All,* India marks sixty years since Brunel became a university. Anniversaries tend to prompt a look backwards, but the editors have used this one to look at how design is done at Brunel now: in clinics and classrooms, in university offices, on the screens where people look for health advice, and in the data systems that sit between a customer and a service. The seven papers come from doctoral researchers, early-career and senior colleagues, a recent graduate of the Product Design Engineering (BSc) programme and collaborators at partner institutions. Their methods, scales and impact differ. The question they share is an old one at Brunel Design School: when people design, who are they responsible to, and for how long?

Design for All starts with a plain observation. People differ in age, ability, language, culture and circumstance, and anything designed for an imagined average user quietly shuts out everyone else. The tradition is well established. It runs from the principles of universal design set out by Ron Mace and colleagues (Story, Mace and Mueller, 1998), through inclusive design research that made the social and commercial case for designing for the whole population (Clarkson et al., 2003), to the Stockholm Declaration of the European Institute for Design and Disability, which presented design for all as a matter of equal opportunity and participation (EIDD, 2004). What these have in

common is that exclusion is treated as a failure of design, not a shortcoming of the person left out. Design for All starts with a plain observation. People differ in age, ability, language, culture and circumstance, and anything designed for an imagined average user quietly shuts out everyone else. The tradition is well established. It runs from the principles of universal design set out by Ron Mace and colleagues (Story, Mace and Mueller, 1998), through inclusive design research that made the social and commercial case for designing for the whole population (Clarkson et al., 2003), to the Stockholm Declaration of the European Institute for Design and Disability, which presented design for all as a matter of equal opportunity and participation (EIDD, 2004). What these have in common is that exclusion is treated as a failure of design, not a shortcoming of the person left out.

Responsible Design asks what designers actually answer for. Victor Papanek's *Design for the Real World* (1971) was among the first books to argue that designers carry moral and ecological responsibility for what they put into the world, and that a profession with so much influence over everyday life cannot claim to be neutral. Papanek wrote about the planet and about people at the margins together, and that pairing matters here, because responsibility has two horizons. One runs across present society: who is included, who is heard, who carries the risks of a decision and who gets the benefits. The other runs across time: who inherits the materials, energy, waste, data and habits that designs set in motion.

Taken together, these ideas make it hard to separate inclusion from sustainability. A product that is accessible but short-lived, impossible to repair and heavy on resources serves today's users by borrowing from tomorrow's, and the cost of that borrowing usually falls first on

communities that are already at the margins. A sustainability strategy that ignores who can afford, reach, understand or trust its solutions does something similar: it moves advantage around rather than sharing it. Design for sustainability has itself moved this way, widening from individual products to product-service systems and socio-technical transitions (Ceschin and Gaziulusoy, 2016). Design for All and Responsible Design are therefore one agenda seen along two axes. Design for All asks *for whom*. Responsible Design adds *for how long*, *at whose expense* and *accountable to whom*. Inclusive design that ignores the planet and future generations is only partly inclusive, since those not yet born are the most excluded stakeholders of all.

The responsibility of art and science. The responsibility of art and science

Asking designers to carry this weight is less unusual than it sounds. The idea that creative and scientific work answers for its consequences has a long history. The sociologist Max Weber set out an ethic of responsibility (1946) in which people are accountable for the foreseeable results of their actions, and not only for their intentions. In the science and innovation literature this has developed into responsible research and innovation, which asks innovators to anticipate consequences, examine their own assumptions, bring in a wider range of voices and stay responsive as circumstances change.

The arts and humanities make a parallel claim. Martha Nussbaum (2010) argues that education in the arts and humanities builds the critical thinking and the imaginative capacity to see other people's lives on which democratic societies depend. Design sits where these traditions meet. It draws on scientific and engineering knowledge and

on the imaginative, empathic and aesthetic work of the arts to propose futures that do not yet exist.

For a university named after an engineer-designer, and a design school within a College of Engineering, Design and Physical Sciences, this is familiar ground. Brunel has long moved between making and thinking, between workshop, laboratory and community, and the papers in this issue show that habit at work.

The seven contributions.

The papers fall into three groups: technologies that mediate care, communication and information in communities, and the environments and institutions where design is learned and practised.

Technologies that mediate care Technologies that mediate care

Ibrahim Dhouafli and Federico Colecchia open with a scoping review of 80 publications on health equity in AI-mediated clinical decision-making systems. They find that inequity enters at every stage of the AI lifecycle, from data collection to post-deployment monitoring, and not only through biased algorithms. Almost all the reviewed studies (79 of 80) invoke Responsible Design, yet few turn it into operational design or governance practice. Disability, digital exclusion and legal liability get little coverage, and underserved communities rarely take part in design or governance. The paper is a useful reminder that responsibility has to be designed into systems over time, with ways to monitor them and put things right, and that it covers who is accountable when harm occurs as well as who is included at the start.

Hilal Şahin Eraslan, Aslı Günay and Gülşen Töre-Yargın review 52 studies of older adults' experiences with voice-based conversational agents. They move the focus from usability to the hedonic side of use:

confidence, companionship, stigma and trust. Three tensions recur, between social connection and social dissonance, assistance and incompetence, and self-confidence and self-doubt. The authors argue that older adults' autonomy should be a precondition of a positive experience and not an afterthought. The same feature, a reminder for example, can empower or infantilise depending on how it is calibrated. This is responsible design at the scale of a single interaction, and the authors rightly note that older adults have too often been treated as evaluated users rather than contributors to design.

Abinaya Sripathy, Gabriella Spinelli and Michele Walsh turn to the body and to a physical device. Avira+ grew out of a final-year Product Design Engineering project within the Design for Health collaboration. It is a wireless, dual-channel electrical stimulation system with a companion app, designed for shoulder pain after stroke or brain injury. The process drew on an observational hospital visit, conversations with neurophysiotherapists and attention to patients, carers and clinicians as three groups with different needs. Safety decisions, such as pre-approved clinician sessions and sensors that detect loss of skin contact, sit alongside a commitment to plain language that came from supporting a stroke survivor with limited English. The paper shows that designing for extreme needs is itself a responsible act.

Communication, information and communities Communication, information and communities

Sena Berktaş, Busayawan Lam and Gülşen Töre Yargın look at schools in Türkiye, where Syrian families displaced by war make up a large part of the migrant population. Through a human-centred review of

18 practice- and research-based cases, they assess interpreter services, video remote interpreting, mobile applications and pictorial booklets as ways of helping parents take part in their children's education. Interpreting comes out as the most effective option, translation applications as a practical complement and booklets as insufficient on their own. The framing matters as much as the findings. Communication tools are treated as relational platforms through which marginalised families become participants in public institutions, and the authors are explicit that the next stage must involve those stakeholders directly.

Yufan Guo examines a different communication environment: short videos on six platforms, from Douyin and Kuaishou to TikTok, Instagram and YouTube Shorts, where health education, personal testimony and supplement promotion share a single frame. She proposes a Responsible Commercial Transparency Framework built on commercial identity disclosure, the boundary between education and promotion, and the visibility of risks and limitations. She applies it to six cases and draws on questionnaire evidence from older Chinese adults. Her argument is that transparency is a visual communication design question as well as a regulatory or marketing one, which places responsibility in hierarchy, emphasis and placement, the choices designers make every day.

Environments and institutions Environments and institutions

Niranjana Menon, Youngok Choi and Fabrizio Ceschin turn to the workplaces of academics themselves. Interviews with thirty academic staff across UK universities identify five barriers to wellbeing and productivity: limited acoustic privacy, environmental discomfort, spatial inflexibility, limited personal control and the absence of

natural, restorative elements. These are translated into a Biomimetic Design Translation Framework that maps needs onto nature-inspired strategies at the levels of form, process and ecosystem. The paper takes natural systems as a model for sustainable design and treats access to quiet, comfortable, restorative space as a matter of equity and dignity that is unevenly distributed across roles and institutions.

Mohammed Elsouri closes with a reflection on design education. A retail-environment brief, set jointly by an audio equipment brand, a UK high-street retailer and a design agency, was taken on by 58 second-year students, with a brief running to over 200 pages and a dozen or more 3D computer models to support them. The paper argues that computer-based knowledge acquisition within industry collaboration helps students learn to design responsibly. Brand goals were interrogated through anthropometrics, wheelchair access, safe circulation and the cultural reading of signs, while generative AI was kept in a supporting role so that knowledge building stayed with the students. If responsible design is to become a habit, it has to be learned, and the paper shows how a school might teach it inside the commercial briefs students will meet in practice.

One thread runs through the collection: participation. Almost every contribution points to the same gap. The people at the centre of the design are consulted late, evaluated rather than engaged, or left out of governance. Sixty years after Brunel became a university, the question these papers pose is the right one to carry forward: not only whether designs work, but for whom, at whose expense and for how long. One thread runs through the collection: participation. Almost every contribution points to the same gap. The people at the centre of the design are consulted late, evaluated rather than engaged, or left out of governance. Sixty years after Brunel became a university, the

question these papers pose is the right one to carry forward: not only whether designs work, but for whom, at whose expense and for how long.

The editors are grateful to the authors, the reviewers and the editorial team of *Design for All* for their generosity and rigour, and to the early-career researchers whose work gives this issue its energy.

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Towards Responsible Design for Equitable AI-Mediated Clinical Decision-Making Systems: A Scoping Review of Health Equity and Underserved Populations

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Federico Colecchia[2]

Abstract

Artificial intelligence is becoming a core feature of Clinical Decision-Making Systems for diagnosis, risk prediction and treatment planning. However, the benefits are not equally distributed and underserved communities remain at risk from algorithmic bias, accessibility barriers and digital exclusion.

This scoping review synthesises evidence on health equity within AI-mediated Clinical Decision-Making Systems from a Responsible Design perspective, with emphasis on racialised communities, disabled patients and digitally excluded populations.

The review followed the Arksey and O'Malley framework (2005) and reported in accordance with the PRISMA-ScR. Scopus was searched iteratively. Overall eligibility covered English-language publications indexed in Scopus and published between 2016 and 2026. 2,082 records were found. After deduplication, relevance screening and structured evidence mapping across seven predefined conceptual domains, 80 publications were selected and analysed using thematic synthesis.

Evidence was dominated by health equity (74/80) and algorithmic bias (55/80). Inequality occurred throughout the entire AI lifecycle, from data collection and model development to implementation, deployment and monitoring, not only from algorithmic performance. Racialised communities received the most attention, while disability (8/80), digital exclusion (23/80) and legal liability (6/80) were underrepresented. Responsible Design was addressed in 79/80 studies, but few translated it into operational design or governance practices. Governance remained fragmented across disciplines and jurisdictions, post-deployment equity assessment was scarce, and underserved communities rarely had a role in system design or governance.

AI-mediated clinical decision-making may reproduce and amplify existing inequalities when deployed within health systems characterised by structural weaknesses. These risks are significant for underserved communities where limitations in data representation, digital access, inclusive participation and infrastructure remain unresolved. Equitable implementation requires these systemic conditions to be addressed alongside AI design, deployment and governance. AI should therefore be understood not as a solution to existing inequities, but as a technology whose effects depend on inclusiveness and quality of systems.

Keywords: ***artificial intelligence; Clinical Decision-Making Systems; health equity; Responsible Design; underserved populations; algorithmic bias; governance; Liability; scoping review***

Introduction

The rapid integration of AI into Clinical Decision-Making Systems (CDMS) is transforming diagnosis, risk prediction and treatment planning (Bashir et al., 2026; Wen et al., 2024). As these systems become routine in clinical practice, they have evolved from technological innovations into socio-technical systems that influence how care is delivered, accessed and distributed across populations (Belmejdoub et al., 2026; Cappello et al., 2026).

Health equity is shaped by social and socioeconomic factors like income, education, discrimination and healthcare access. These factors influence both real-world health outcomes and the clinical data used to train AI systems (WHO, 2025). Consequently, AI trained on biased or unrepresentative data may treat patients "equally" while producing inequitable outcomes. This underscores the difference between equality (treating everyone the same) and equity (allocating resources based on need), where health inequities represent avoidable and unjust differences (Whitehead, 1992; Whitehead & Dahlgren, 2006). Here, health equity is defined as the absence of systematic, remediable differences in health outcomes or resource access between socially advantaged and disadvantaged groups (Braveman & Gruskin, 2003).

Because AI-mediated clinical decision-making systems (CDMS) learn from historical data within unequal healthcare environments, underserved communities need specific safeguards (Hoffman, 2021; Tsai et al., 2022). Algorithmic bias, underrepresentation, and digital exclusion create inequitable outcomes that disproportionately impact vulnerable populations (Budhu et al., 2025; Hilling et al., 2025). Specifically, racialised groups face lower diagnostic precision from

imbalanced datasets (Chin et al., 2023), disabled patients encounter accessibility barriers (Olawade et al., 2025; Ricchezze et al., 2025), and digitally excluded populations experience reduced access to AI healthcare (Osonuga et al., 2025).

Research in technical fields has addressed bias mitigation, algorithmic fairness, and explainable, trustworthy AI (Al-Duais et al., 2026; Lan et al., 2025). Design research promotes human-centred, inclusive, and participatory methods, involving clinicians, patients, and community representatives in technology development (Bokolo et al., 2026; Clifford et al., 2022). Legal, ethical, and policy researchers have established governance frameworks for accountability, transparency, and regulatory oversight (Cary et al., 2025; Lau, 2025).

Fragmented evidence and isolated designs create a critical gap in equitable AI systems for underserved communities. Existing studies usually evaluate demographic groups separately, neglecting how interconnected factors impact health equity in AI-mediated CDMS (Belmejdoub et al., 2026; Ingraham et al., 2023). While some reviews address specific healthcare AI aspects (Adegunle et al., 2026; Murphy et al., 2025), none integrate these via a Responsible Design lens for underserved groups.

Unlike isolated approaches to fairness, accessibility, transparency, or governance, Responsible Design provides an integrated solution. It advances equitable technology by combining ethical, organizational, technical, and societal factors throughout system development (Arockiasamy, 2025; Bagali et al., 2026). This framework promotes stakeholder engagement, inclusivity, accountability, and real-world system context during implementation, monitoring, and continuous improvement (Bokolo et al., 2026; Dinc and Ardic, 2026).

This scoping review synthesises the current evidence on health equity within AI-mediated CDMS from a Responsible Design perspective, addressing four questions: (1) How does the literature conceptualise health equity within AI-mediated CDMS? (2) What equity challenges are experienced by racialised communities, disabled patients and digitally excluded populations? (3) How are Responsible Design, governance and accountability currently incorporated into AI-mediated CDMS? (4) What evidence gaps and future research priorities emerge from the existing literature?

2. Methods

2.1 Study Design

A scoping review method was selected for synthesising literature on health equity in AI-mediated CDMS, emphasising underrepresented communities and Responsible Design, given the field's multidisciplinary nature. The review followed Arksey and O'Malley framework and was reported according to PRISMA-ScR. No protocol was prospectively registered.

Scopus was searched through 16 iterative searches combining AI-mediated CDMS terms with equity, harm, design, or governance concepts. Eligibility covered English publications (2016–2026), yielding 2,082 records (1,697 unique after removing 385 duplicates: 365 by DOI, 20 by title/year).

Titles and abstracts were evaluated against the predefined eligibility criteria. Eligible records were assessed across seven conceptual domains: AI-mediated CDMS, health equity/disparities, underserved communities, Responsible Design, governance/accountability, methodological relevance, and publication type. For the first six, predefined relevance terms identified in the title, author-supplied

keywords recorded in Scopus, and the abstract were weighted 3, 2, and 1 points, respectively, with each term counted once at its highest-value location. Domain scores were capped at 12, converted to a 0–4 scale, and multiplied by specific domain weights: 2.5 (CDMS), 3.0 (health equity), 3.0 (underserved), 2.0 (Responsible Design), 1.5 (governance), and 1.0 (methodology), totalling up to 52 points. The seventh domain, publication type, contributed a source-type score of 1.0 for journal articles and 0.5 for conference papers and book chapters. A post-2020 recency bonus of 0.5 points per year, capped at 3.0, was added. The resulting weighted relevance score had a maximum of 56 points, with 15.0 used as the minimum relevance threshold. Records meeting the threshold were subsequently ranked, and the 80 highest-ranked publications were retained.

Table 1: Evidence Mapping Framework

Conceptual Domain	*Purpose*
AI-mediated CDMS	***Relevance to clinical AI***
Health equity and healthcare disparities	***Focus on equity outcomes***
Underserved communities	***Inclusion of target populations***
Responsible Design	***Design principles and approaches***
Governance and accountability	***Oversight, regulation and responsibility***
Methodological relevance	***Contribution to the review objectives***
Publication type	***Contribution to relevance ranking based on publication type***

2.2 Eligibility Criteria

This review evaluated literature on AI-mediated CDMS and health equity. During screening, papers were eligible if they investigated CDMS design, implementation, governance, or evaluation while

addressing health equity, algorithmic fairness, healthcare disparities, underserved populations, or Responsible Design—particularly racialised, disabled, or digitally excluded groups. These screening criteria were not encoded in the search queries.

Two other parameters bounded the corpus. First, all records came from Scopus, a multidisciplinary database spanning healthcare, computer science, and social sciences. Second, the 2016–2026 publication window varied by search: only six of sixteen searches used the full range, ten started later, and one ended in 2025. Thus, early year coverage is uneven; themes like governance, liability, and automation bias had shorter windows than health equity, bias, and underserved populations.

Table 2. Eligibility criteria.

Criterion	*Inclusion*	*Exclusion*
Population	***Underserved communities and other vulnerable groups***	***Populations outside the review scope***
Context	***AI-mediated CDMS***	***Non-clinical AI or general AI applications without healthcare relevance***
Concept	***Health equity, algorithmic fairness, Responsible Design***	***Purely technical algorithm development without clinical or equity implications***
Study type	***Peer-reviewed research articles, systematic and scoping reviews, conference papers, book chapters, and other scholarly publications***	***Editorials, commentaries, opinion pieces, and non-scholarly or non-peer-reviewed material without sufficient relevance to the review questions***

Criterion	*Inclusion*	*Exclusion*
	relevant to the review questions	
Language	***English***	***Non-English***
Timeframe	**Published 2016–2026**	**Published before 2016**
Information source	**Indexed in Scopus**	**Not indexed in Scopus**
These criteria defined the final corpus eligibility rather than identical parameters for every retrieval search.		

2.3 Study Selection

Study selection followed PRISMA-ScR framework. After screening titles and abstracts against eligibility criteria, remaining records underwent full-text assessment for relevance to AI-mediated CDMS, health equity, underserved communities, and Responsible Design. Eligible records were scored across seven conceptual domains using weighted criteria based on title, abstract, and author-supplied keywords recorded in Scopus. Records meeting a 15.0-point minimum threshold were ranked by score. The top 80 records were selected and grouped into three priority tiers: Core (27), Important (27), and Relevant (26). The final ranked list was verified by the author.

2.4 Data Charting

Data were extracted using a charting format developed for this review. For each publication, key information was collected on publication details, study design, healthcare context, AI application, target population and geographical setting, health equity issues, algorithmic bias, accessibility, disability, digital exclusion,

governance, liability and Responsible Design approaches, together with the main findings and research gaps identified.

2.5 Data Synthesis

Thematic synthesis used a hybrid deductive–inductive approach. The initial data-charting framework captured equity, algorithmic bias, disability, digital exclusion, Responsible Design, governance, liability, care quality, and healthcare access. Extracted evidence was repeatedly examined to identify recurring patterns, differences and relationships across studies, allowing codes to be refined and grouped into broader themes. The final nine themes were retained as they consistently represented the principal issues identified across the evidence and provided a coherent basis for synthesis. For each theme, the evidence was synthesised to identify barriers to equitable AI implementation, current design approaches and improvement opportunities.

3. Results

3.1 Characteristics of Included Studies

The search and screening process revealed 80 publications that met the inclusion criteria from an initial 2,082 records, illustrated in the PRISMA-ScR flow diagram (Figure 1).

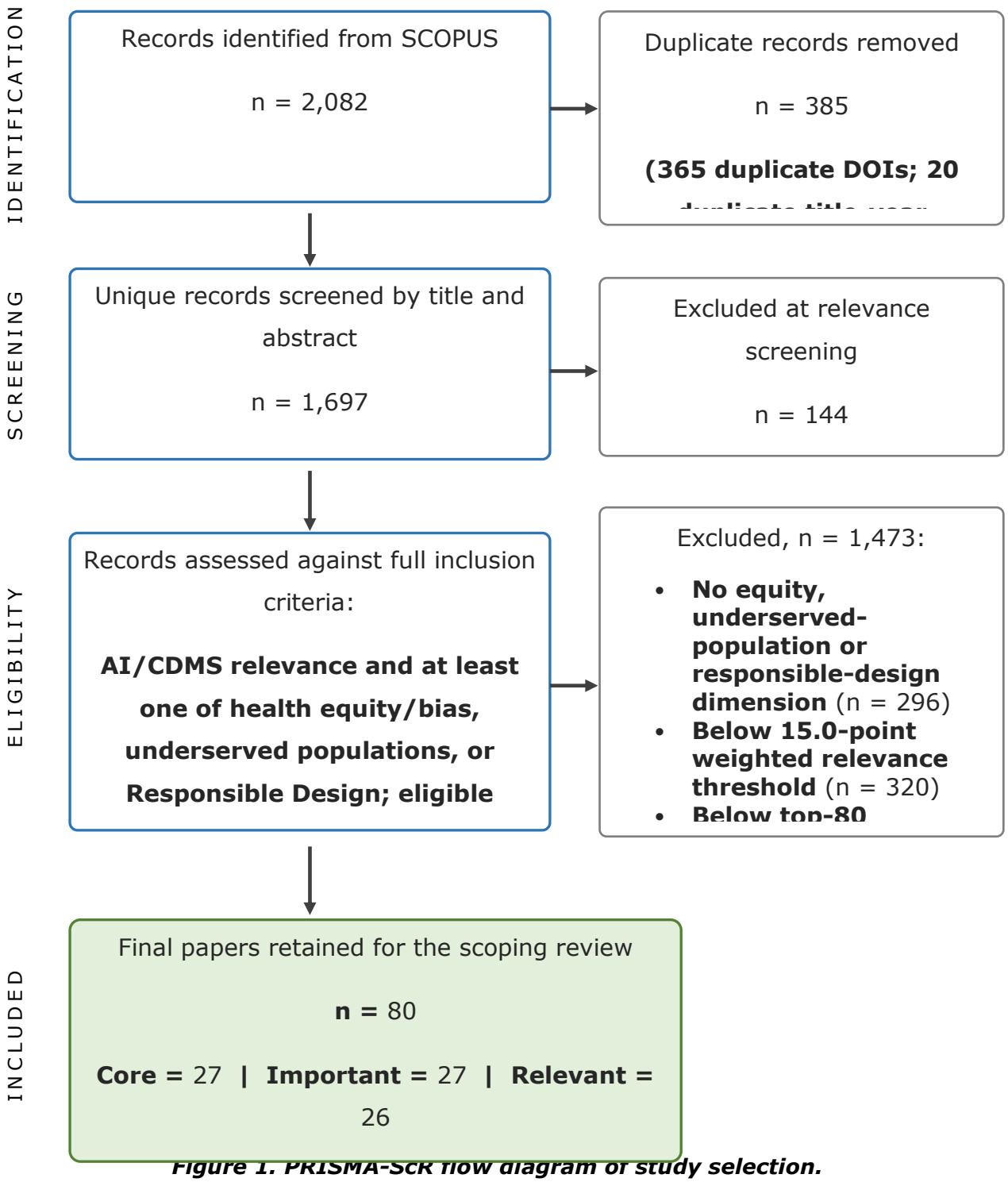


Figure 1. PRISMA-ScR flow diagram of study selection.

Note: The 15.0 threshold functioned as an initial relevance floor; it was not the criterion determining the final sample size. Records meeting the threshold were subsequently ranked by their total weighted relevance score, and the 80 highest-ranked records were retained.

Most included studies were published between 2022 and 2026 (Figure 2), reflecting the growing use of AI in healthcare and increasing attention to how algorithmic systems may reinforce existing inequalities when equity is not embedded in AI design, implementation and governance (Murphy et al., 2025; Zarnegar, 2026).

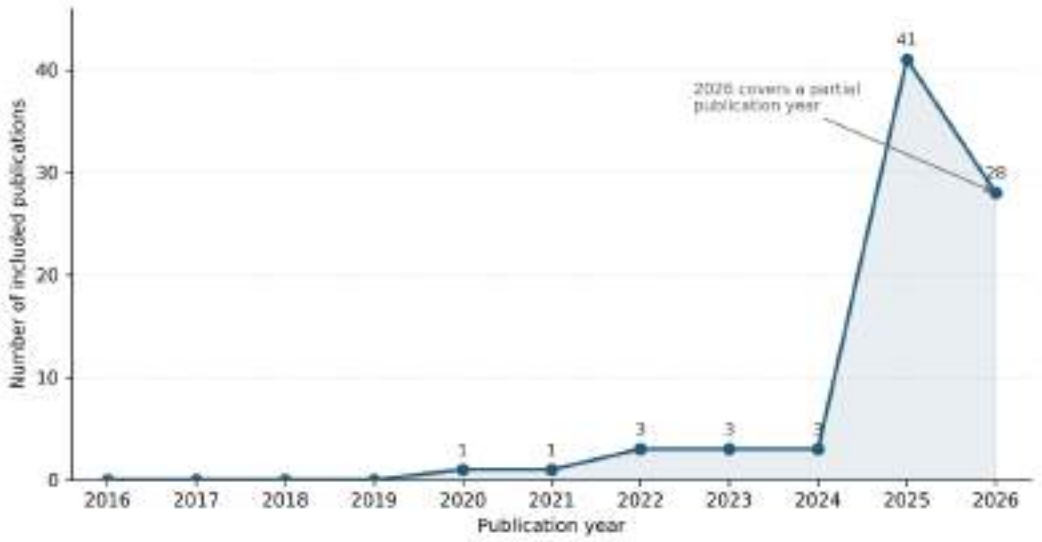


Figure 2. Included publications per year, 2016–2026 (N = 80).

The evidence base was methodologically diverse. Empirical studies focused on AI in diagnostic decision-making, clinical risk prediction, medical imaging, electronic health record analytics and patient triage (Al-Duais et al., 2026; Kukkar et al., 2026). Reviews examined algorithmic fairness, ethical governance and disparities (Adegunle et al., 2026; Murphy et al., 2025). Conceptual papers explored Responsible Design, inclusive governance (Bokolo et al., 2026; Ekuta, 2025).

Table 3. Characteristics of the included studies (N = 80).

Characteristic	*n*	*%*
Study design		

Narrative and literature reviews	***24***	***30.0***
Conceptual, perspective and policy papers	***18***	***22.5***
Technical/empirical model studies	***17***	***21.3***
Systematic and scoping reviews	***10***	***12.5***
Qualitative and mixed-methods studies	***10***	***12.5***
Other	***1***	***1.3***
Publication year		
2016–2022	***5***	***6.3***
2023–2024	***6***	***7.5***
2025	***41***	***51.3***
2026	***28***	***35.0***
Geographical context		
USA	***18***	***22.5***
Europe	***14***	***17.5***
of which United Kingdom	***(5)***	***(6.3)***
India / India-focused	***11***	***13.8***
Other countries	***20***	***25.0***
Not reported (global-scope reviews and conceptual papers)	***17***	***21.3***
AI application		
LLM, NLP and generative AI	***22***	***27.5***
Predictive and risk-prediction models	***17***	***21.3***
Diagnostic and screening AI	***17***	***21.3***
CDMS	***13***	***16.3***
Telemedicine, mobile and wearable AI	***11***	***13.8***

Most included studies focused on high-income-country settings, particularly the USA and Europe, including the United Kingdom (Adegunle et al., 2026; Hilling et al., 2025). Research from India

outlines increased interest in AI alongside persistent inequality in healthcare access, digital infrastructure and socio-economic status (Baruah and Majumdar, 2026; Roy et al., 2025).

Across the literature, AI-mediated CDMS emerged as socio-technical systems in which health equity is shaped by systems-level barriers including data quality, technical and algorithmic performance, accessibility, clinician oversight, digital literacy and institutional governance (Belmejdoub et al., 2026; Cappello et al., 2026).

Health equity, algorithmic bias and fairness dominated the corpus, while disability, digital exclusion, access to support and legal accountability were underrepresented (Hoffman, 2021; Olawade et al., 2025). Similarly, few studies examined lifecycle Responsible Design, favouring technical performance over its impact on people and society (Bagali et al., 2026; Ingraham et al., 2023).

3.2 Health Equity Challenges in AI-mediated CDMS

Health equity emerged as a central topic in the literature. AI-mediated CDMS can potentially improve healthcare but also contribute to inequalities through algorithmic design, healthcare systems, and broader social determinants of health (Iloanusi and Chun, 2024; Murphy et al., 2025; Lau, 2025).

Table 4. Thematic synthesis: findings and evidence gaps across the 80 included studies.

Theme	*Papers (n)*	*Main findings*	*Remaining gaps*
Responsible Design	***79***	***Participatory/co-design, explainable AI, accountability; principles shifting to operational tooling.***	***Limited framework replication; no reporting standard.***

Health equity	***74***	***Data representation and service access dominate outcomes.***	***Often aspirational; rarely measured; limited post-deployment evidence.***
Algorithmic bias	***55***	***Mainly linked to unrepresentative training data.***	***Mitigation rarely validated; intersectional bias overlooked.***
Quality of care	***55***	***Improved diagnosis, personalisation and care continuity***	***Few subgroup or longitudinal evaluations.***
Governance	***50***	***EU AI Act, US and WHO guidance dominate.***	***Largely conceptual; equity auditing remains aspirational.***
Access to support	***44***	***Telemedicine, mobile health and conversational AI expand access.***	***Outcomes rarely evaluated.***
Digital exclusion	***23***	***Literacy, connectivity, device access as structural preconditions of inequity***	***Mainly descriptive; affordability underexplored.***
Disability	***8***	***Assistive technology, rehabilitation, inclusive design.***	***Limited intersectional analysis with race, income and geography; little outcome data***
Liability	***6***	***Least developed; clinician liability concerns.***	***No adopted liability framework for clinical AI harm.***

Algorithmic bias was the primary source of inequity, driven by biased training data, underrepresentation, and unequal model performance across demographic groups (Al-Duais et al., 2026; Bai et al., 2026). These limitations are rooted in historical healthcare disparities, diagnosis and treatment. AI systems can inherit, reproduce and amplify existing inequalities (Hoffman, 2021; Tsai et al., 2022). Fairness therefore extends beyond algorithmic performance, as

higher accuracy cannot by itself address inequalities rooted in institutional structures (Husebo et al., 2025; Sarkar et al., 2025). Because inequities may emerge across the AI lifecycle, continuous governance is required rather than isolated technical interventions (Hasanzadeh et al., 2025; Chandra et al., 2025; Lan et al., 2025). Finally, although AI can improve diagnostics and decision support, its benefits are not necessarily distributed equitably (Bray et al., 2025; Wong et al., 2025).

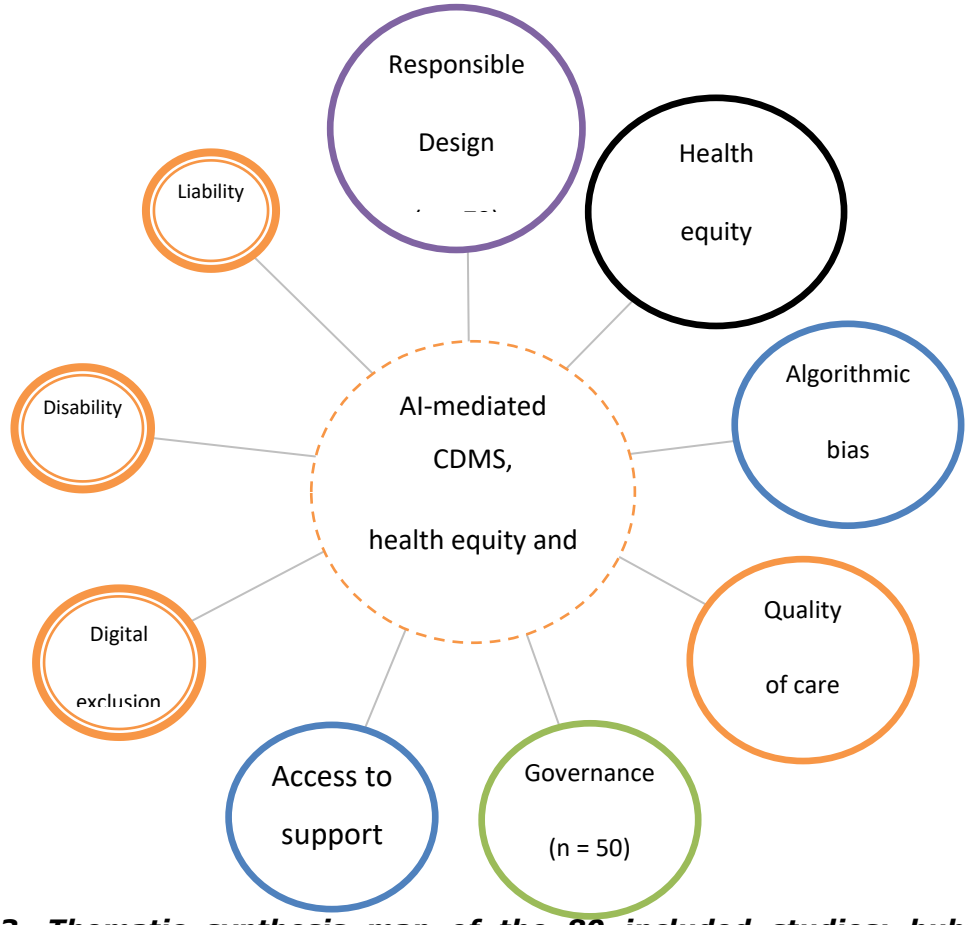


Figure 3. Thematic synthesis map of the 80 included studies; bubble size is proportional to the number of studies coded to each theme.

3.3 Experiences of Underserved Communities

The literature showed that the impact of AI-mediated CDMS is unequal, disproportionately affecting communities facing structural healthcare barriers (Budhu et al., 2025; Olawade et al., 2025). The

descriptor "Underserved" is contextual rather than universal, reflecting local histories and health systems conditions: it may apply to minorities (Chin et al., 2023; Hoffman, 2021), rural and linguistic groups (Baruah and Majumdar, 2026; Roy et al., 2025; Dinc and Ardic, 2026; Mwogosi, 2025), migrants (Cheong and Kubota, 2026), sexual minorities (Racine, 2025) and other populations experiencing structural barriers to healthcare. These groups share data underrepresentation, limited digital access, and exclusion from system design (Bokolo et al., 2026; Nair et al., 2025). Understanding these experiences depends on cultural, linguistic, and systemic contexts rather than a single profile.

3.3.1 - Racialised Communities

Racial and ethnic inequities were the most discussed issues in the literature (Ekuta, 2025; Murphy et al., 2025). AI systems can reproduce biases present in initial clinical data, with underrepresented populations potentially experiencing poorer outcomes (Hasanzadeh et al., 2025). These disparities reflect not only algorithmic limitations but broader inequalities in healthcare access, delayed diagnosis and social disadvantage (Hilling et al., 2025; Hoffman, 2021). The literature widely recognises demographic representation as essential (Chin et al., 2023; Zarnegar, 2026) and highlights that equitable AI requires continuous monitoring, transparent reporting and meaningful engagement with affected communities (Budhu et al., 2025; Clifford et al., 2022).

3.3.2 - Disabled Patients

Disability received less attention than racial inequities within the final corpus despite its importance in Responsible Design research (Olawade et al., 2025; Ricchezze et al., 2025). Most current research

focused on digital health rather than AI-mediated CDMS (Liu et al., 2025; Thorat and Kalani, 2026), and AI systems often disadvantage users with physical, sensory or cognitive impairments (Murugesan and Viswanathan, 2024; Olawade et al., 2025). The literature supports more inclusive design, but empirical evidence remains limited (Ricchezze et al., 2025; Thorat and Kalani, 2026).

3.3.3 - Digitally Excluded Populations

Digital exclusion was also a major contributor to inequitable AI-mediated CDMS (Fanarioti and Karpouzis, 2025; Nair et al., 2025). The main causes are device access, language barriers, poor connectivity, poverty, and limited literacy (Cheong and Kubota, 2026; Mwogosi, 2025). As a result, digital reliance creates new barriers that reflect broader structural inequalities (Kannadasan, 2026; McGrath et al., 2025; Mendez-Lopez et al., 2026).

3.3.4 - Cross-cutting Patterns Across Underserved Communities

Across all three groups, inequitable AI outcomes resulted not only from algorithmic bias but from the interaction of technical design with broader social and healthcare inequalities (Belmejdoub et al., 2026; Iloanusi and Chun, 2024). Underrepresentation and lack of community participation in AI governance were common concerns (Chin et al., 2023; Clifford et al., 2022). Researchers must adopt socio-technical approaches to address structural inequalities across the AI lifecycle, with systematic bias identification and mitigation extending from model conception through deployment and post-deployment surveillance (Hasanzadeh et al., 2025; Cappello et al., 2026; Lan et al., 2025).

3.4 Responsible Design, Governance and Accountability

Through the reviewed literature, Responsible Design emerged as a promising perspective to address the ethical and societal implications of AI-mediated CDMS (Cappello et al., 2026; Ekuta, 2025) (Figure 4). Many studies stressed fairness, inclusivity, transparency and human-centred development (Arockiasamy, 2025; Fesabas and Shaker, 2025), but few translated these principles into practical approaches supporting equitable CDMS (Bagali et al., 2026; Cary et al., 2025).

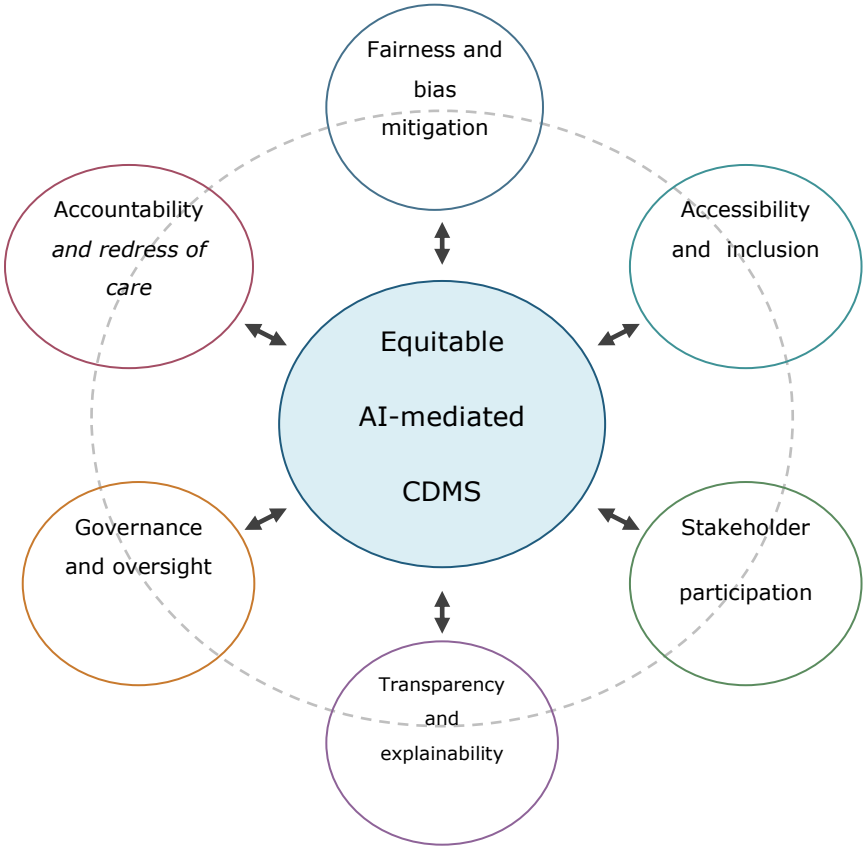


Figure 4. The Responsible Design perspective for equitable AI-mediated CDMS.

Responsible Design is described as a multidisciplinary approach integrating technical performance with broader ethical, social and organisational responsibilities, rather than a single methodology

(Arockiasamy, 2025; Radanliev, 2025). Equitable AI is not limited to algorithmic accuracy, it depends on understanding who benefits, who can be disadvantaged and how inequities can be addressed during development, deployment and evaluation (Bagali et al., 2026; Ekuta, 2025).

Participatory and human-centred approaches were widely recognised as core components of Responsible Design (Bokolo et al., 2026; Budhu et al., 2025). Several studies recommended clinicians, patients and community representation throughout AI-CDMS development to improve transparency, trust and inclusivity (Cheong and Kubota, 2026; Liu et al., 2025). However, this involvement was limited to system evaluation rather than the full AI lifecycle (Bokolo et al., 2026; Ingraham et al., 2023). Transparency and explainability also appeared as preconditions for trustworthy AI and professional accountability (Abu Assab et al., 2026; Sarkar et al., 2025).

The literature considers Responsible Design an organisational responsibility requiring constant monitoring of algorithm performance and unexpected consequences after deployment (Bagali et al., 2026; Wilkie et al., 2025). Formal governance is needed, with ethical guidelines, frameworks and policy initiatives to ensure fairness, transparency, human oversight and accountability. Within the deliberately targeted UK–India evidence, studies indicated differences in governance maturity but common gaps in ethical implementation (Baruah and Majumdar, 2026; Yu et al., 2026). Legal accountability is underrepresented in the final corpus, with few studies investigating responsibility or patient redress when AI leads to inequitable outcomes (Abu Assab et al., 2026; Savastano et al., 2025).

4. Discussion

This review synthesised 80 studies on health equity in AI-mediated CDMS through a Responsible Design perspective. Its main finding is that inequity is not solely a technical problem but a systemic one, produced across the AI lifecycle and amplified by fragmented governance.

4.1 Assessing the Gap: Why Advanced CDMS May Fail to Reduce Health Inequities?

The persistence of health inequities remains difficult to explain because research has not yet fully established where inequities arise across the clinical AI lifecycle or how different contributing factors interact. Most work has been oriented towards improving algorithmic accuracy rather than understanding how these systems work in real-clinical practice (Ingraham et al., 2023; Nouis et al., 2025).

Equity is an emergent property of the broader clinical ecosystem rather than the algorithm itself (Belmejdoub et al., 2026; Cappello et al., 2026). Because bias can arise throughout the AI lifecycle and poor monitoring harms performance, a model might pass a fairness audit but still cause inequitable outcomes (Hasanzadeh et al., 2025; Radanliev, 2025; Tsai et al., 2022). Ongoing model evaluation must look beyond metrics like classification accuracy to assess impact across diverse communities, especially marginalized groups (Chin et al., 2023; Ingraham et al., 2023). An intersectional approach helps clarify how systemic barriers like socio-economic status, ethnicity, and disability are interwoven (Lau, 2025; Putri, 2026). Most importantly, this evaluation must be continuous, spanning from model development to post-deployment surveillance (Al-Duais et al., 2026; Bagali et al., 2026).

4.2 Responsible Design as an Integrating Perspective for Equitable AI

A recurring pattern across the literature is a quiet emergent consensus. Studies on responsible AI, inclusive, human-centred, participatory design, and responsible innovation share one idea: equitable AI must actively protect the people impacted by technological decisions at all lifecycle stages (Arockiasamy, 2025; Clifford et al., 2022). This review interprets this consensus as a bridge to Responsible Design, not as one more methodology but as the perspective within which various approaches become synergistic: human-centred design is based on clinical and patient relevance (Giri et al., 2025; Gupta and Jaiswal, 2025); participatory and co-design involve local communities in designing systems rather than receiving them (Bai et al., 2026; Iloanusi and Chun, 2024); inclusive design extends usability beyond the average user (Bokolo et al., 2026; Thorat and Kalani, 2026). Responsible Design provides an integrating perspective that makes a place for fairness, accessibility, participation, transparency and accountability, the latter remaining comparatively underdeveloped in the literature (Figure 5).

The corpus demonstrates how far this integration is from being implemented. Some studies reduce Responsible Design to ethical principles like fairness and transparency (Fesabas and Shaker, 2025; Radanliev, 2025), others regard it as a participatory process with clinicians, patients or communities (Clifford et al., 2022; Liu et al., 2025) and only a few extend it to governance, monitoring and organisational learning after deployment (Bagali et al., 2026; Cary et al., 2025), highlighting a critical deficit in institutional infrastructure.

This is why Responsible Design addresses the gap discussed in Section 4.1. If inequity arises across a socio-technical lifecycle, the response should be distributed across it: inclusive datasets and explainability relevant to clinical reasoning at development (Marvin et al., 2023; Nouis et al., 2025), participatory processes at design, and mechanisms to monitor performance and adapt governance after deployment (Cappello et al., 2026; Ingraham et al., 2023). Responsible Design is thus an ongoing process, not a one-time checklist.

A structured approach to move from principle to practice is still lacking. Design Research Methodology provides this by cycling through research clarification, descriptive, prescriptive, and further descriptive studies (Blessing and Chakrabarti, 2009). This review aids the initial descriptive stage by synthesising how equity, harm, and governance interact across the AI lifecycle and lays the groundwork for a prescriptive stage in which Responsible Design artefacts can be developed and tested.

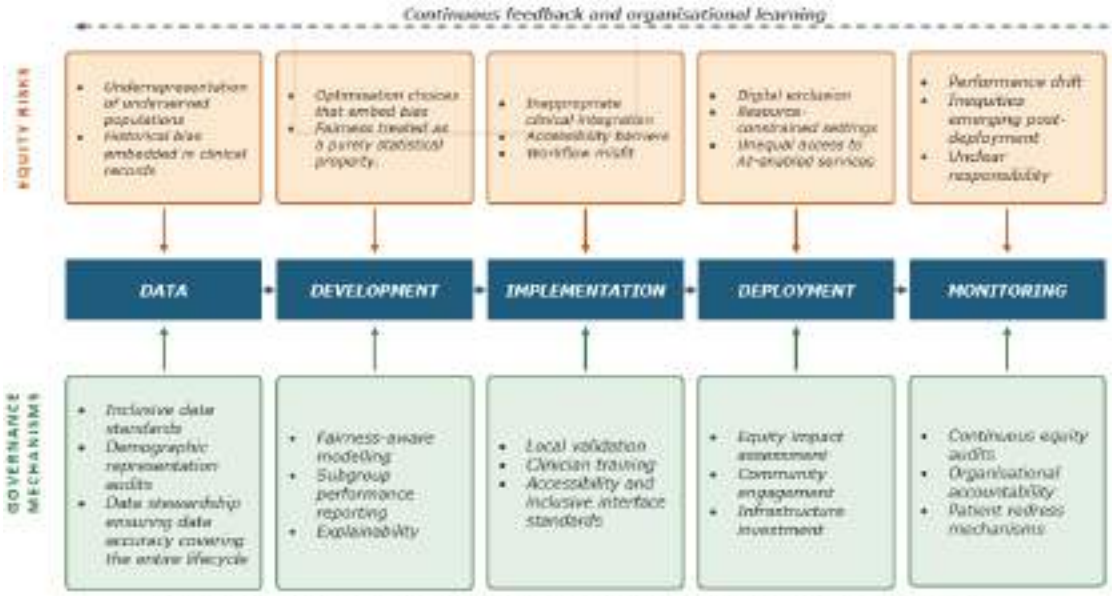


Figure 5. Responsible Design across the AI lifecycle: equity risks and governance mechanisms.

4.3 Governance and Accountability Beyond Technical Fairness

Governance was discussed in most studies (50/80) where the evidence remains fragmented. Ethical frameworks focused on fairness, transparency and autonomy (Fesabas & Shaker, 2025; Ricchezze et al., 2025). Regulatory guidance emphasised compliance and safety (Adegunle et al., 2026; Lacmanovic & Skare, 2025). Technical research focused on bias, explainability and model performance (Lan et al., 2025; Sarkar et al., 2025). Healthcare governance concentrated on clinical quality and patient safety (Cary et al., 2025; Nouis et al., 2025). Few studies integrated these perspectives into a single framework over the whole AI lifecycle (Bagali et al., 2026). This fragmentation is exacerbated by jurisdictional differences, as developers navigate frameworks such as the GDPR and the EU AI Act. Neither framework was specifically designed as a comprehensive framework for addressing health equity in clinical AI (Adegunle et al., 2026; Bagali et al., 2026).

A focused comparison between India and the UK, both deliberately targeted in the search strategy, is instructive. UK studies show strict rules exist, but new approaches are needed to ensure accountability and public inclusion in decision-making (Nouis et al., 2025; Racine, 2025). India studies highlight a struggle to build governance capacity as adoption speeds up alongside disparities (Baruah and Majumdar, 2026; Giri et al., 2025). Based on the literature analysed in this study, both systems converge on the same need for principles to be translated into operational practice (Dinc and Ardic, 2026), thereby showing that the fragmentation is structural rather than jurisdictional.

Accountability becomes progressively distributed and more difficult to trace through AI lifecycle stages. Continuous post-deployment monitoring is often suggested but rarely carried out in practice (Bai et al., 2026; Cary et al., 2025). Organisational and professional responsibilities remain undefined (Abu Assab et al., 2026; Wilkie et al., 2025) and only six of eighty papers discussed legal liability (Hoffman, 2021; Savastano et al., 2025). No explicit framework for allocating responsibility or compensating patients was identified within the included literature, creating a gap between organisational governance before deployment and mechanisms for addressing post-deployment algorithmic harm.

4.4 Strengths and Limitations of the Review

The search covered only Scopus and English-language publications, so relevant work indexed elsewhere or in other languages may have been missed, particularly from low and middle income countries. Screening relied on structured evidence mapping and weighted relevance ranking rather than duplicate independent full-text review. As screening was conducted by one reviewer, some selection bias cannot be excluded. Papers using different terminology or addressing equity implicitly may have been missed. Publication type contributed a source-type score to the relevance ranking rather than constituting a formal appraisal of methodological quality.

These limitations are balanced by clear strengths. The review followed PRISMA-ScR framework with a documented and transparent screening and ranking process, and synthesises 80 studies from 2016 to 2026 across diverse designs and regions.

4.5 Implications and Future Research

For developers, equity cannot be restricted to dataset diversification and fairness metrics. It must be built across the lifecycle and treated as a foundational design principle rather than an evaluation afterthought.

For healthcare organisations, implementation is itself an equity intervention: workflow design, clinician training and local monitoring determine whether a fair model delivers fair care. For policymakers, the priority is connecting regulatory instruments to organisational practice. Across all three, underserved communities must be repositioned from recipients of AI to participants in its design and governance.

The evidence gaps summarised in Table 4 define a future research agenda. Disability, digital exclusion and legal liability are underrepresented in the final corpus despite their importance for fairness and there is no long-term evidence on whether these systems remain fair after implementation. Future research should prioritise accessible and inclusive CDMS design for disabled patients, equity evaluation in digitally excluded and low-resource settings, intersectional equity assessment, and empirical study of how AI-mediated systems perform across populations after routine adoption.

Table 5. Research gaps and future research priorities.

Current state	*Identified gap*	*Future research priority*
Algorithmic fairness	***Focus on technical metrics***	***Socio-technical evaluation***
Responsible AI	***Principle-based***	***Operational implementation***
Accessibility	***Interface-focused***	***Whole-lifecycle inclusion***

Governance	***Fragmented***	***Integrated governance***
Health equity	***Population-specific***	***Cross-population synthesis***

5. Conclusion

Artificial intelligence is transforming clinical decision-making. It offers potential to improve diagnostic accuracy, clinical efficiency and healthcare delivery. This review demonstrates that these opportunities are not distributed equitably. Health inequities associated with AI-mediated CDMS occur not only from algorithmic bias but also from the interaction between technical design, healthcare infrastructure, organisational practices and wider social determinants that disproportionately affect underserved communities.

Across the reviewed literature, racialised communities, disabled patients and digitally excluded populations remain at increased risk of being excluded from AI-enabled healthcare. Despite progress in addressing fairness, transparency and explainability, these efforts remain largely fragmented. Combining evidence from design, law and healthcare, this review shows that equitable AI cannot be achieved through siloed technical interventions or regulatory measures alone. Approaches recognising the interdependence of design, governance, organisational practice and patient experience must be considered throughout the AI lifecycle.

While Responsible Design is broadly recognised as an essential perspective to develop equitable AI-mediated CDMS, its application remains fragmented, with limited integration across design, governance and post-deployment practice. Few studies integrate participatory design, inclusive development, algorithmic fairness, and

trustworthy AI into a coherent, holistic governance approach extending beyond development to implementation, monitoring and continuous evaluation (Bokolo et al., 2026; Wilkie et al., 2025).

This review reframes health equity in clinical AI as an ongoing responsibility embedded throughout the socio-technical lifecycle, rather than as a property determined solely by technical performance. It positions Responsible Design as an integrating perspective through which equity, participation, governance and accountability can be considered across the lifecycle. The next critical step for researchers is to move from simply diagnosing bias to designing real-world solutions by testing practical ways to embed equity and public participation into daily clinical practice. The next generation of clinical AI represents a critical turning point: it may either contribute to reducing long-standing gaps in care or reinforce them if equity is not embedded in design, implementation and governance.

Translating this agenda into real-world practice requires deeper collaboration between scholars, regulatory bodies, healthcare providers, researchers, and most importantly patients, community representatives and advocacy organisations representing racialised, disabled and digitally excluded populations.

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Author Contributions

ID developed the legal underpinnings of the research idea prior to the commencement of his PhD project. He led on research conceptualisation, investigation, literature search, data extraction and charting, analysis and thematic synthesis, as well as original manuscript drafting. FC provided input on the methodological framing and on the alignment of the discussion with the scope of the journal, offered critical intellectual input and supervised the project. All authors approved the manuscript before submission and agreed to be accountable for the work.

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APPENDIX

I. NOTE ON METHODOLOGICAL TRANSPARENCY

Manuscript: "Towards Responsible Design for Equitable AI-Mediated Clinical Decision-Making Systems: A Scoping Review of Health Equity and Underserved Populations"

Design for All - Special Issue on Responsible Design: Inclusive, Ethical and Sustainable Futures

The Methods section of this manuscript summarises the search strategy at corpus level, as is conventional for a scoping review of this length. Four features of the strategy warrant explicit statement, and are documented in full in II section 1.

1. The figure of 2,082 records is a composite retrieval total.

Sixteen separate searches were executed in Scopus between early May and June 2026, using an iterative strategy in which each search paired AI and clinical decision support terminology with a specific equity, harm, design or governance concept. The searches were designed to overlap. The figure of 2,082 is therefore the sum of the sixteen individual query yields rather than a count of distinct publications; 385 duplicates were subsequently removed, leaving the 1,697 unique records that entered screening. Per-search yields are reported in Section 2 and the full reconciliation in Section 4.

2. Search parameters were not uniform across the sixteen searches.

Search parameters were not uniform across the sixteen searches. Six searched the full 2016-2026 period, and the remainder used later starting years or an upper limit of 2025. Four searched with an explicit English language limit, and seven restricted document type for

articles and reviews. These variations were a result of the iterative search strategy adopted, while the overall eligibility criteria were applied during screening. Coverage of the governance, liability and automation-bias themes nonetheless extends over a shorter period than coverage of health equity and algorithmic bias.

3. Retrieval for the United Kingdom and India was deliberately targeted.

Three searches restricted retrieval to the United Kingdom or India, contributing 625 records in total, and a fourth targeted low-resource and Global South settings. The prominence of these two systems in the corpus, and the UK–India comparison developed in the Discussion, are therefore a designed contrast between a high-regulatory-maturity system and a rapidly scaling one, rather than an unprompted pattern in the wider literature. The comparison is offered on that basis and the authors do not claim it is representative of the global distribution of research on this topic.

4. Sparse representation of some themes reflects the prioritisation strategy as well as the literature.

Of the 1,553 records assessed against the full inclusion criteria, 857 passed the 15.0-point weighted relevance threshold but were excluded solely for falling below the top-80 relevance cut-off. Four searches targeting liability and accountability returned 677 records in combination, while six of the eighty included studies were coded to liability; disability terms appeared in eight searches and eight included studies were coded to disability. Retrieval volume is not equivalent to topical coverage, and several of these searches overlapped substantially. Nonetheless, where the manuscript describes disability, digital exclusion and legal liability as under

examined, that observation is properly understood as describing their representation within this corpus and the review's prioritisation, rather than as a measured claim about the volume of available literature.

II. Scopus Search Strategy and Record results

Supplementary to: "Towards Responsible Design for Equitable AI-Mediated Clinical Decision-Making Systems: A Scoping Review of Health Equity and Underserved Populations"

Design for All — Special Issue on Responsible Design: Inclusive, Ethical and Sustainable Futures

Section 1 - Search process:

Sixteen searches were executed in Scopus using an iterative strategy. Each search combined terms for Artificial Intelligence (AI)-mediated Clinical Decision-Making Systems (CDMS) with a specific equity, harm, design or governance concept, and successive searches were refined in response to the records retrieved. Search parameters therefore varied across the individual searches.

The sixteen searches returned 2,082 records in total. Because the searches were designed to overlap, this figure is the sum of individual query results rather than a count of distinct publications. Following export into the review database, 385 duplicates were removed (365 matched by Digital Object Identifier (DOI) and 20 identified through title and publication-year matching) leaving 1,697 unique publications. This dataset formed the basis for title and abstract screening, assessment against the full inclusion criteria, and structured relevance scoring across seven conceptual domains.

Boolean operators, phrase searching, single-character wildcards (?) and truncation (*) were used throughout. The wildcard form

raciali?ed retrieves both British and American spellings. Search parameters were not uniform across the sixteen searches; the variation is documented in Section 2 and its implications are set out in Section 4.

Section 2 - Search characteristics and yields

	Focus	*Years*	*English*	*Geographic limit*	*n*
1	*Exploratory scoping search — harm and racialised communities*	*2016–2026*	*No*	*—*	*7*
2	*AI, harm and underserved populations — UK and India*	*2016–2026*	*Yes*	*UK / India*	*255*
3	*AI and equity — India-focused*	*2016–2026*	*Yes*	*India*	*362*
4	*Responsible Design and equity — UK and India*	*2021–2026*	*Yes*	*UK / India*	*8*
5	*Harm, liability and accountability with equity*	*2021–2026*	*No*	*—*	*292*
6	*Harm, liability and accountability with equity — widened*	*2016–2026*	*No*	*—*	*329*
7	*Responsible Design and equity — no geographic limit*	*2016–2026*	*Yes*	*—*	*178*
8	*Algorithmic harm and safety*	*2017–2025*	*No*	*—*	*131*
9	*AI-mediated healthcare and patient-centred harm*	*2016–2026*	*No*	*—*	*76*
10	*Automation bias and human oversight*	*2017 onwards*	*No*	*—*	*80*
11	*Participatory design and AI governance*	*2019 onwards*	*No*	*—*	*188*
12	*Cross-jurisdictional regulation and low-resource settings*	*2020 onwards*	*No*	*LMIC / Global South*	*17*

13	*Responsible Design and governance mechanisms*	*2019 onwards*	*No*	*—*	*62*
14	*Algorithmic harm, legal frameworks and compensation*	*2018 onwards*	*No*	*—*	*25*
15	*Training-data bias in diagnosis and triage*	*2019 onwards*	*No*	*—*	*41*
16	*CDSS harm, liability and oversight*	*2019 onwards*	*No*	*—*	*31*
				Total:	*2,082*

Note: The searches used varied retrieval parameters as part of the iterative strategy. Six of the sixteen searches used the full 2016–2026 window; four applied an explicit English-language limit; and seven restricted document type to articles and reviews. The overall eligibility criteria were applied during screening.

Section 3 - Search queries as executed

Reproduced verbatim. Record counts are those returned at the time of searching; Scopus coverage changes over time and re-running these queries may return different totals.

Search 1. Exploratory scoping search — harm and racialised communities n = 7

TITLE-ABS-KEY (healthcare AND harm AND ("racialized communities" OR "affected populations"))

AND PUBYEAR > 2015 AND PUBYEAR < 2027

Search 2. AI, harm and underserved populations — UK and India n = 255

TITLE-ABS-KEY (("artificial intelligence" OR AI OR "machine learning" OR "clinical decision

support system*" OR "clinical decision-making" OR "AI-mediated" OR algorithm*) AND (healthcare

OR health OR medicine OR clinical OR patient*) AND (harm OR injur* OR "adverse event*" OR

"patient safety" OR inequity OR inequit* OR unfair* OR fairness OR bias OR discrimination OR

"health disparit*" OR "health inequit*") AND ("raciali?ed communit*" OR "raciali?ed

population*" OR minorit* OR underserved OR vulnerab* OR marginali?ed OR disability OR disabled

OR "digital exclusion" OR "digital divide" OR "digital literacy" OR "social exclusion") AND (

"United Kingdom" OR UK OR England OR Scotland OR Wales OR "Northern Ireland" OR India)) AND

PUBYEAR > 2015 AND PUBYEAR < 2027 AND (LIMIT-TO (LANGUAGE , "English"))

Search 3. AI and equity — India-focused n = 362

TITLE-ABS-KEY (("artificial intelligence" OR AI OR "machine learning" OR "clinical decision

support" OR algorithm*) AND (healthcare OR health OR medicine) AND (equity OR fairness OR

disability OR bias OR "digital exclusion" OR underserved) AND (India OR "Indian healthcare" OR

"National Digital Health Mission" OR Ayushman)) AND PUBYEAR > 2015 AND PUBYEAR < 2027 AND (

LIMIT-TO (LANGUAGE , "English"))

Search 4. Responsible Design and equity — UK and India n = 8

TITLE-ABS-KEY (("artificial intelligence" OR AI OR "machine learning" OR "clinical decision

support system*" OR "clinical decision support" OR "clinical decision-making" OR "AI-enabled

healthcare" OR "AI-mediated healthcare" OR algorithm*) AND (healthcare OR health OR medicine

OR clinical OR patient*) AND (equity OR fairness OR inclusion OR inequit* OR disparit* OR

discrimination OR bias OR accessibility OR "health equity" OR "healthcare disparities") AND (

"responsible design" OR "inclusive design" OR "human-centred design" OR "human centered design"

OR "universal design" OR "participatory design" OR co-design OR "responsible innovation" OR

"responsible AI" OR "trustworthy AI") AND (disabled OR disability OR "raciali?ed communit*" OR

"raciali?ed population*" OR minority OR vulnerable OR underserved OR marginali?ed OR "digital

exclusion" OR "digital literacy" OR "social inequality" OR "health inequality") AND ("United

Kingdom" OR UK OR Britain OR England OR Scotland OR Wales OR "Northern Ireland" OR India)) AND

PUBYEAR > 2020 AND PUBYEAR < 2027 AND (LIMIT-TO (LANGUAGE , "English"))

Search 5. Harm, liability and accountability with equity n = 292

TITLE-ABS-KEY (("artificial intelligence" OR AI OR "machine learning" OR "clinical decision

support system*" OR "clinical decision-making") AND (harm OR injury OR "adverse event*" OR

liability OR accountability) AND (equity OR fairness OR inequit* OR disparit* OR

discrimination OR bias) AND ("racialised communit*" OR disability OR disabled OR "digital

exclusion" OR "digital literacy" OR "underserved population*" OR "marginalised population*" OR

"disadvantaged population*")) AND PUBYEAR > 2020 AND PUBYEAR < 2027

Search 6. Harm, liability and accountability with equity — widened n = 329

TITLE-ABS-KEY (("artificial intelligence" OR AI OR "machine learning" OR "clinical decision

support system*" OR "clinical decision-making") AND (harm OR injury OR "patient safety" OR

"adverse event*" OR liability OR accountability) AND (equity OR fairness OR inequit* OR

disparit* OR discrimination OR bias) AND ("raciali?ed communit*" OR disability OR disabled OR

"digital exclusion" OR "digital literacy" OR "underserved population*" OR "marginali?ed

population*" OR "disadvantaged population*")) AND PUBYEAR > 2015 AND PUBYEAR < 2027

Search 7. Responsible Design and equity — no geographic limit n = 178

TITLE-ABS-KEY (("artificial intelligence" OR AI OR "machine learning" OR "clinical decision

support system*" OR "clinical decision-making" OR "AI-enabled healthcare" OR "AI-mediated

healthcare" OR algorithm*) AND (healthcare OR health OR medicine OR clinical OR patient*) AND

(equity OR fairness OR inclusion OR inequit* OR disparit* OR discrimination OR bias OR

accessibility OR "health equity" OR "healthcare disparities") AND ("responsible design" OR

"inclusive design" OR "universal design" OR "human-centred design" OR "human centered design" OR

"participatory design" OR co-design OR "design for all" OR "responsible innovation" OR

"responsible AI" OR "trustworthy AI") AND (disabled OR disability OR "raciali?ed communit*" OR

"raciali?ed population*" OR minority OR vulnerable OR underserved OR marginali?ed OR "digital

exclusion" OR "digital literacy" OR "social inequality" OR "health inequality")) AND PUBYEAR >

2015 AND PUBYEAR < 2027 AND (LIMIT-TO (LANGUAGE , "English"))

Search 8. Algorithmic harm and safety n = 131

TITLE-ABS-KEY ((algorithmic harm* OR "clinical decision support") AND (harm OR injury OR

adverse OR safety) AND (disab* OR "racial* communit*" OR minority OR vulnerable OR underserved

OR marginalized OR "digital literacy" OR "digital exclusion")) AND PUBYEAR > 2016 AND PUBYEAR

< 2026

Search 9. AI-mediated healthcare and patient-centred harm n = 76

TITLE-ABS-KEY (("AI-mediated healthcare" OR "clinical decision-support systems" OR "patient-

centred harm") AND (equity OR fairness OR inequality OR disparities OR inclusion OR

discrimination OR bias)) AND ("healthcare disparities" OR "racialised populations" OR

"disadvantaged populations" OR "digitally and socially excluded patients" OR "social inequality"

) AND PUBYEAR > 2015 AND PUBYEAR < 2027

Search 10. Automation bias and human oversight n = 80

TITLE-ABS-KEY ("automation bias" OR "over-reliance" OR "algorithm aversion" OR "human-in-the-

loop" OR "meaningful human oversight") AND TITLE-ABS-KEY ("clinical decision" OR "diagnostic

AI" OR "AI-assisted" OR "AI recommendation") AND TITLE-ABS-KEY ("patient safety" OR "harm" OR

"accountability" OR "governance") AND DOCTYPE (ar OR re) AND PUBYEAR > 2016

Search 11. Participatory design and AI governance n = 188

TITLE-ABS-KEY ("participatory design" OR "co-design" OR "patient involvement" OR "patient-

reported" OR "patient-centred participation") AND TITLE-ABS-KEY ("artificial intelligence" OR

"digital health" OR "AI governance" OR "healthcare algorithm") AND TITLE-ABS-KEY ("governance"

OR "accountability" OR "harm reporting" OR "evidence generation" OR "design principles") AND

NOT TITLE-ABS-KEY ("app development" OR "user interface testing" OR "usability testing") AND

DOCTYPE (ar OR re) AND PUBYEAR > 2018

Search 12. Cross-jurisdictional regulation and low-resource settings n = 17

TITLE-ABS-KEY ("regulatory asymmetry" OR "cross-jurisdictional" OR "comparative AI regulation"

OR "global AI governance" OR "regulatory divergence" OR "regulatory capacity") AND TITLE-ABS-

KEY ("artificial intelligence" OR "digital health" OR "healthcare AI") AND TITLE-ABS-KEY (

"low-income" OR "low-resource" OR "Global South" OR "developing countr*" OR "North Africa" OR

"Sub-Saharan" OR "LMIC") AND DOCTYPE (ar OR re) AND PUBYEAR > 2019

Search 13. Responsible Design and governance mechanisms n = 62

TITLE-ABS-KEY ("responsible design" OR "responsible AI" OR "value-sensitive design" OR "human-

centred design" OR "ethical AI design") AND TITLE-ABS-KEY ("governance mechanism" OR

"governance infrastructure" OR "accountability framework" OR "regulatory compliance") AND

TITLE-ABS-KEY ("healthcare" OR "clinical AI" OR "artificial intelligence" OR "medical

technology") AND NOT TITLE-ABS-KEY ("autonomous vehicle" OR "robotics" OR "smart city" OR

"surveillance capitalism") AND DOCTYPE (ar OR re) AND PUBYEAR > 2018

Search 14. Algorithmic harm, legal frameworks and compensation n = 25

TITLE-ABS-KEY ("digital injury" OR "AI-mediated harm" OR "algorithmic harm" OR "data-driven

harm" OR "AI harm" OR "digital harm") AND TITLE-ABS-KEY ("governance" OR "legal framework" OR

"accountability" OR "compensation" OR "compensable" OR "regulatory gap") AND TITLE-ABS-KEY (

"healthcare" OR "clinical" OR "patient" OR "medical AI") AND DOCTYPE (ar OR re) AND PUBYEAR >

2017

Search 15. Training-data bias in diagnosis and triage n = 41

TITLE-ABS-KEY ("algorithmic bias" OR "training data bias" OR "representational bias" OR

"demographic underrepresentation") AND TITLE-ABS-KEY ("diagnosis" OR "triage" OR "treatment

recommendation" OR "clinical pathway") AND TITLE-ABS-KEY ("harm" OR "health disparity" OR

"inequity" OR "misclassification" OR "false negative") AND NOT TITLE-ABS-KEY ("natural

language processing" OR "text classification" OR "sentiment analysis") AND DOCTYPE (ar OR re)

AND PUBYEAR > 2018

Search 16. CDSS harm, liability and oversight n = 31

TITLE-ABS-KEY ("clinical decision support" OR "AI-CDSS" OR "AI-assisted diagnosis" OR "AI-

assisted clinical decision") AND TITLE-ABS-KEY ("harm" OR "misdiagnosis" OR "adverse outcome"

OR "patient safety incident") AND TITLE-ABS-KEY ("governance" OR "accountability" OR

"liability" OR "oversight" OR "regulatory") AND NOT TITLE-ABS-KEY ("image segmentation" OR

"natural language processing" OR "drug discovery" OR "wearable") AND DOCTYPE (ar OR re) AND

PUBYEAR > 2018

Section 4 - Record counts

Stage	*nb*
Sum of results across the sixteen searches	*2,082*
Duplicates removed — matched by DOI	***365***
Duplicates removed — matched by title and publication year	***20***
Total duplicates removed	***385***
Unique records screened by title and abstract	*1,697*
Excluded at relevance screening (no AI/CDMS or equity relevance in title or abstract)	***144***
Records assessed against full inclusion criteria	***1,553***
Excluded: no equity, underserved-population or responsible-design dimension	***296***
Excluded: below 15.0-point weighted relevance threshold	***320***

Excluded: passed threshold but below top-80 relevance cut-off	***857***
Studies included in the review	*80*
Tier 1 (Core) / Tier 2 (Important) / Tier 3 (Relevant)	*27 / 27 / 26*

Section 5 - Limitations arising from the search design

- **Uneven temporal coverage by theme**

Only six of the sixteen searches applied the full 2016–2026 window. Searches 10 to 16, which targeted automation bias, participatory governance, regulatory divergence, algorithmic harm, training-data bias and CDSS liability, began at 2017 to 2020 and carried no upper bound. Search 8 was capped at 2025. The union of all windows spans 2016 to 2026, so the corpus as a whole covers the stated period, but pre-2019 literature on the governance, liability and automation-bias themes was searched less comprehensively than literature on health equity and algorithmic bias.

- **Deliberate geographic targeting of the United Kingdom and India**

Searches 2, 3 and 4 restricted retrieval to the United Kingdom or India, together contributing 625 records, and Search 12 targeted low-resource and Global South settings. The prominence of the United Kingdom and India in the geographic distribution of included studies, and the UK–India comparison discussed in the Discussion, therefore reflect a deliberate feature of the search strategy rather than an unprompted pattern in the wider literature. This does not invalidate the comparison, and should be read as a designed contrast between a high-regulatory-maturity and a rapidly scaling health system rather than as evidence about the global distribution of research.

- **Relevance cut-off and apparent thematic gaps**

Of the 1,553 records assessed against the full inclusion criteria, 857 passed the 15.0-point weighted relevance threshold but were excluded solely for falling below the top-80 cut-off. Retrieval for liability and accountability was substantial — Searches 5, 6, 14 and 16 returned 677 records in total — yet only six of the eighty included studies were coded to liability. Similarly, disability terms appeared in eight of the sixteen searches, and eight included studies were coded to disability. The sparse representation of these themes in the final corpus therefore reflects the

review's prioritisation strategy as opposed to the volume of available literature, and claims about under examination should be read with that in mind.

- **Single database and lack of independent validation**

Retrieval was limited to Scopus, so relevant work indexed only in PubMed, Web of Science, IEEE Xplore, ACM Digital Library or regional databases was not captured. The search strategy was not validated by an independent information specialist. Screening was carried out by a single reviewer in consultation with another member of the study team. Grey literature, preprints and non-English publications were not searched.



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Hedonic Experiences in Older Adults' Interactions with Voice-Based Conversational Agents: A Systematic Review

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Abstract

Existing research has extensively focused on the functional and practical dimensions of older adults' engagement with Voice-based Conversational Agents (VCAs). While this body of work offers valuable insights, it largely frames human–technology interaction through pragmatic and medical perspectives, leaving hedonic and experiential dimensions relatively underexplored. Yet, these aspects are equally important for enabling responsible and meaningful interactions for older adults. We therefore carried out a systematic review of six databases (ACM Digital Library, Scopus, IEEE Xplore, Web of Science, EBSCO HOST, and ScienceDirect) to consolidate current evidence and examine the relationship between VCAs and older adults beyond pragmatic aspects. 52 studies met our criteria and were analyzed using inductive qualitative content analysis.

Our analysis identified a range of positive and negative hedonic aspects and, more importantly, the recurring tensions between them.

Rather than functioning solely as assistive technologies, VCAs emerge as design-mediated systems that shape older adults' quality of life through emotional, social, and cognitive experiences. Our findings point to three recurring design tensions: (1) from social connection to potential social dissonance, (2) from assistance to user incompetence, and (3) from self-confidence to self-doubt. Across all three, autonomy and self-perception emerge as central determinants of hedonic experience. The same design features that foster independence, confidence, and companionship may, when poorly calibrated, also reinforce dependency, stigma, and mistrust.

These findings highlight the importance of responsible design for conversational agents intended for older adults. Because age-related vulnerability raises the stakes of individual design decisions, older adults' autonomy should be treated as a precondition for positive hedonic experience rather than a secondary concern. By foregrounding these tensions, this review contributes to a more holistic understanding of older adults' experiences with VCAs and offers design knowledge for human-centred design of VCAs.

Keywords

Human-Computer Interaction, Older Adults, Voice-Based Conversational Agents, User Experience, Positive Design, Responsible Design

1. INTRODUCTION

Population ageing is reshaping the design, adoption, and use of digital technologies. By 2050, one in six people worldwide will be aged 65 or

older [81]. At the same time, Voice-based Conversational Agents (VCAs) offer older adults natural, hands-free interaction that can reduce barriers associated with conventional interfaces [33, 42, 53, 85]. As conversational technologies become embedded in everyday routines, the question is no longer only whether older adults can use these systems, but how they experience and relate to them.

Existing studies show that older adults use VCAs for everyday activities, social connection, entertainment, and health management, and may view them as companions rather than tools [20, 56]. They are also widely used for healthcare management, from accessing health information to tracking medication [8, 15, 59, 66].

However, older adults also face age-related barriers, such as hearing decline and difficulty remembering activation phrases, that lead to more errors and longer task times than for younger users [6, 18, 54, 78]. Despite the barriers, older adults report more positive attitudes toward VCAs overall than other age groups [80].

Research on older adults and VCAs has largely examined interaction through pragmatic and medical perspectives, substantially advancing usability, functionality, and learnability [1, 67]. The hedonic dimension of interaction, the non-instrumental and affective qualities that shape how users emotionally relate to a product [39], remains comparatively underexplored. The Positive Design framework also argues that virtue, personal significance, and pleasure each independently support well-being, with their intersection fostering human flourishing [30], and that a balanced view of both positive and negative emotion is necessary to understand well-being [73]. For older adults, meaningful VCA interaction extends beyond pragmatic

performance to emotional, social, and psychological experiences [27, 38].

Although previous studies have documented both the benefits and challenges of VCAs, these experiences have typically been discussed independently and focusing dominantly on pragmatic aspects [41]. Less attention has been paid to how positive and negative hedonic experiences may coexist, interact, and shape older adults' relationships with these technologies. Examining these potential tensions is important because features and interaction contexts intended to support older adults may also introduce unintended consequences. Understanding the trade-offs is essential for designing VCAs that support older adults' well-being and for treating autonomy and trust as central design considerations.

In light of this, this review synthesizes existing evidence on older adults' hedonic experiences with VCAs. We first characterize the existing body of empirical work, including its methodological approaches, contexts of use, and participant groups (RQ0), before addressing:

RQ1. Which positive and negative hedonic aspects arise in older adults' experiences with VCAs?

RQ2. How do VCA characteristics and contexts of use shape these experiences?

RQ3. How can VCA design mediate the trade-offs between positive and negative hedonic aspects?

We define hedonic aspects as the non-instrumental qualities of interaction that shape how older adults emotionally experience VCAs, including feelings of confidence or self-doubt, perceptions of

companionship, and concerns about autonomy, trust, and social perception. We distinguish positive aspects (supporting well-being, enjoyment, and connectedness) from negative ones (discomfort, mistrust, or stigma) as an analytical lens rather than a rigid classification, acknowledging that the two are not mutually exclusive; rather, they may coexist within the same experience. To address these questions, we conducted a systematic review of the existing empirical literature.

2. METHODOLOGY

We conducted a systematic review, which is a method to identify, select, and evaluate existing studies grounded on a set of research questions [87]. We used the PRISMA 2020 statement and checklist to guide the reporting of the review process [61]. Figure 1 summarizes our methodology, and we elaborate on it in the following sub-sections.

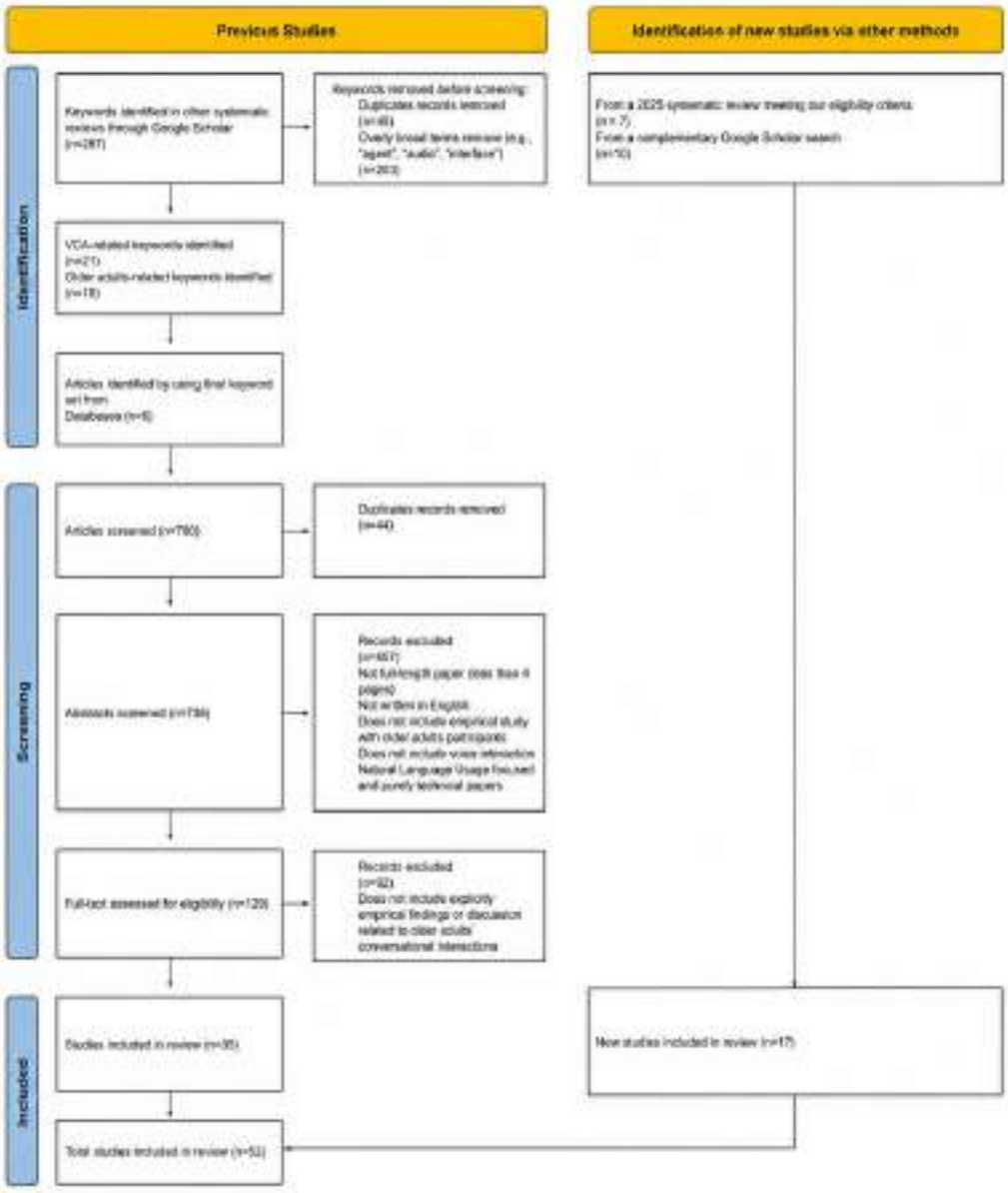


Figure 1: Data collection process

2.1 Data Collection Process

Given the wide range of terminology used in the field [78], we conducted a preliminary scan to identify appropriate search terms before starting the systematic review. We first compiled a keyword

pool from several systematic reviews on VCAs [62, 71, 78]. After removing duplicates, we collated 238 relevant keywords into two main categories, VCAs (218 keywords) and older adults (20 keywords). We then excluded overly broad terms that could capture other technologies and paradigms beyond the current scope (e.g., "agent", "audio", "interface"). This process resulted in 21 VCA-related keywords and 15 older adults-related keywords, which were used in the systematic review (Figure 2).

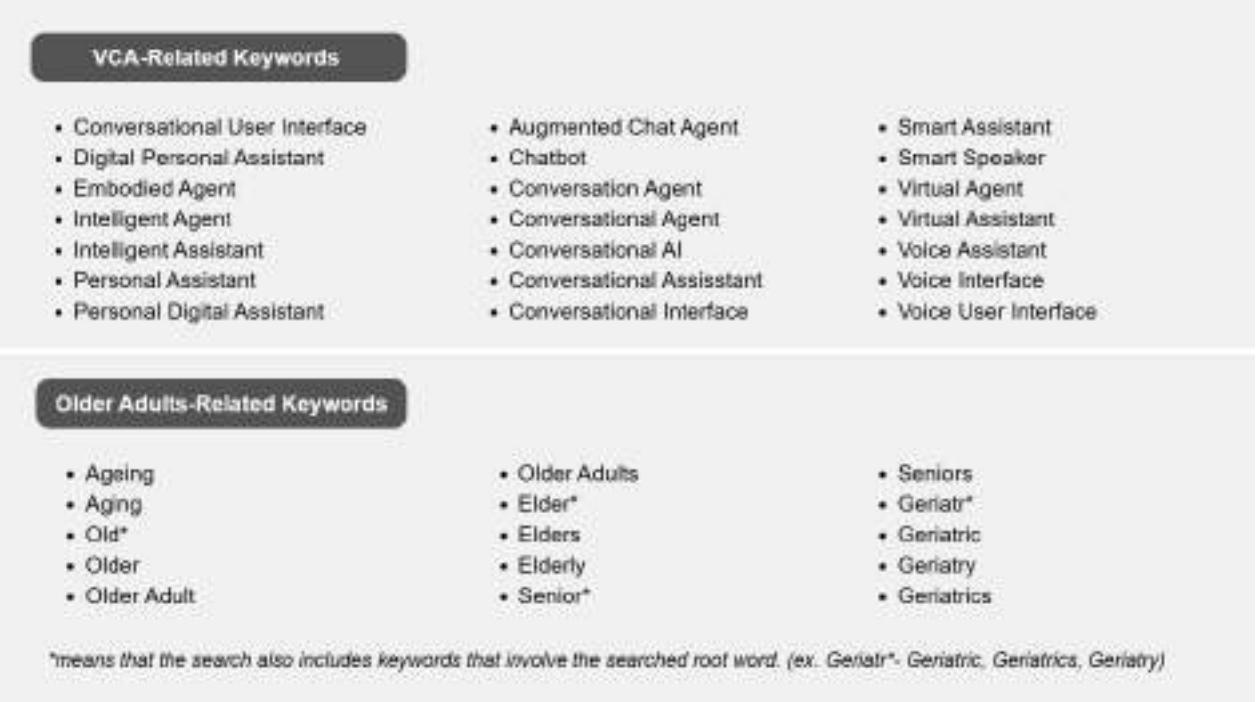


Figure 2: Selected keywords

We searched ACM Digital Library, Scopus, IEEE Xplore, Web of Science, EBSCO HOST and ScienceDirect with the selected keyword combinations in article titles and abstracts. The search strategy for each database is available in Table A.1. We did not set a time limit to be as comprehensive as possible. At the end of this process, we listed 780 articles that met our eligibility criteria. After removing 44

duplicate articles, we included 736 articles in the abstract level selection. At this first level of review, we excluded articles that were not full-length papers, such as posters, short communications, and works in progress, and not written in English, did not include voice interaction, or were primarily focused on Natural Language Understanding (NLU) performance or other purely technical development without empirical investigation of users. We also made sure that the main focus was on older adults. Studies were included if older adults were either the sole participant group or if mixed participant samples were used. Other potential key actors were also considered(e.g., caregivers, healthcare providers, and designers) since they may have insights into the lives of older adults and thus help to design products that are in line with their wants and needs. Yet, studies were excluded when older adults were only marginally mentioned, included as a small subgroup without separate analysis, or not central to the study's research questions.We reached 129 articles with older adult focus in their abstracts. These articles passed to the full text level selection stage for further detailed review.

Then, informed by prior human-centered systematic reviews in HCI and VCAs [e.g., 32, 35], we conducted a more rigorous screening of the 129 articles. Title and abstract screening and full-text eligibility assessment were conducted by the first author based on the predefined inclusion and exclusion criteria, selecting studies that included empirical investigations with users and examined their experiences, perceptions, or interactions with the technology. Uncertain or borderline eligibility decisions were discussed with the co-authors before a final determination was made. This process resulted in 35 studies that met the inclusion criteria and formed the initial corpus.

The search was originally conducted in late 2022. To incorporate recent developments, a targeted update search was conducted in April 2026. This update identified 7 studies from a 2025 systematic review [41] that met our eligibility criteria and 10 additional studies through a complementary Google Scholar search, yielding 17 additional eligible studies and resulting in a final corpus of 52 studies. The same inclusion and exclusion criteria and screening procedure were applied to the newly identified studies. They were coded using the same codebook and contributed additional examples to existing categories without altering the overall thematic structure of the findings.

2.2 Analysis

The analysis included two strands. First, in relation to the RQ0, we extracted descriptive information from the articles to contextualize the subsequent analytical findings by outlining key characteristics of the reviewed literature, including study contexts, participant groups, application domains, and methodological approaches.

Second, to address the remaining RQs, we conducted an inductive qualitative content analysis focusing on interpreting the substance of textual data in relation to its meanings, contexts, and purposes [25]. This approach allowed patterns related to hedonic aspects and VCA characteristics influencing older adults' experiences to emerge across studies.

The first author initially coded 10% of the corpus in MAXQDA to develop a preliminary coding scheme. These codes were then discussed with the other authors to refine code definitions, clarify ambiguities, and establish a shared understanding. Following these discussions, a consensus-based codebook was developed. The first

author subsequently coded the remaining articles using this codebook, with regular discussions among all authors to review coding decisions, identify emerging patterns, and resolve ambiguities. This iterative and collaborative process supported reflexivity and analytical consistency, in line with recommendations for inductive qualitative analysis in HCI research [58].

Hedonic aspects were subsequently organized into positive and negative categories. This categorization was employed as an analytical lens to structure the findings rather than as a rigid classification of user experience. Within these categories, subcategories were identified to capture recurring patterns across studies and mapped to relevant VCA characteristics. Figure 3 summarizes the refined codebook with major themes and the relationships between the identified codes.

3. FINDINGS

3.1 Descriptive Information Related to Studies

The descriptive analysis addresses RQ0, providing an overview of study characteristics, including user profiles, methods, durations, contexts, and VCA terminology. Table 1 presents the main patterns, while Table A.2 provides an extended matrix.

Overall, the distribution of studies suggests that research on VCAs with older adults has been shaped primarily by care- and support-oriented applications, with health emerging as the dominant context, reflected also in the broader involvement of caregivers and professionals in this domain. This care orientation is further reflected in the diversity of settings covered by health-related studies, which spanned home, hospital, facility, and laboratory contexts, whereas

studies in other domains were concentrated almost exclusively in the home, suggesting that health research has achieved not only greater volume but also broader institutional reach. Notably, however, this care orientation has not extended to the oldest-old, as samples were dominated by the young-old (60–75), while the old-old (75+) remain markedly underrepresented, a gap worth noting given that these are the groups most likely to benefit from, or struggle with, VCA-based support. The limited representation of everyday and psychological/well-being applications suggests that VCAs' potential beyond functional purposes remains underexplored.

Methodologically, the evidence base is characterized largely by interviews and surveys, while participatory approaches such as co-design and workshops appear less frequently, suggesting that older adults have more often been positioned as evaluated users than as active contributors to design. Study durations are predominantly short-term, though a smaller body of longitudinal work has examined VCA use over extended periods. Taken together, these patterns point to a literature with a substantial empirical basis for understanding older adults' experiences with VCAs, but one still limited in participatory design, everyday non-care applications, and long-term engagement. Finally, although the terminology used to describe VCAs varies considerably, reflecting the field's conceptual heterogeneity and lack of a standardized vocabulary, this diversity at the level of language is not matched at the level of technology. The studies converge heavily on a small number of commercial platforms, most notably Amazon Alexa, followed by Google Assistant, indicating that the field's terminological pluralism coexists with a fairly narrow industrial base.

Table 1: Descriptive characteristics of included studies by topic



3.2 Hedonic Aspects during Older Adults' Interaction with VCAs

Addressing RQ1 and RQ2, we examined older adults' experiences with VCAs in terms of positive and negative hedonic aspects, together with the VCA characteristics and contextual factors shaping them (Figure 3).

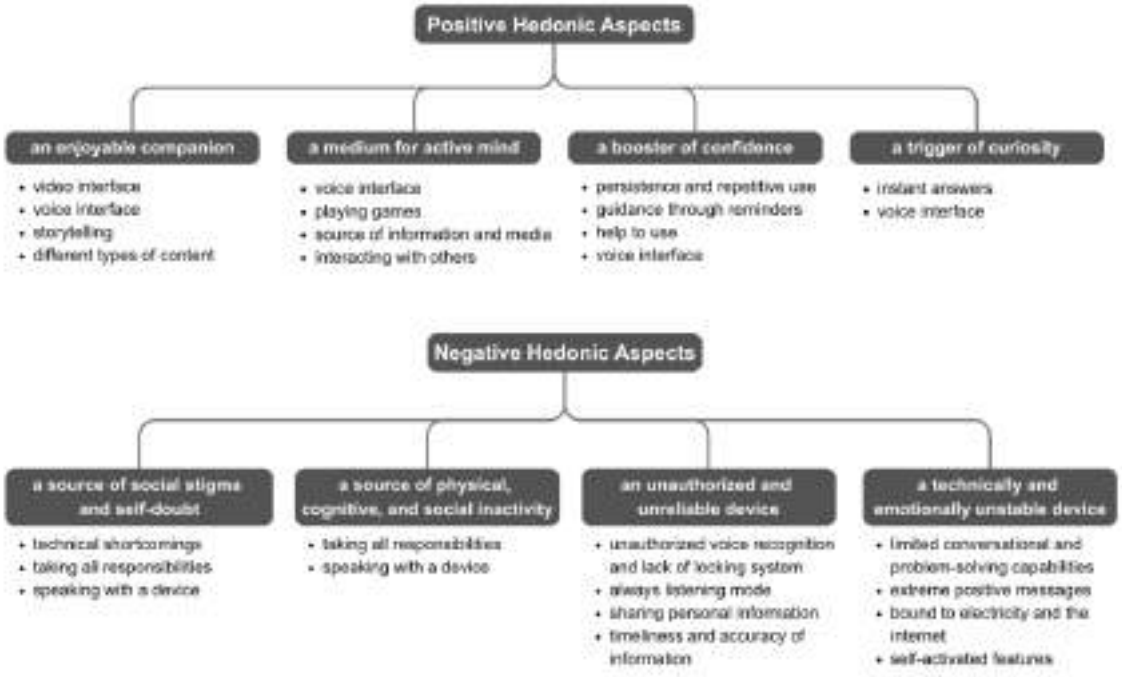


Figure 3: Hedonic aspects and their relationship with VCA features

3.2.1 Positive Hedonic Aspects

VCA as an enjoyable companion: Because older adults generally have lower access to digital technologies and media compared to younger generations, VCAs served as a gateway to entertainment and digital experiences [34], leading some users to perceive them as companions [31].

This sense of companionship was reinforced through enjoyable and meaningful interactions. Listening to music through VCAs had been reported to alleviate pain among those with chronic illnesses [31, 79], encourage dancing to the rhythm [60] and together with card games and video calling features made them feel good, especially during periods of social isolation such as Covid19 [31, 74, 76, 77]. Video calling and conversational interactions especially helped alleviate loneliness and created a feeling comparable to receiving visitors at home [22, 31, 64].

Additionally, accessing stories, jokes and recipes on demand, and repeating religious verses together, reduced feelings of boredom and loneliness [65, 74], leading some older adults to form deep emotional attachments to VCAs as indispensable companions [24]. The constant availability of VCAs further strengthened the perception of companionship, providing reassurance for older adults living alone and reducing the burden on caregivers of socially isolated individuals [7, 10, 47, 86]. According to Astell and Clayton (2024), companionship was associated with both a perceived sense of presence and the ability to engage with the assistant on users' own terms, as VCAs created a feeling of someone being there while allowing older adults to decide when and how to interact [2]. Its experience also varied depending on the context of use, with VCAs

described as particularly comforting at home after social gatherings, during extended periods of being alone, or in residential and care settings where opportunities for social interaction were limited [31, 64, 65].

VCA as a medium for active mind: Several studies highlighted VCA's role in simulating cognitive activity among older adults. Conversational interactions, access to information, media content and games helped older adults remain mentally engaged, while communication features supported both cognitive and social stimulation, particularly for users experiencing memory decline and social isolation [10, 31, 36, 77, 79 86]. VCAs also enabled older adults to search for information, verify knowledge, and engage in cognitively stimulating activities, supporting their active involvement in maintaining cognitive health rather than focusing solely on cognitive decline [82]. Similarly, older adults expressed willingness to incorporate VCAs into their daily routines for cognitive stimulation through engaging activities [13, 23]. This need to keep the mind engaged was also reflected in a study where older adults expressed a desire to incorporate a positive reminiscing probe, which asked reflective questions about personal achievements, attitudes towards loneliness, and life experiences, into their daily routine, as it encouraged them to think more [24]. Beyond supporting older adults themselves, VCAs may also provide meaningful support for individuals in caregiving roles. For example, a participant caring for his wife with dementia described Amazon Echo as a companion that helped him remain mentally active and reduced feelings of isolation [66].

VCA as a booster of confidence: Successful interactions with VCAs boosted older adults' confidence, particularly when these devices

helped them accomplish tasks that might otherwise create difficulties. Reminder functions reduced concerns about making mistakes [3, 69] and voice interaction enabled users to ask "silly questions" [49, 76]. This non-judgmental quality also encouraged users to push their own boundaries, as errors met with a neutral or reassuring response rather than criticism made older adults feel more comfortable continuing to experiment and engage with the assistant [24, 28, 75]. For older adults with mild cognitive impairment specifically, positive reinforcement from the assistant fostered a distinct sense of accomplishment, with users reporting that being praised for completing a task made them feel they had achieved something meaningful [57], while for people with dementia, similar comfort emerged from the assistant's patience with repeated questions, expressed without frustration [88]. Moreover, repetitive use and persistence, together with appropriate onboarding support facilitated technology adoption [22, 31, 62, 63, 86]. Importantly, such confidence gained through VCA use was transferred to use of other digital technologies [66], as curiosity, experimentation, and repeated engagement helped older adults develop "digital living skills" by learning how to integrate and navigate digital devices in everyday life [79, p. 710].

VCA as a trigger of curiosity: The conversational nature of VCAs sparked older adults' curiosity about technology, while the ease and simplicity of voice interaction encouraged them to explore device capabilities [66]. Participants actively experimented with different questions to test the system's abilities and understand its limitations, reflecting an exploratory engagement with technology. In peer and group settings, these exploratory behaviours tended to become stronger, as observing how others interacted with VCAs encouraged

older adults to try out new commands and question formats themselves [12]. Time emerged as an important factor in this exploratory engagement, as sustained use over a longer period supported an ongoing process of discovery, with older adults increasingly testing the boundaries between the assistant's pre-programmed responses and its natural language capacities [82]. Moreover, experiences with VCAs could evoke a sense of amazement among older users, demonstrating how these devices may foster curiosity and engagement with emerging technologies [2, 49].

3.2.2 Negative Hedonic Aspects

VCA as a source of social stigma and self-doubt: Social perceptions surrounding talking to digital devices prevented older adults from adopting VCAs. Some older adults expressed distancing attitudes toward peers perceived as dependent on others or living with disabilities, reflecting broader societal narratives around technology dependency [48]. Although VCAs were intended to support daily living, they unintentionally reinforced stigmas regarding technology dependency and diminished autonomy [48, 64, 70]. In some cases, the omnipresence of VCAs in the home served as a constant reminder of aging and caused irritation [77]. Also, older adults were concerned that they are perceived as "silly", "crazy" or even "pathetic" for talking to machines [49, 65, 66], although these feelings often diminished with continued use [65].

Self-doubt regarding technological competence further discouraged adoption [24, 26, 46, 49,]. This especially happens during initial setup [26] or when memory related difficulties disrupted interaction, which occurred in two ways: Older adults may forget information provided during conversations, affecting continuity of interaction [14], or

forget to use VCAs when they could be helpful, which can be supported through reminders [66]. Beyond individual concerns about technological ability, self-doubt could also emerge through family dynamics. In some multigenerational households, adult children's overprotectiveness contributed to self-doubt, as older adults feared both using it wrong and being labelled as the parent who constantly causes problems when something went wrong [68].

VCA as a source of physical, cognitive and social inactivity: The possibility of developing dependence on VCAs and losing autonomy was a recurring concern, as devices are perceived as taking over responsibilities from older adults and potentially pushing them toward passivity [64, 79]. Fears about physical inactivity emerged when VCAs are imagined as enabling a lifestyle where users rely on technology instead of moving or performing tasks themselves, while concerns about cognitive inactivity center on preferring active reading and mental effort over passive consumption of content read aloud by VCAs [55].

Older adults themselves voiced this risk, associating excessive reliance on the system with an idle, sedentary lifestyle that could hasten decline unless offset by continued activity [64]. Caregivers raised a related but distinct concern. They stressed that VCAs should remain assistants rather than independent decision-makers acting on the user's behalf, warning that if VCAs took over caregiving responsibilities, older adults' social interactions might diminish and contribute to isolation [64, 66]. This dynamic was not limited to caregiver concerns; older adults themselves resisted assistant-initiated interventions that threatened their autonomy [40]. Some older adults rejected proactive suggestions from assistants, such as unsolicited reminders or recommendations triggered without their

explicit request but framed as being in the older person's best interest, because they perceived these interventions, even when benevolently intended, as a form of "benevolent paternalism" that threatened their independence [40].

VCA as an unauthorized and unreliable device: Despite reassurance from emergencies and reminder features, trust eroded when these proved insufficient [26, 55, 64, 66, 77]. Concerns about security further weakened trust, as the absence of voice authentication or locking mechanisms raised fears of unauthorized access, including misuse by family members and exposure of financial information to intruders [55, 64, 66]. Privacy and surveillance concerns compounded distrust, as always-listening modes evoked "Big Brother" surveillance, fears of overheard conversations, and threats to freedom and autonomy [26, 31, 48, 59, 64, 70]. Among some older adults experiencing cognitive decline, these anxieties escalated into beliefs that the device was "watching" them, leading them to turn it off at night and further illustrating how surveillance-related fears can undermine trust in VCAs [10].

Beyond privacy concerns, distrust also extended to the reliability and credibility of information provided by VCAs. Some older adults avoided voice purchasing, preferred local data storage, or misunderstood the personal data required for VCA operation [48, 55, 66]. In health-related contexts, concerns emerged when VCAs could not provide rapidly changing medical knowledge or comprehensive symptom coverage [22, 59]. Worries about who could access and use health information, together with unclear reasoning behind recommendations, further undermined trust in health-related assistants [11, 21]. In a health-focused co-design study, older adults emphasized the importance of credibility mechanisms, such as

references to trusted medical providers, citations to underlying studies, visible update dates, and disclosure of the assistant's background and credentials, highlighting that trust depends not only on functionality but also on transparency and perceived authority [29]. Proposed mitigations included professional oversight, multi-stakeholder consensus [55, 59], and crowdsourced credibility assessment mechanisms [66].

VCA as a technically and emotionally unstable device: Gaps between expected and actual VCA conversational abilities frequently led to misunderstandings, disappointment, and frustration [17, 19, 24, 60, 66, 84]. Dependence on electricity and internet connectivity further undermined distrust, discouraging reliance on VCAs for critical functions such as alarms and reminders [31, 59, 64, 66]. These technical limitations were compounded by linguistic diversity, as regional accents, dialects, and unfamiliar speech patterns were frequently misrecognized, at times so severely that users had to consciously adapt their manner of speaking to be understood [9, 37, 68]. In some cases, this extended to the assistant failing to register even simple, clearly enunciated responses [52], which one participant described as "a critical failure" given the voice-driven nature of the system [43].

Instabilities also extended to emotional interactions. Poorly timed, self-activated notifications disrupted daily routines [64]. Additionally, contextually inappropriate affective responses, such as repeated expressions of affection, caused irritation rather than comfort or encouragement [17]. This unpredictability could also run in the opposite direction, toward an unexpectedly critical or scolding tone, as when an assistant reprimanded a user for repeating a request more than three times, illustrating how an assistant's affective

register could shift without contextual justification [79]. Emotional responses that were intended positively could also backfire in their intensity. In one deployment, enthusiastic verbal praise and celebratory sound effects following successful task completion were experienced by some users as overwhelming rather than encouraging [57].

4. DISCUSSION

While our analysis distinguishes between positive and negative hedonic aspects, these experiences are deeply interconnected and shaped by the pragmatic characteristics of VCAs. Factors such as functional support, reliability, and ease of use influence older adults' emotional responses, self-perception, and sense of autonomy, blurring the boundary between hedonic and pragmatic qualities in later life.

Across the reviewed literature, these hedonic aspects consistently involve trade-offs rather than isolated states. VCAs support companionship through voice-based interaction and their physical presence in the home, yet the resulting sense of closeness must be carefully calibrated, as concerns about social stigma and impersonal interaction can undermine it. Similarly, while VCAs offer valuable reminders and information, the appropriate level of assistance varies across individuals and requires deliberate design choices to avoid fostering dependency. Voice communication is engaging, yet trust breaks down when communication fails or privacy is threatened, underscoring the need for trustworthy design. We argue that attending to these trade-offs is what allows VCAs' pragmatic qualities to reinforce, rather than undermine, positive hedonic experience for

older users. Below, in response to RQ3, we discuss these trade-offs along three dimensions: social, assistance, and confidence.

4.1 From Social Connection to Potential Social Dissonance: VCA Influence on Companionship and User Labeling

Consistent with previous research [44], companionship emerged as a core role of VCAs. Alternative entertainment features such as music, storytelling, and games strengthened this relationship, while the context of use (e.g., bedroom, hospital, care home) shaped how companionship was experienced. For example, older adults could feel socially connected during the day yet lonely returning to a room without a companion to say "good night." Design decisions should therefore consider not only when and where VCAs are used, but also relational features, such as personality and screen presence, that help older adults build a sense of intimacy with the device. VCAs may also become companions for caregivers themselves, for instance supporting those caring for an older adult with dementia [7, 20].

However, companionship through VCAs involved tensions, including communication interruptions, persistent speech limitations for continuous everyday conversation, and the feeling of talking to a machine, all of which fed worries about appearing foolish. The level of emotional closeness established with VCAs therefore requires careful balancing. While some users developed strong emotional attachment, inappropriate affective responses, ranging from repeated expressions of affection to unpredictable shifts toward an overly critical or overly enthusiastic tone, became irritating rather than reassuring [17, 57, 70, 79], clearly illustrating this trade-off.

Thus, designing responsible VCA experiences requires attention not only to conversational quality but also to appearance, personality, and social interpretation around stigma and inadequacy. As VCAs can be embodied in visual forms such as holograms or anthropomorphic agents [65], designers should carefully consider how features such as voice, appearance, gender, and language shape attachment, social substitution, and gender stereotypes, particularly given the significance of personal relationships in older adults' lives [45, 83, 85].

4.2 From VCA Assistance to User Incompetence: VCA Influence on Well-being and User Dependency

VCAs' assistance features, particularly reminders and information provision, positioned them as helpers [4, 26, 72] . Yet older adults with established routines, such as using a medicine box instead of an alarm, or those who could otherwise meet their own needs, often found VCAs less useful [48]. Expectations of assistance therefore varied with health conditions, living situations, and whether others also interacted with the device, meaning the appropriate level of support differed across individuals rather than following a single template.

This variability extended to autonomy itself. Both older adults and caregivers cautioned that excessive reliance on VCAs could foster inactivity and eroded autonomy, echoing calls in the literature for assistive technologies that support independence, social connection, and self-efficacy rather than substituting for them [5, 7, 16]. This tension surfaced concretely when VCAs moved from assisting to deciding. Older adults resisted proactive suggestions, unsolicited

reminders and recommendations they had not requested, even when well intentioned, experiencing them as a form of benevolent paternalism that undermined their independence [40]. Within families, this dynamic could be reinforced rather than resolved, as adult children's overprotectiveness left some older adults doubting their own competence and fearing being labelled as the parent who constantly causes problems [68]. Designing for assistance therefore means preserving the older adult's role as decision maker. Rather than replacing meaningful activities, VCAs could enhance existing routines. For instance, replacing reading with automated narration may reduce enjoyment and mental engagement, whereas features such as personalized playlists, reading trackers, and reminders could support the activity without displacing it. VCA design should also avoid reinforcing feelings of aging by allowing personalization of both functionality and appearance.

4.3 From Self-Confidence to Self-Doubt: VCA Influence on Older Adults´ Confidence

Voice-based interaction itself triggers curiosity among older adults. Eliminating the worry of pressing the wrong button can motivate them to use the product, or even to ask seemingly silly questions. The reminder feature and accompanying guidance made them confident in knowing what to do and encouraged experimentation with new technological products. However, certain concerns discouraged sustained interaction, including unauthorized use of the voice assistant and forgetfulness, such as difficulty remembering a simple wake-up word [14, 26, 66]. Limited conversational and problem-solving skills, such as being unable to sustain daily communication, misunderstanding the user, or repeating similar answers, made older

adults feel guilty and undermined their self-confidence. Concerns about privacy, constant surveillance, storage of sensitive personal data, and the accuracy of information provided, particularly for health-related questions, further weakened trust [51]. Perceived system reliability therefore emerges as a critical design consideration, supporting both sustained engagement and users' confidence in interacting with VCAs. Together with the ethical concerns already raised around companionship and social labeling, these reliability and privacy issues raise a further question that designers cannot avoid, namely whether older adults should be encouraged to commit to an always-connected voice assistant at all.

Looking across these trade-offs, the interaction between the hedonic dimensions plays a central role in shaping design decisions for VCAs targeting older adults. Rather than addressing individual hedonic aspects in isolation, designers need to consider how improvements in one dimension may influence others. For example, reminder features that support well-being and reinforce self-confidence can, if relied upon too heavily, tip toward dependency and self-doubt, illustrating how the same feature can move users along both the assistance and confidence dimensions at once. Figure 4 visualizes these trade-offs across the three dimensions.

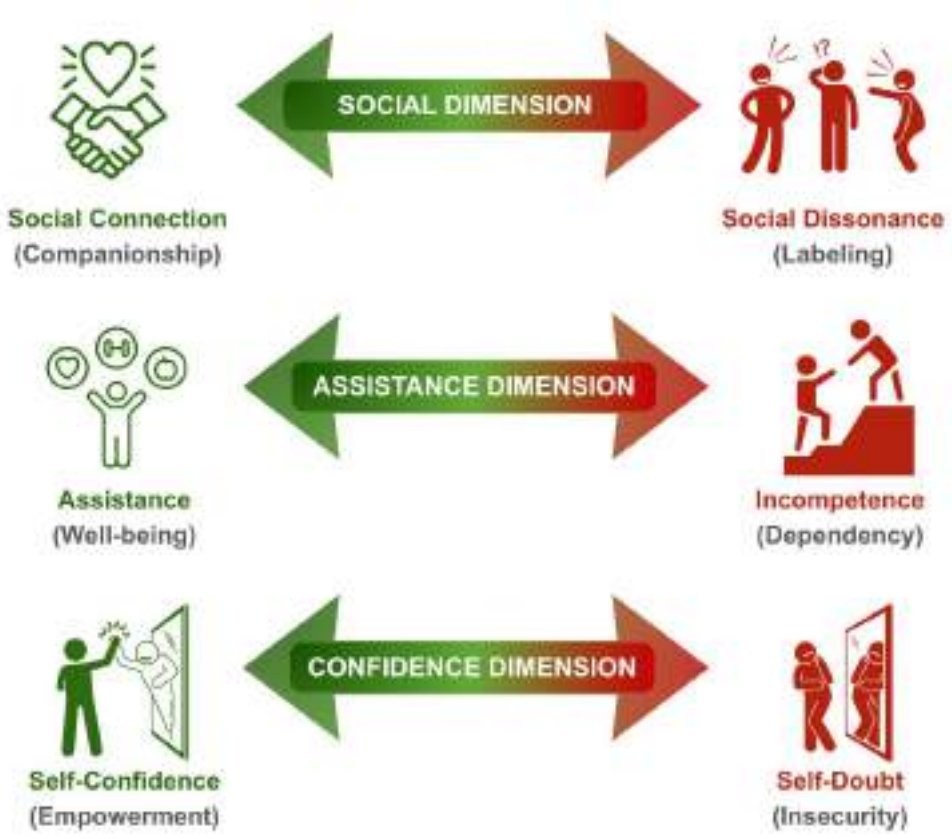


Figure 4: Trade-offs across hedonic aspects

5. LIMITATIONS

This review synthesizes patterns in literature rather than making definitive or causal claims about the positive and negative hedonic aspects of older adults' interactions with VCAs. To focus on dimensions beyond pragmatics, we included studies that examined users' experiences and design implications, while excluding studies focused primarily on NLU or other pragmatic concerns. Consequently, studies without direct user involvement that may nevertheless inform hedonic experience could have been overlooked.

The literature also has methodological gaps. Adults aged 75 and over are underrepresented relative to younger older adults, participatory approaches such as co-design are less common than interviews and surveys, and evidence is concentrated on a narrow range of commercial platforms. Future research should address these gaps.

6. CONCLUSION

This review synthesized 52 studies from 6 databases to examine hedonic aspects of older adults' interactions with VCAs. Balance emerged as a key design principle, as companionship may entail social labeling, assistance may foster passivity, and confidence may be undermined by mistrust. Designing VCAs for older adults therefore requires addressing these trade-offs rather than optimizing any single dimension. Understanding these hedonic elements and their trade-offs can guide the development of VCAs that address not only pragmatic but also emotional and social needs.

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Design and Development of a Wireless Electrical Stimulation Device for Shoulder Pain Management - Case Study Practice-Based Paper

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Abstract

This report outlines the design process of a wireless electrical stimulation device intended for patients with shoulder pain following brain injury. To ensure the solution is clinically relevant and beneficial, extensive primary and secondary research was conducted in collaboration with key stakeholders. A clinical champion and supervisors provided ongoing guidance and facilitated access to specialist lectures and practical sessions, where existing rehabilitation devices were evaluated first hand. In addition, discussions with a competitor market product user provided insight into current solutions and their clinical adoption. An observational visit to Hillingdon Hospital enabled direct understanding of rehabilitation environments and patient interactions. Meetings with neurophysiotherapists from London Northwest University Healthcare NHS Trust helped define current pain points faced by clinicians and opportunities for improvement.

The proposed solution consists of four electrode pods and a silicone cuff, with teal and purple elements indicating channel 1 and channel

2 stimulation. In dual-channel operation, one channel targets the anterior and posterior deltoid muscles, while the second targets the supraspinatus and middle deltoid stabilising muscles. Channel 1 utilises a closed-loop magnetic connection embedded within the cuff between two pods, while channel 2 integrates its closed-loop system within the scapular pod, connected via a fabric-covered wire to the supraspinatus pod. Both channels wirelessly connect to the Avira+ app, providing an accessible and intuitive user interface for clinicians and patients.

Key design decisions prioritise patient safety, usability, and treatment adherence. Pre-approved clinician ES sessions prevent unintended changes to stimulation parameters, addressing risks observed in clinical environments such as muscle burns or spasms. An information hierarchy within the app improves accessibility by reducing reliance on complex medical terminology. Capacitive proximity sensors within the electrode pods detect loss of skin contact and alert the user. The wireless design eliminates trailing wires found in existing ES devices, improving mobility, usability, and patient engagement during rehabilitation.

Keywords

Electrical Stimulation (ES), Shoulder Pain. Supraspinatus Deltoid, Wearable Medical Devices, Neuro Rehabilitation

Introduction

This project forms part of a collaborative brief with Design for Health for a major design engineering project. The brief involves working alongside a clinical champion, Michele Walsh, who is currently conducting research related to electrical stimulation (ES) and shoulder following brain injury. The brief, titled *Electrifying Recovery: Stimulating Shoulder Stability Post Brain Injury to Reduce Pain and Increase Function*, addresses the clinical challenge of shoulder pain, a common complication following brain injury e.g. stroke. This condition often leads patients to adopt protective behaviours, avoiding movement of the affected shoulder due to pain, which can subsequently limit engagement in rehabilitation activities and slow recovery outcomes.

The design brief outlines how electrical stimulation can support shoulder stability by facilitating muscle activation and improving joint alignment. Electrical stimulation also provides sensory input which may impact pain receptors and neuroplasticity.ES is therefore positioned as a potential intervention to enhance functional recovery and reduce pain associated with shoulder weakness. However, existing commercial ES devices are often bulky, rely on trailing wires, and are not easily usable by patients independently in real-world settings (Walsh et al., 2026).

The primary aim of this collaborative brief is therefore to design a wireless, dual-channel ES device, supported by a digital interface, that improves usability and patient independence while maintaining clinical effectiveness. This article will provide a reflective account of the design project, discussing the research process, iterative

development, and key decisions that shaped the final proposed solution.

Literature review

Stroke and Shoulder Pain

Approximately 13.7 million people worldwide experience a stroke each year. These conditions can result in damage to the upper motor neurons and the neural pathways connected to them. Stroke patients can have difficulties in movement, walking and performing activities of daily living (Kristensen, Busk and Wienecke, 2021).

Stroke is one of the leading causes of long-term disability worldwide, and shoulder pain is a common complication that can significantly affect recovery. Hemiplegic shoulder pain (HSP) affects up to 84% of stroke survivors. HSP usually develops within the first two to three months after a stroke and can reduce upper limb function, limit participation in rehabilitation, lower quality of life, increase the length of hospital stays and add to healthcare costs (Murie-Fernández *et al*., 2012; Royal College of Physicians, 2023). The condition has several possible causes, including muscle weakness, spasticity, shoulder subluxation, rotator cuff injuries, adhesive capsulitis (frozen shoulder), changes in muscle tone and pain caused by damage to the central nervous system (Harrison and Field, 2015; Winstein*et al*., 2016). Because there are many possible causes, managing post-stroke shoulder pain requires early assessment and a combination of treatments. These may include correct positioning of the arm, therapeutic exercises, functional electrical stimulation, pain relief, and patient education to help improve recovery and reduce further

complications (Winstein*et al*., 2016; Royal College of Physicians, 2023).

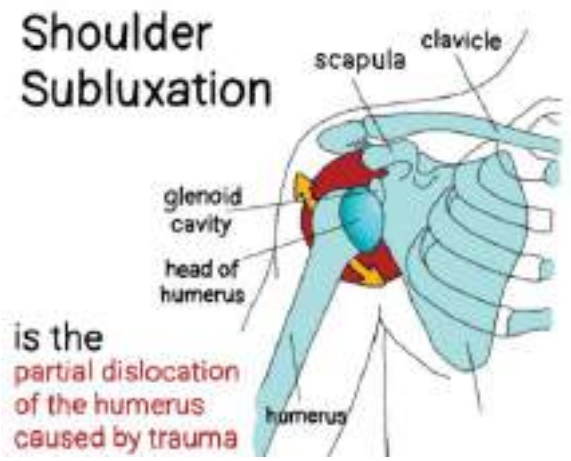


Figure 1 Shoulder Subluxation visual diagram with labelled associated muscles (Illustrated by A. Sripathy,2025)

Shoulder Subluxation is a frequently found complication after a stroke which results in the loss of voluntary control of shoulder muscles affecting up to 81% of patients(Kumar and Swinkels, 2009).

Shoulder Subluxation can be detected due to an increased gap between the acromion of the scapula and head of the humerus. Electrical stimulation can be applied to help increase properties in the muscle akin to strengthening reducing the painful effects of shoulder subluxation (ES& Shoulder Subluxation Odstock medical, 2024). Electrodes are placed on the supraspinatus and deltoid muscles before the ES device is turned on. The muscle contractions and movement that occur during ES therapy allow the humerus bone to be lifted back into the glenohumeral socket.

ES devices currently on the market are not particularly suited for extended use during activities of daily living. The devices can be too bulky to carry in pockets which most lounge and hospital wear does not include, along with trailing wires that can catch onto wheelchair armrests causing inconvenience (M. Walsh, 2025).

Stroke Recovery



Figure 2: In the physio lecture that the student attended a diagram outline was shown showing the large team of people involved to support patient recovery and rehabilitation process.

A stroke causes weakness or paralysis on one side of the body and problems with movement and carrying out everyday activities (Stroke Association, 2024). Recovery and rehabilitation are different for everyone and can depend on various factors such as the severity of the stroke along with the overall health of the patient and intensity of the rehabilitation program (Bence, 2023).

The first few days and weeks, after a stroke patient is stabilized in a hospital, is defined as the Acute Phase (The Royal Buckinghamshire Hospital, 2025). During the Acute phase, the patient is in the most effective time for rehabilitation where neuroplasticity is most likely to occur. The Sub Acute phase is the first 6 months post stroke and is the most important for recovery and in which time patients will see the most improvement (Raghavan, 2022). In the chronic phase of a stroke, which begins around six months after the event, the focus shifts to long-term management of residual disabilities and adaptation to new routines (Majithia, 2024).

Neurophysiotherapists Interview (London Northwest University Healthcare Trust NHS) – Highlighting Key Pain Points

An interview was conducted with two neurophysiotherapists from

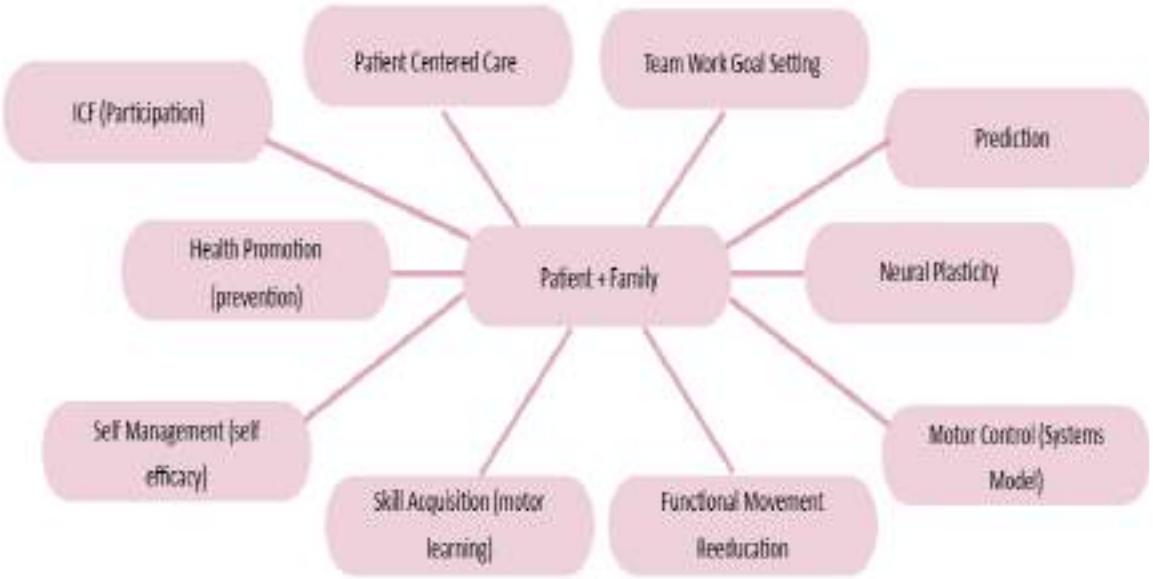


Figure 3: Principles for Neurological Rehabilitation - In the physio lecture that the student attended the principles of Neurological Rehabilitation were provided in a neat diagram. This interlinks with the Team work diagram showcasing just how extensive the patient neuro rehabilitation process can be (Lennon et al 2018 Physical Management)

London Northwest University Healthcare NHS Trust to inform them about the development of the ES device for shoulder pain rehabilitation. The discussion highlighted that hemiplegic stroke is the primary patient group requiring upper limb rehabilitation and ES intervention with Traumatic Brain Injury (TBI) as the secondary cohort.

Clinicians reported that ES is introduced in the subacute phase of stroke recovery commonly between three to four months post injury. A key insight from the consultation was the importance of monitoring patient compliance and usage of the devices once patients are sent

home. Treatment adherence was mentioned as a key pain point for clinicians alongside the lack of reliable methods for tracking stimulation duration and pad usage in current systems. Clinicians highlighted that device usage data identified as a valuable tool for clinical decision-making and treatment optimization.

Why is dual channel ES required for shoulder pain?

For an effective outcome, 6 – 8 weeks of treatment may be required with stimulation applied two times a day for up to 6 hours (ES Mobility Channel, 2019). An asymmetrical waveform is used with current intensity to patient tolerance – channel 1 active electrode over the anterior deltoid & channel 2 active electrode over the middle portion of the deltoid (ES Mobility Channel, 2019). This combined stimulation lifts the humeral head into the glenoid fossa from multiple angles, promoting alignment without excessive shoulder abduction (VR, 2025b).

Methodology

Market Research

By evaluating current products on the market, gaps were identified, uncovered unmet user needs, and determined how Avira + could be positioned against competitors. The analysis revealed a lack of wireless dual-channel ES devices with intuitive companion apps, instead relying on overfilled instruction booklets - highlighting an opportunity to improve accessibility and user experience.



Figure 4: SaeboStim One £128 (SaeboUK, 2026)

The device offers a portable, wireless design for electrical stimulation (ES), with multiple size options, ultra-thin wing-like electrode placements, a rechargeable battery, reusable electrodes, and suitability for home use. However, its functionality is limited by single-channel stimulation and the absence of a companion monitoring app, while effective use depends on accurate electrode placement and adhesion, often requiring clinical guidance. Additionally, electrode storage is inefficient, and the device provides less powerful and versatile stimulation than comparable alternatives such as the SaeboStim Pro.



Figure 5: SaeboStim Pro £239 (SaeboUK, 2026)

The device provides dependable dual-channel stimulation and supports NMES, ES, and TENS therapies for muscle re-education, targeted training, and strength recovery. Its programmable parameters, including pulse width, frequency, and ramp settings, enable treatment customization. However, wired electrodes can be inconvenient for home use, accurate electrode placement is essential, skin irritation and storage issues may occur. The absence of a companion monitoring app may reduce patient engagement and motivation.



Figure 6: MicroStim 2V2 £128.00 (Odstock, 2025)

The device offers dual-channel stimulation with ten preset treatment modes, including dedicated programs for reciprocal muscle activation, while also allowing clinicians to customize output intensity across a range of stimulation parameters. However, the bulky wired design can restrict mobility during treatment, and accurate electrode placement is essential, with stimulation settings requiring adjustment for one muscle at a time.

Physiotherapists Focus Group Survey Results

A survey was created by the student to gain feedback on the current devices used additional results can be found in Appendix B. The survey included responses from nine participants, predominantly physiotherapists, alongside physiotherapy students and one occupational therapist. Most respondents used ES primarily with stroke patients, with several also treating individuals with traumatic brain injury, spinal cord injury, and other neurological conditions. The MicroStim 2V2 was the most frequently used device and was generally rated positively for overall usability, reliability, and ease of clinician setup. Respondents highlighted its consistent stimulation performance and straightforward operation once familiar with the device. However, a recurring limitation was poor patient independence, as electrode placement often required assistance and could be time-consuming. Additional comments also identified difficulties with electrode positioning, limited integration with

functional activities, and the potential for accidental adjustment of stimulation settings.

The SaeboStim Pro received mixed evaluations, with users appreciating its flexibility and trigger functionality but noting that it could be more complex to configure and did not perform consistently across all patients. The SaeboStim One received the least favourable feedback, with several participants describing it as limited by its single-channel design, restricted functionality, and the need for regular user interaction during prolonged treatment sessions. When considering the design of a new ES device for shoulder subluxation, respondents consistently rated simple setup, portable home use, comfortable electrodes, patient independence, adjustable stimulation parameters, long battery life, and integration with rehabilitation programmes as highly important. These findings suggest that future device development should prioritise ease of use for both clinicians and patients while maintaining reliable stimulation performance and supporting independent use in home-based rehabilitation.

Direct Competitor Review

The clinical champion kindly arranged a demo of this device with one of her colleagues who is also a physiotherapist. The student was able to view the Valkyrie eir in person close up observing the manufacturing styles. Below are photos taken during the session and critical design evaluation notes.



Figure 8 After the pods were connected the physiotherapist explained the need for the device to adapt to inferior subluxation too. The clinical champion mentioned that as much as she preferred the exoskeleton concept for encasing all the electrode pods there would be minimal movement of freedom. The cuff concept is able to offer adjustability for inferior, anterior and



Figure 7 - This image shows the Clinical Champion attaching the device onto the physiotherapist's shoulder. The arrangement of which was for anterior subluxation. The strap which connected the pods together was not very flexible and due to the physiotherapist's measurements being on the higher end of the percentile it was difficult to get the pods to connect.



Figure 9 The student noticed that the design decision to make the pods slightly flexible to conform to the shoulder anatomy has been interpreted in a similar way by this product. Valkyrie eir had a curvature on the underside of the pod instead. LEDs were used to distinguish Channel 1+2 whereas the student has decided to colour them directly. Adjustability has been redesigned instead of using multiple button pin

Ethics Approval

This project followed Brunel University London's research into ethics procedures. Participant Information Sheets and Consent Forms were created for the clinician and patient participants, and risk assessments were completed throughout the project to identify and manage any potential risks. The ethical documentation and research process were reviewed by my first supervisor. Informed consent was

obtained from the clinician and patient before the observational study at Hillingdon.

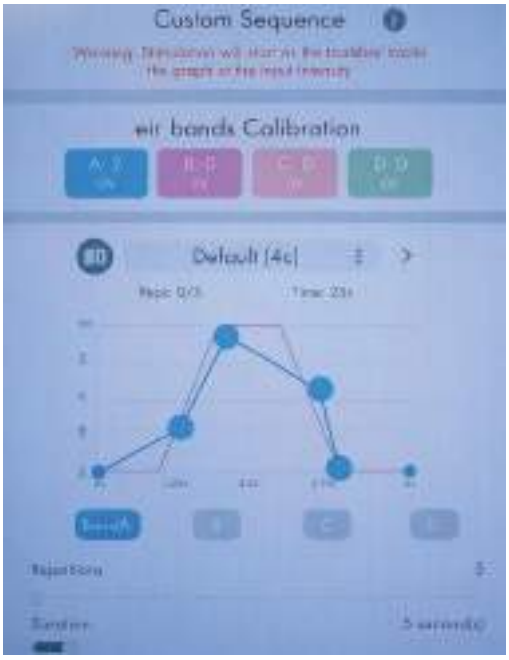


Figure 10 Shown on the left is the UX/UI for the pairing application. The clear layout with minimal changes in font and clear colour indications create ease of access. The wireframes specifically shown are those that allow the clinician to test out various cycle times and device settings. Custom calibration is an availability that is offered clinician side that has encrypted access. A similar ideology is one the student has adopted having an information accessibility hierarchy between the

Observation at Hillingdon Hospital

The clinical champion, Michele Walsh, kindly arranged a meeting at Hillingdon Hospital to allow the student to observe an ES session with a recovering stroke patient. During the visit, the student observed a range of physical resources used for post-stroke muscle rehabilitation, including resistance bands, cones, and jars. These tools were used alongside the GRASP program, which the student noted as a structured approach to upper-limb recovery.

Several key design-relevant pain points were identified during the session. The patient experienced difficulty putting their T-shirt back on once the ES device had been set up, highlighting challenges related to device bulk, wearability, and ease of use during everyday activities. The clinician also noted that patients can unintentionally or

intentionally adjust device settings, either due to involuntary movement or a lack of medical understanding, indicating a need for clearer control hierarchies and safeguards within the system. The form of the device was a significant inconvenience, particularly the bulkiness of the unit and the presence of trailing wires. Electrode placement was critical to the effectiveness and comfort of the therapy, requiring clinician expertise and initial verbal feedback from the patient regarding electrical impulse sensations. These observations underline the importance of intuitive setup guidance, real-time feedback and reassurance within a digital pairing application. These insights informed the design of a companion app focused on monitoring, patient engagement, and motivation, with an emphasis on usability, safety, and reducing cognitive and physical burden for stroke patients.



Figure 13 Electrodes being applied: Patients sometimes can change settings due to involuntary movement or lack of medical knowledge.



Figure 14 Controls for the existing ES devices are not very patient,friendly, and welcoming.



Figure 11: Clinician struggles to put patient's t-shirt back on due to trailing wires everywhere getting tangled.



Figure 12: Device simply has a label for misuse which the design student noticed was not enough of a deterrent.

Physiotherapy lecture

During a physiotherapy teaching session, the student gained hands-on experience using the SaeboStim One and SaeboStim Pro electrical stimulation (ES) devices. This provided valuable insight into their clinical application alongside rehabilitation techniques such as mirror therapy and splinting.

Practical interaction with the devices enabled a critical evaluation of their usability, accessibility, and user interface, identifying opportunities to improve product interaction for both clinicians and patients. In particular, the current method of storing the adhesive electrode pads on a reusable plastic sheet was found to be impractical for long-term use, as it can be easily misplaced. This resulted in storage solutions within the concept development. User guides for the devices were very extensive, and it was doubtful if patients/clinicians would find it easy to refer to it for continued safety.

The session also provided an understanding of the products' manufacturing methods, including their button mechanisms and injection-moulded components, which informed the feasibility and direction of the subsequent design concepts.



Figure 15: Extensive user booklet thirty-five plus pages long along with wires that can get easily tangles SaeboStim Pro



Figure 16: Student trialed out SaeboStim One on arm to understand safety disclaimers to include within pairing application e.g., uncomfortable tingling sensation.



Figure 17: female and male buttons pin to connect the components together.



Figure 18: Twist lock mechanism to separate the adhesive pads from main unit



Figure 19: A flimsy plastic sheet provided for the electrode pads to be placed on after each session.



Figure 20: Mirror therapy trialed by the student during a physiotherapy lecture.



Figure 21: SaeboStim one electrical connection shown using snap buttons.

Figure 22: Splints worn by the student during physiotherapy lecture.



Figure 23: SaeboStim One being used on another physiotherapy student to see the muscle contractions that help neuro rehabilitation patients with shoulder pain.

Design

Initial Concepts

The student created a range of design concepts to explore how the electrode pods and app system could be placed together. The top three concepts were included in a survey that was sent out to neurophysiotherapists where they were able to give their professional opinion and rank each concept based on accessibility, usability, easy to clean etc. The full product design specification can be found in Appendix A.

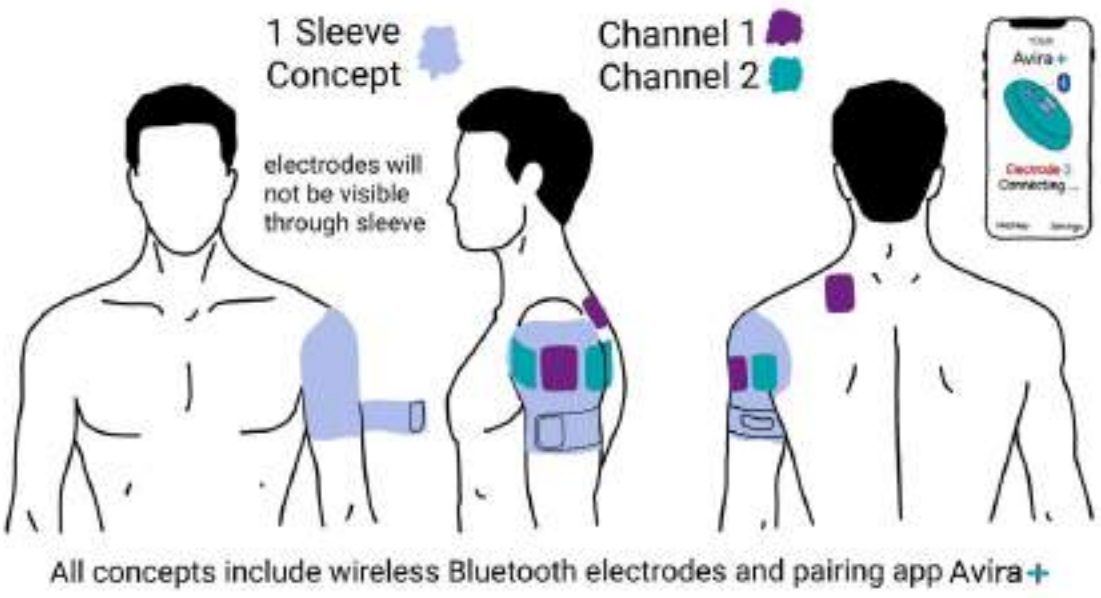


Figure 24: Illustration drawn by student to visualize concept 1. The colored blocks shown in purple and teal are the electrode pod of which the technology and design will be explained further down.

The electrodes would be placed on the patient's shoulder, and a sleeve would be worn on top. Adjustable strap on the sleeve determines the tightness to secure the sleeve in place. The sleeves and electrodes

remain unattached. Once the sleeve is comfortable, the patient/carer can connect Avira+ and begin their exercises. Materials would include a derma silk lining to ensure breathability and patient skin safety during longer periods of wear. The sleeve can be removed and machine washed.

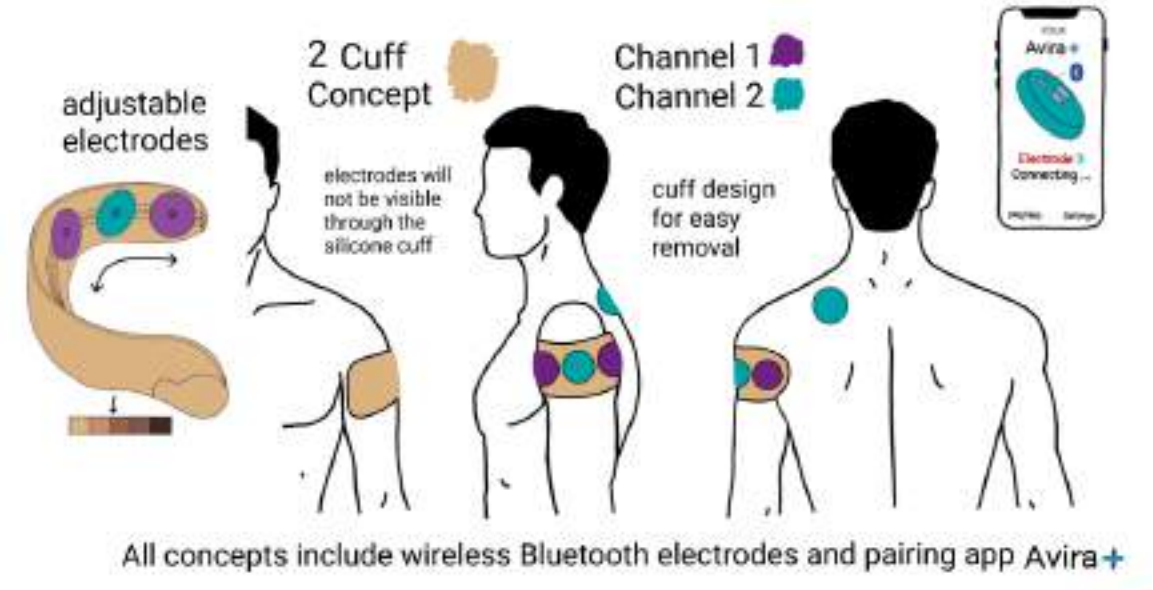


Figure 25: Design illustration by student to show concept two which became the chosen one to be developed further.

The patient/carer can adjust the electrodes by sliding them across the cuff. Once the placement of electrodes is finalized, the cuff can be placed on the shoulder and wrapped around. Once the cuff is comfortable the patient/carer can connect to Avira+ and begin their exercises. The silicone cuff would be made from similar material to modesty pads and stay attached to patient. Electrodes can slide out of the cuff, and the cuff can be hand washed.

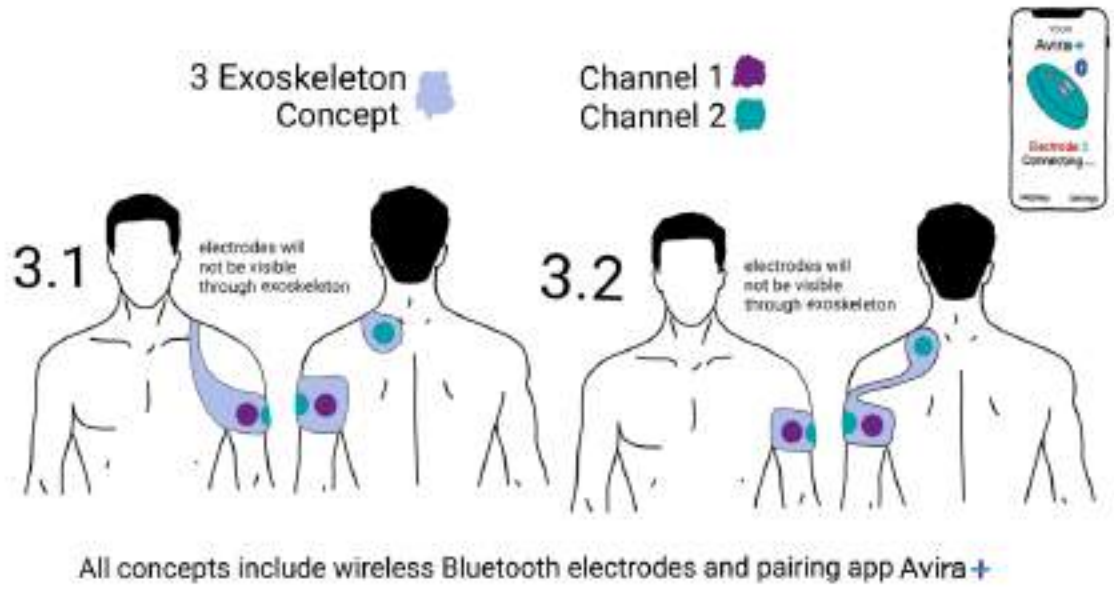


Figure 26: Illustration shows concept 3.1 and 3.2 of the exoskeleton concept which the student wanted to explore further but due to tie constraints and the clinician's enthusiasm towards concept two, this design remains unexplored.

The patient/carer can adjust the electrodes by sliding them across the exoskeleton. Once the placement of electrodes is finalized, the exoskeleton can be placed on the shoulder. Once the exoskeleton placement is comfortable, the patient/carer can connect with Avira+ and begin their exercises. The hard yet flexible silicone exoskeleton would be made with various hardness of materials to try and ensure that patient has the widest range of motion. Electrodes can slide out of exoskeleton, and the exoskeleton can be hand washed.

Initial Product Design Specification – Appendix A

The student identified a set of key product requirements to guide the design and development process. These requirements were established to ensure the final product meets the needs of the

intended users while satisfying the functional, usability, and performance objectives of the project.



Figure 27: Product Design Specification Initial

Stakeholder Mapping

Stakeholder mapping helps the student understand everyone involved in or affected by a healthcare rehabilitation device. In healthcare design, this is especially important to ensure patient safety. (ISO, 2019). The student also explored the stakeholders involved if this product were to make it into a commercial stage. For example, a clinician may want advanced features, while a patient may want something more simple to understand. Mapping key stakeholders helps the



Figure 28 Stakeholder Mapping

student see these differences and make compromises before product development begins.

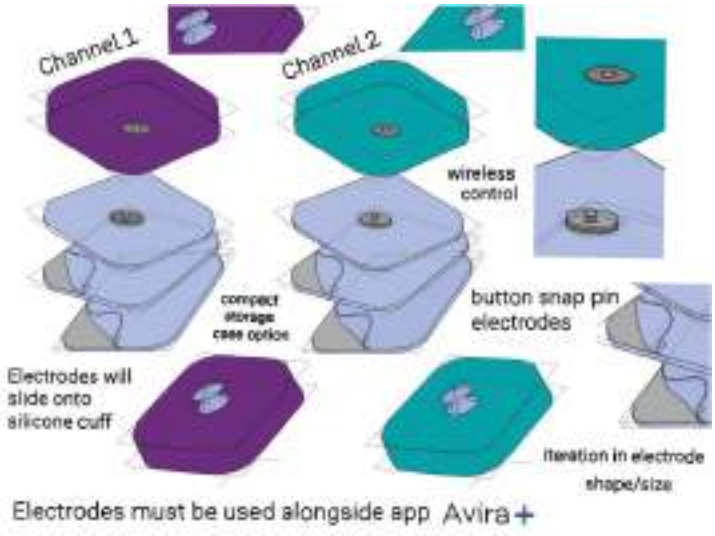


Figure 29:The Electrodes connect to the adhesive pads similar to the way TENS electrodes work with a button pin. This ensures that each unit is connected with its own electronic Bluetooth module allowing for the Avira+ app to function.

The electrodes are colour coded for easy identification of both channels. The Bluetooth unit will remain with the patient during their use over the years and the patient will only have to

Design Development – Low Fidelity

The low fidelity prototypes meant that the student was able to see scale and form more easily. Results from the survey aided in terms of refinement and further iteration through modelling + CAD. The student explored the cuff form and development through sketches and paper prototyping. The shoulder breadth (BI deltoid) is the distance across the shoulders at the widest point (outer deltoids). The shoulder breadth (Biacromial) is the distance between the acromion processes (bone landmarks on the shoulder) (ISO 7250-1:2017). These measurements were vital for the student while developing the three initial concepts. Contextual images shown (Roymech, 2020)

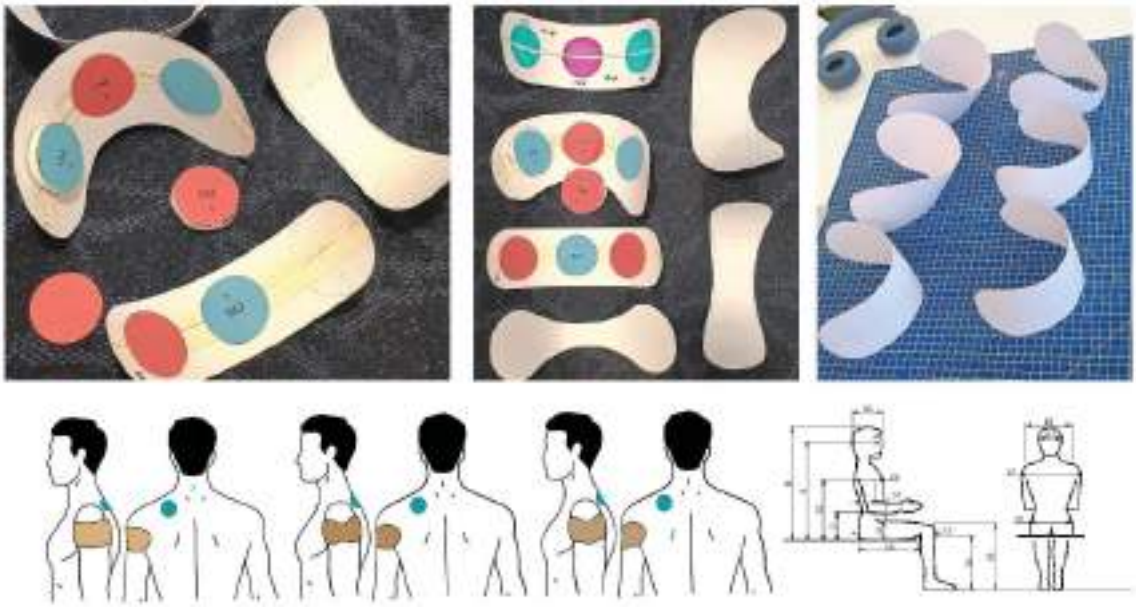


Figure 30: Images show low fidelity paper prototyping and student's use of anthropometric measurements. Shape and sizing were effectively explored to support development process of Avira+

Open Loop ES

Open-loop electrical stimulation (ES) refers to a mode of ES in which electrical stimulation is delivered using pre-defined parameters (such as intensity, duration, and timing) that do not change in response to real-time physiological or biomechanical feedback from the user (Teslasuit, 2023). In an open-loop ES system, the control action is independent of the actual muscle activity or movement achieved, meaning the stimulation settings are set in advance by a clinician or programmed into the device and remain unchanged during a session regardless of how the muscles respond or how the task is performed (Wolf and Schearer, 2017).

Within this Avira+ predefined parameters will be clinician approved before being accessed by the patient. Adopting Open - loop ES in the pairing app ensures patient safety reducing the risks of muscle

fatigue, spasms, or burns. Patients like the one that the student observed at Hillingdon Hospital will not be able to change the setting either due to involuntary movement and or lack of medical device knowledge.

Design Development – Electronics

The student used an Arduino Nano to demonstrate the four electrodes, initially including manual controls for parameters such as amplitude. Later the design changed to just the digital app and wireless cuff to increase portability and range of movement for the patient. After the design changed so that the clinician would pre-program the FES cycles, the manual controls were removed, and the electronics were rearranged onto a smaller breadboard to better represent the electrode pods. The code was updated to include ramp-up and ramp-down times, an emergency stop added, and BLE-controlled operation so the FES cycle only ran when connected to the application. Avira+ will turn on only when the device is in contact with the skin. This will be achieved using capacitive proximity

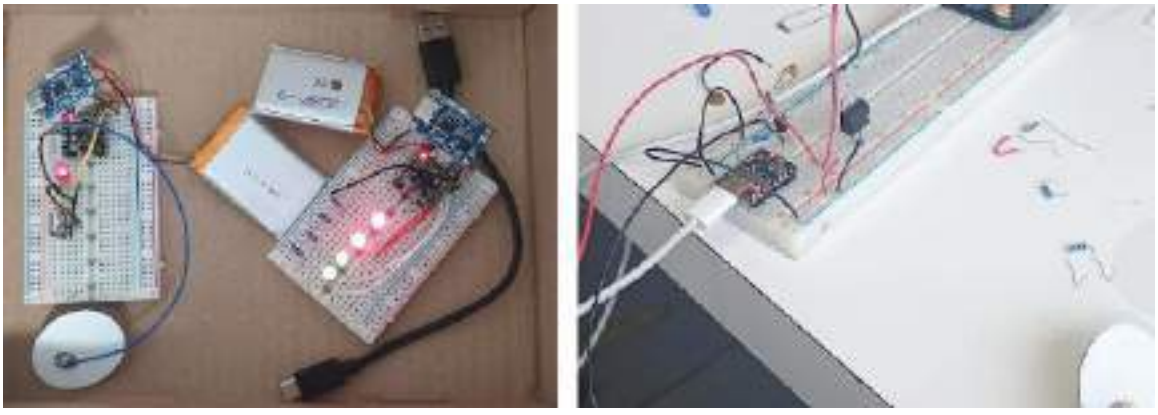


Figure 31: Figure showing electronics development and proof of concept created using 10V battery rather than full voltage due to health and safety risk assessment. Bluetooth ramp up and ramp down feature visibly shown using LEDs.

sensors similar to the ones used on ECG devices. TENS electrodes were also used in the proof of concept to demonstrate interaction with the ESP32.

Design Development – Prototyping and CAD

The student produced an initial foam model to test the size of the ESP32-C3 Mini and evaluate how the electronics could fit within the design. The images show the development from using LEDs to demonstrate ramp-up and ramp-down, to creating simple electronics for a single pod, and then visualizing the complete system. The ESP32-C3 Mini proved to be a suitable microcontroller due to its compact size and BLE functionality. In the final commercially available device, a



Figure 32: Images show foam modelling and 3D printed PLA prototyping to explore size, thickness and adjustability. Lateral adjustment was the final choice after clinician's input.

custom PCB would be used to achieve overlapping ramp-up and ramp-down dual-channel stimulation. The student interacted with the models in the same way a user would assess usability. As the foam

models were not flexible, they were used only to demonstrate form and size. Following this stage, small design changes were made, including reducing the thickness and corner fillet dimensions. Both lateral and vertical adjustment concepts were also explored.

The student created a curved CAD model to demonstrate how the cuff would flex around the arm and how the electrodes could be adjusted using the slot feature. This model was for the final render. The design shows three electrode pods attached to the cuff, along with a cross-section that highlights the proof-of-concept manufacturing considerations. The fourth electrode pod is shown separately and is positioned on the scapular muscle at the back of the shoulder, where the neck meets the shoulder.

For technical drawings of the electrode POD and silicone cuff refer to Appendix D and E.

App Development Design Goals



Figure 33: Image showing the CAD model prerender to explore the final design curvature of the silicone cuff conce and electrode pods.

The final Avira Plus application successfully meets the original design goals by providing a simple, accessible interface that reduces

cognitive load through the use of clear navigation, intuitive icons, and a consistent colour scheme. Patients can securely log in using their unique ID to access clinician-programmed FES sessions within the calendar, while session feedback, pain scores, and perceived muscle strength can be recorded after each treatment and reviewed by the clinician.

The app also incorporates gamification through achievements and progress statistics to encourage engagement and long-term adherence to therapy. Safety is enhanced with notifications that alert users if electrode contact is lost, and BLE connectivity ensures stimulation sessions only operate when the device is correctly connected. Clinicians can remotely configure treatment parameters, including stimulation intensity and ramp-up/ramp-down timings, removing the need for manual adjustment by the patient. In addition, the app supports clinician communication and provides a convenient way for patients to purchase replacement accessories, creating a comprehensive platform for home-based FES therapy.

Patient Safety and Risk Management

Another major health and safety risk can be seen from the contextual images the student provided from the observation at Hillingdon hospital. A label is simply placed on top of the device stating that others beside the patient should not use it. Due to being a weak barrier, a key design decision taken to have a unique patient ID sign in allows for a higher level of protection and privacy. A unique clinician ID could be implemented further down the line of product development for a more medically orientated feedback view. Only the patients who have a valid ID will be able to sign in and access control of their device and their personal ES sessions. This feature could be

used by patients who have shoulder subluxation not due to a stroke but sports related injuries.

Why do we have a device control and feedback viewing hierarchy?

As seen by the student during the Hillingdon hospital observation patients can change the settings of the ES device during a physiotherapy session either due to involuntary movements or a lack of medical knowledge. A key decision by the student to have clinician approved preprogrammed sessions reduced the health and safety risk of the patient accidentally causing themselves muscle fatigue or muscle burns (Muhammad Ahmed Khan et al., 2023b). To allow the patients to have a clear understanding of their recovery journey, Avira+ helps patients view a different style of feedback compared to the clinician. Less medical heavy and a motivating approach will aid with patient engagement in their sessions and improve the outcomes of their physiotherapy.

Due to preprogrammed sessions set by the clinician the patient need not worry about experiencing muscle fatigue or spasms due to incorrect device setting being used. Reducing the cognitive load and convenience for patients will make them more likely want to continue their treatment. The student has made the decision that the sessions will be accessed by a calendar –a familiar user interface. The student will gain feedback on the wireframes and evaluate the usability of older age groups.

Physical Prototyping and Materials

The student used medical grade silicone for the cuff geometry to encase the electrode pods as they sit upon the patient's shoulder. The light adhesive tendency of the silicone material along with the biocompatible adhesive of the electrode patches will ensure minimal movement, reducing the risk of the patches falling off or the wrong



Figure 34: Image showing the medical grade silicone process. The student created the mould learning about various elements such as air vent holes and lubrication release agents and more.

muscles being stimulated. The student gained inspiration from modesty pads, and the curvature is of which was initially modelled up. The student purchased 20A - 30A Shore Hardness skin Safe silicone to ensure conformity around the shoulder anatomy.

During the Valkyrie Demo with the clinical champion and the technician consultation the student discussed the possibility of a custom 3D print for the patient depending on their desire of personalization and cost they were happy to pay. The technology for 3D printing medical grade silicone exists along with 3D scanning such as Reality CR-Scan; both can work hand in hand to create a more

custom user experience. For off-the-shelf purchasing and minimal spending, the cuff will be available in three to four sizes and be cast at a large scale.

Additional Conceptual Renders

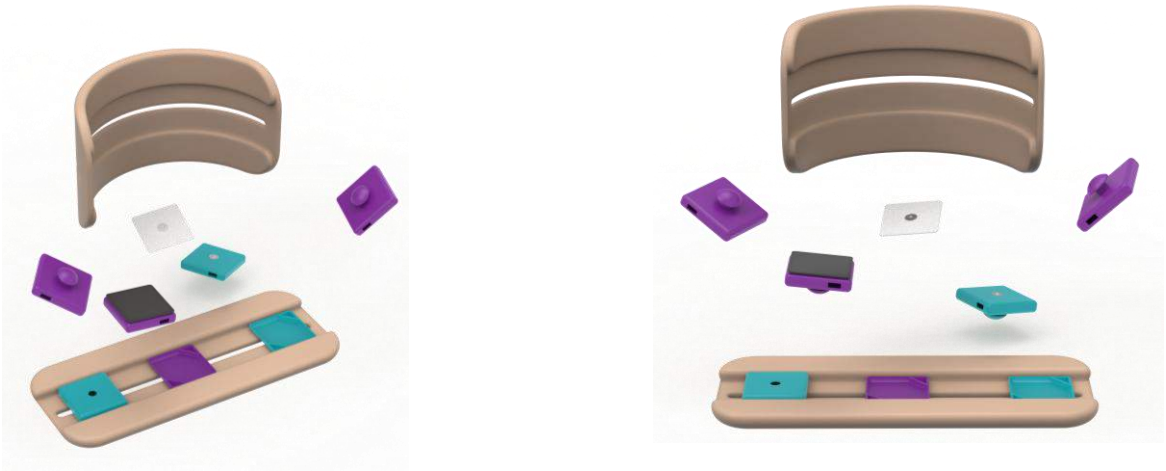


Figure 35 Images show final renders completed by the student to show product features on the presentation boards.

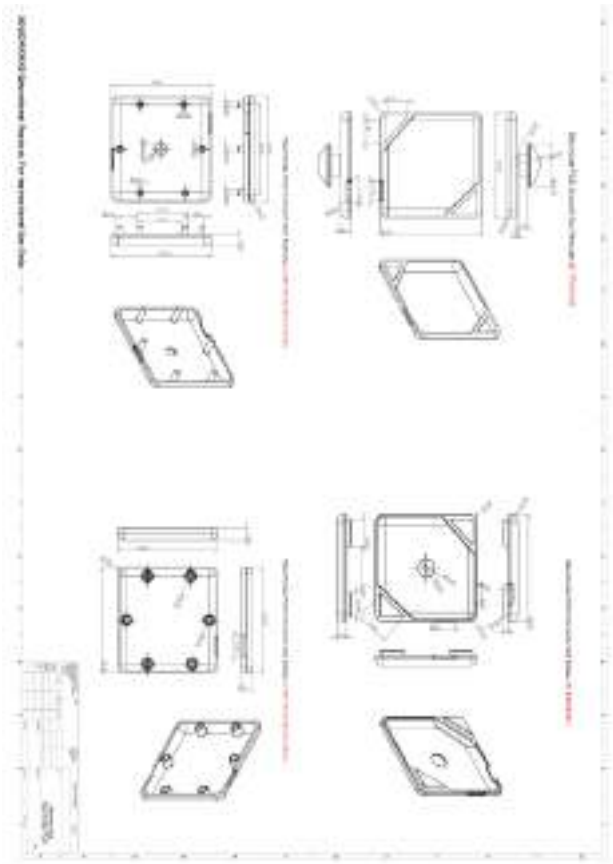


Figure 36: Technical drawing of electrode pods for Avira+ which slot onto the silicone cuff

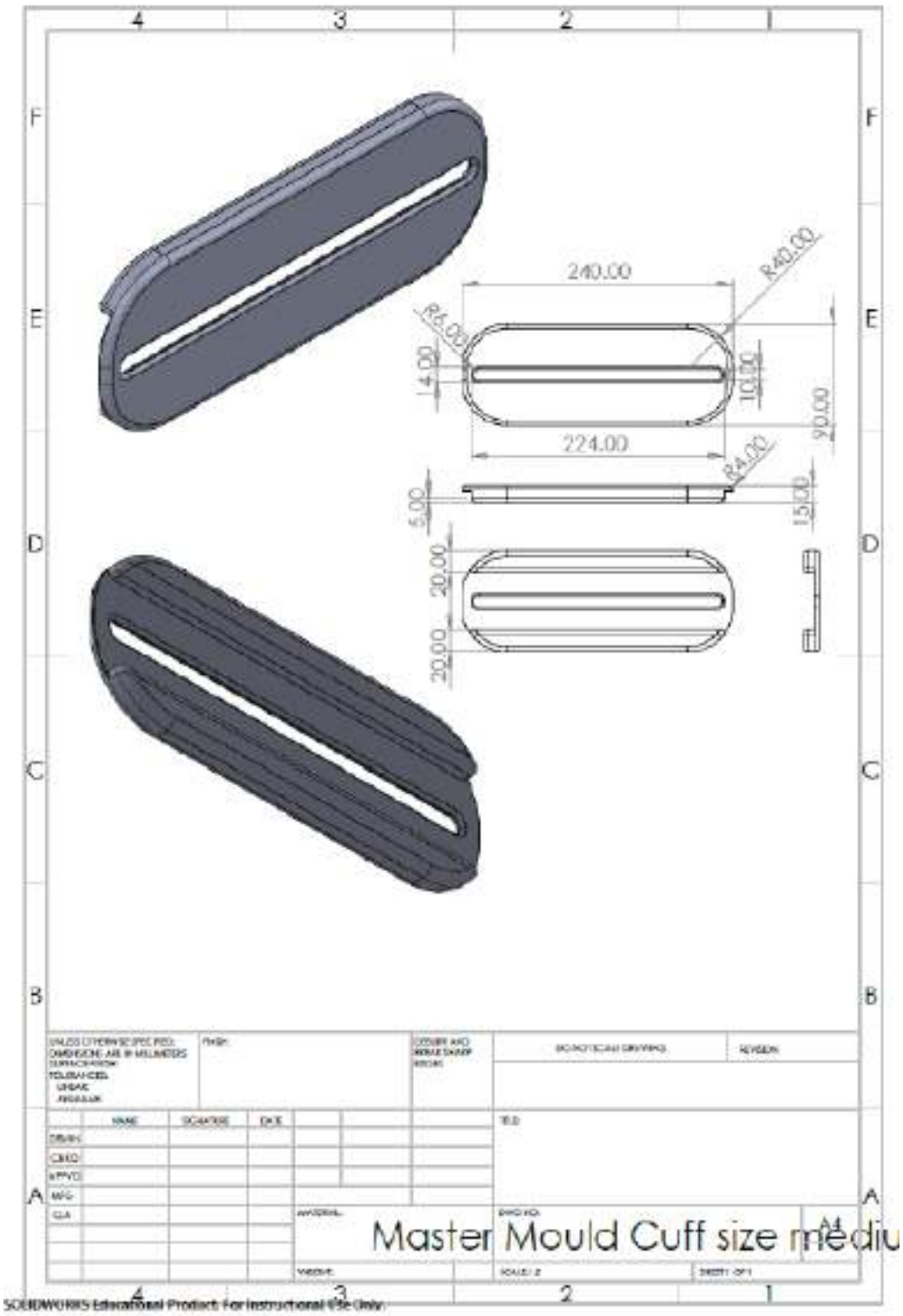


Figure 37: Technical drawing of Silicone cuff size medium with lateral adjustment slot after design has been fully developed alongside clinical champion.

Final Concept Electronics

The electrode button provides the connection between the pod and the electrode itself. To provide channel one for the deltoid muscles the closed loop system is embedded within the cuff to connect magnetically via pogo pins between the two pods. The electronics for the channel two have its closed loop system embedded in the middle deltoid and a fabric covered wire that attached across to the supraspinatus pod. Both channel one and channel two connect wirelessly to the Avira+ app providing a more accessible and intuitive user experience.

PDS Evaluation

The student evaluated the initial product design specification by rewriting the statements that were made prior to the development process. Avira+ was unable to be tested on the patients directly due to electronic limitations and safety. Proof of concept was created to test the basic electronics involved. Capacitive proximity sensors allow detection of skin contact which activates the ramp up ramp down sequence. This ensures that patient safety is placed first and foremost.

Due to university safety regulations, full operational testing of the prototype at its intended voltage was not possible. Therefore, some design requirements remain unverified. The student designed the product with these requirements in mind and carried out research into the relevant Class 2b requirements, expected service life, and electrical safety considerations throughout the design process.In particular, Class 2b compliance, the expected 3–5-year functional life,

and electrical safety at full operating voltage could not be experimentally demonstrated within the scope of this project.

These requirements should therefore be considered design expectations and future targets, rather than confirmed characteristics of the current prototype. If the Avira+ were to be further developed towards a commercial stage, appropriate testing and certification would be required to demonstrate compliance, establish its expected service life, and confirm safe operation at the intended voltage.



Figure 38 Final product design specification

App Evaluation + Feedback

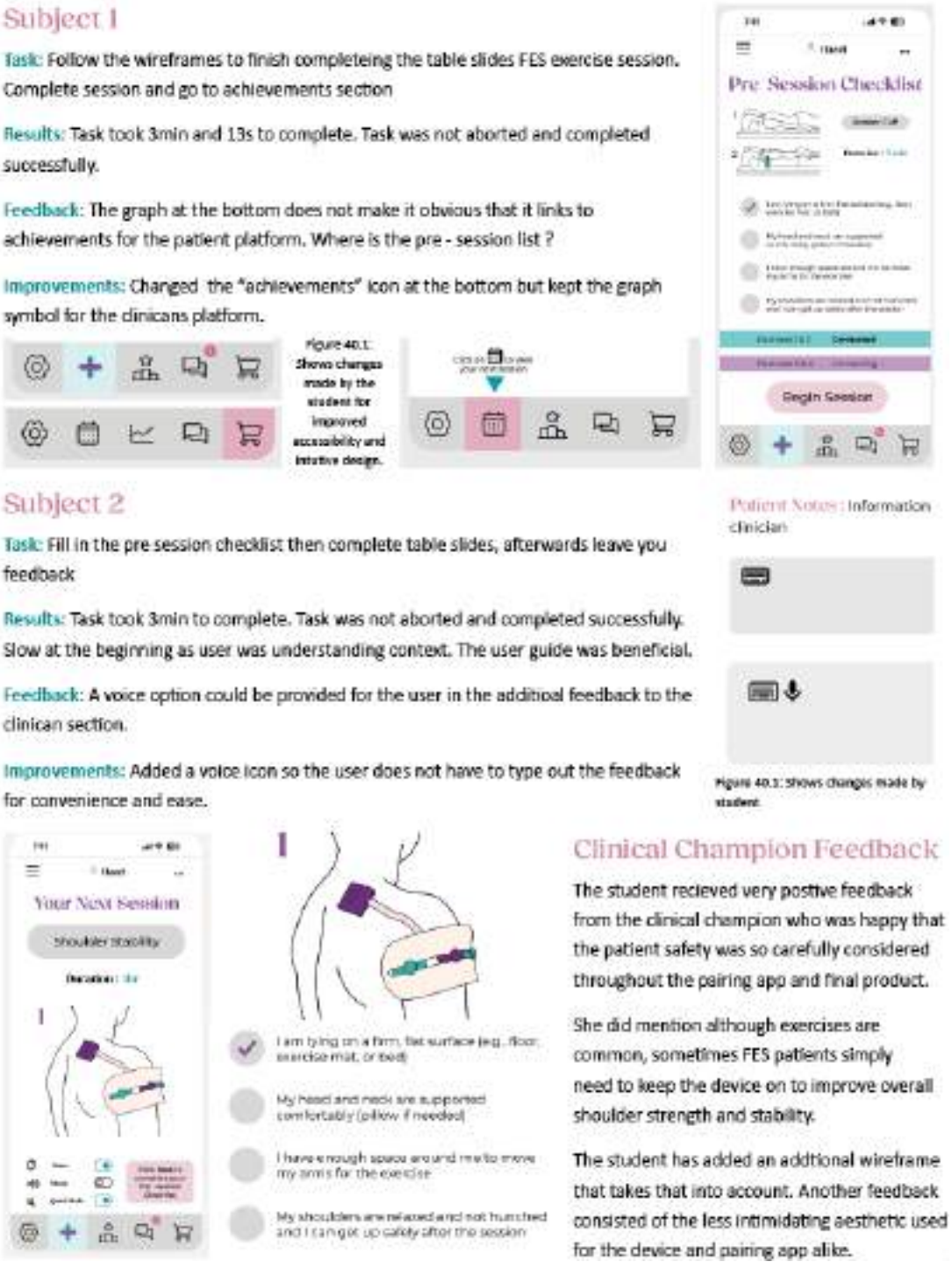


Figure 39: Figure showing user testing completed by the student on the Avira+ wireframes and direct feedback from the clinical champion.

The student tested the Avira+ app to evaluate its usability, functionality, and overall user experience. The wireframe design was updated based on observed user behaviors while the app was being used by participants from various age groups, ensuring the interface better met the needs of different users. In addition, the student received direct feedback from the clinical champion, whose insights helped validate the design decisions and identify further improvements to enhance the app's usability and effectiveness.

Physiotherapists Clinicians Feedback

Following the project presentation, nine clinicians completed an anonymous feedback survey evaluating the proposed Avira+ FES device and companion app. Overall, the responses were highly positive, with most ratings ranging from 4 to 5 out of 5 across all evaluation criteria. Clinicians agreed that the clinical purpose and intended benefits of the device were clearly explained, with ratings predominantly of five, and most believed that the device could provide meaningful benefits in clinical practice. The usability of both the FES device and companion app was also rated favorably, with respondents indicating that the system appeared easy to set up, navigate, and use. The device's comfort, practicality, and safety were consistently rated highly, and clinicians agreed that the companion app would be useful for configuring, monitoring, and managing treatment.

Importantly, all respondents indicated that they would consider using or recommending Avira+ in clinical practice once fully developed, with scores ranging from 4 to 5 out of 5. Qualitative feedback suggested only minor improvements, including providing a training guide for digitally inexperienced users, addressing considerations for multi-patient use, reviewing the necessity of safety checks before each

exercise, expanding educational content explaining the rationale for FES, and exploring the device's thickness and compatibility with other supports. Overall, the survey findings demonstrate strong clinician confidence in the concept, usability, and potential clinical value of the Avira+ system.

Conclusion

This project has been one of the most valuable learning experiences I have had, both academically and personally. Coming from a non-medical background, I had limited knowledge of stroke rehabilitation and medical device design. Throughout the development of this project, I had to independently research and learn about the challenges stroke survivors face during recovery, as well as the clinical environments and rehabilitation processes that support them. Through speaking with physiotherapists, clinicians,and stroke survivors, I gained a much deeper understanding of the importance of accessibility and patient-centered design within healthcare. These conversations and experiences continuously shaped the direction of the project and helped me develop a more informed and human centered approach to Avira+.

Throughout the design process, I considered the different needs and priorities of patients, carers and clinicians, including how each group would interact with the device and what requirements they desired. I maintained frequent communication with the clinician to ensure that professional requirements and clinical needs were continuously considered. Alongside this, I carried out ongoing research into patients' and carers' needs and how they would interact with the product. I used this information to identify commonalities and differences between the three user groups, which I represented

through a Venn diagram. This allowed me to balance the requirements of patients, carers and clinicians and incorporate as many of their shared needs as possible. These design requirements were continually revisited throughout each iteration, allowing me to refine and adapt the product based on new findings and feedback. By considering all three perspectives throughout the process, I was able to develop what I considered to be the optimum version of Avira+

A major part of this learning process came from direct engagement with professionals and real clinical settings. I visited Hillingdon Hospital for an observational visit, which gave me valuable exposure to real rehabilitation environments and patient interactions. Meeting with neurophysiotherapists from North West University Healthcare NHS Trust helped me identify further clinical requirements and areas

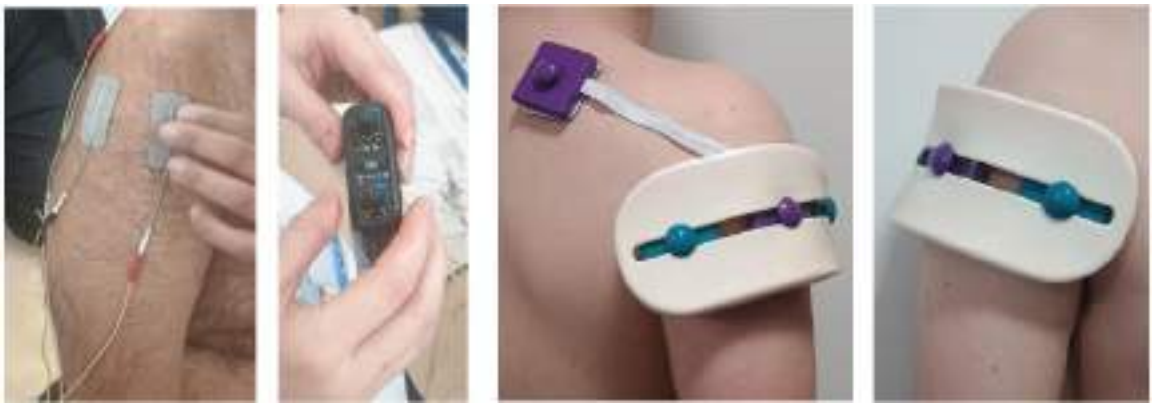


Figure 40: Image showing the before and after of the application of the ES device as opposed to the MicroStim 2V2 used at Hillingdon Hospital

where the proposed solution could solve the current issues faced.

This project was strongly influenced by personal experience and family engagement. Having a close family member who is a stroke survivor gave me additional motivation to ensure the solution is as intuitive and accessible as possible. In particular, supporting a stroke survivor with limited English proficiency highlighted the importance of reducing language barriers and creating interactions that rely less

on complicated instructions or medical terminology. This encouraged me to focus on making the experience simple, inclusive, and easy to understand for a wider range of users. Overall, this process has taught me a significant amount about healthcare design, communication, research, and stakeholder collaboration, and it has reinforced my interest in developing meaningful solutions within rehabilitation and assistive technology. I look forward to continuing to develop this project further during my postgraduate studies in Innovation Design Engineering MA/MSc at Royal College of Art and Imperial College London.



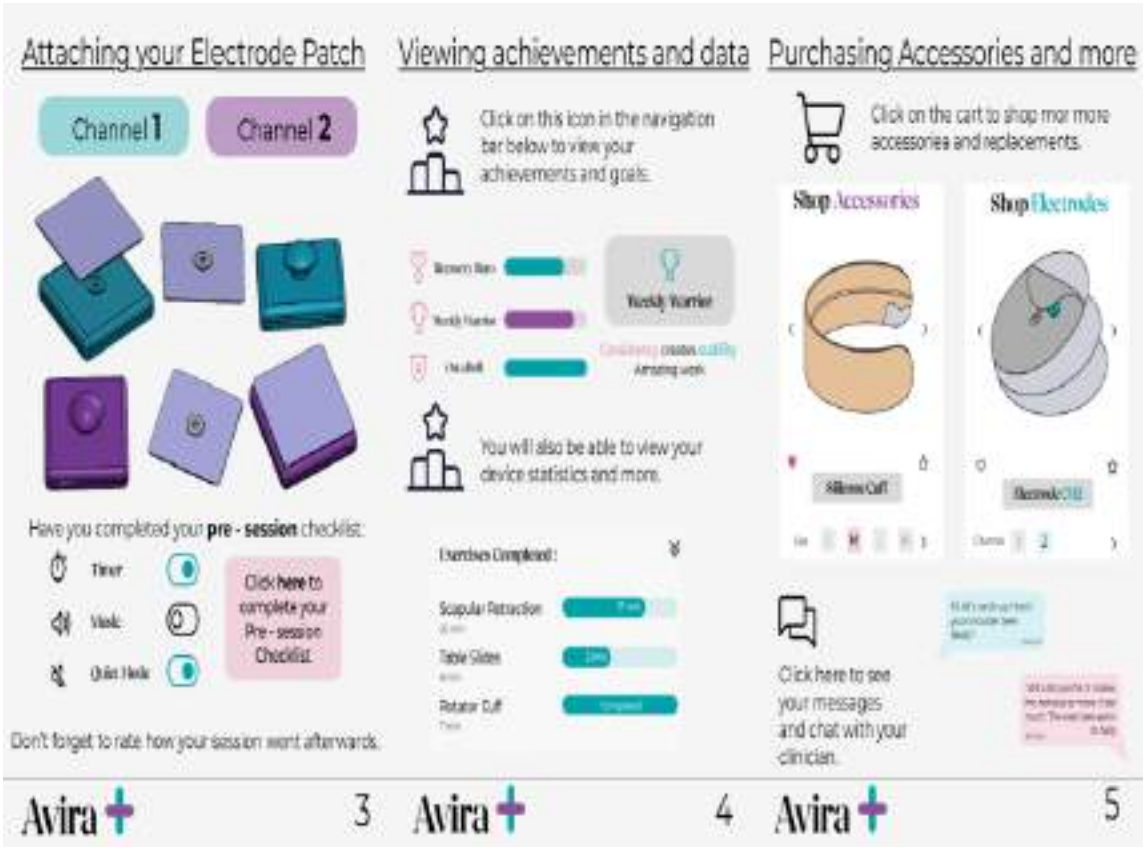


Figure 41: Figure showing User guide concept developed near the end of the project to provide easy guidance to the app. As a concept this does not include the disclaimers and safety warnings, but the aim is to make the booklet far shorter approximately 16 pages rather than the commonly found 30+ pages.

Conflict of Interest: Co-contributor and Guest Editor

The author's supervisor is a co-contributor to this manuscript and also serves as the Guest Editor for the relevant issue. This relationship is disclosed for transparency. The author declares that no other conflicts of interest exist in relation to this manuscript.

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Exploring Communication Tools to Enhance Social Inclusion of Marginalised Communities in Schools Through a Human-Centred Approach: A practice-Based Review Focusing on the Turkish Context

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Abstract:

This paper, underpinned by Human-Centred Design (HCD), presents secondary research examining communication tools to enhance interactions between Turkish teachers and Syrian immigrant parents – marginalised communities displaced by the Syrian war -, with the aim of enabling their participation in their children's educational process. Limited preparedness for integrating Syrian students into Turkish schools has created educational challenges with long-term consequences for students' educational attainment and future participation in society. This paper reviews 18 purposively selected practice- and research-based studies, covering commonly used tools such as interpreter services, video remote interpretation (VRI), mobile applications and pictorial booklets. Using case study analysis and SWOT evaluation, the appropriateness of these tools for this

group was assessed in light of existing literature, with thematic mapping applied throughout. The findings contribute to the design context by illustrating how HCD principles support the development of contextually appropriate practical communication tools. Interpreter services were identified as the most effective means of facilitating teacher–parent collaboration, while translation-enabled digital platforms provided practical alternatives in contexts where interpreter services were unavailable. Their effectiveness can be further enhanced through targeted strategies informed by practical examples. The study underscores the need for further research with key stakeholders, and highlights the role of HCD in contributing to participatory practices with marginalised communities for social inclusion and educational equity.

Keywords: ***Human-Centred Design; Communication Practices;Language Barriers; Inclusion of Marginalised Communities; Immigrant Parent-Teacher Communication***

1. Introduction

This paper presents research grounded in Human-Centred Design (HCD), focusing on the Inspiration stage of the design process outlined by IDEO (2015), which guides the generation and refinement of design solutions that are inclusive, contextually appropriate, and ethically accountable. Given the demonstrated effectiveness of HCD in addressing social challenges, this research applies its principles to review relevant case studies, with particular attention to problems in educational contexts affecting vulnerable groups, specifically

immigrant families. While this study focuses on evaluating communication channels between Turkish teachers and Syrian immigrant parents, its broader analytical contribution lies in advancing participatory practices with marginalised communities (Theme 1). Rather than treating communication tools—such as VRI services or translation apps—merely as transactional language instruments, we frame them through the lens of social innovation literature. As argued by Manzini (2015) and the broader DESIS Network (Manzini & Staszowski, 2013), design for public services must foster 'relational platforms' that empower vulnerable populations to participate as active stakeholders in public institutions, as considered within the scope of this paper.

Background research shows that communication between Turkish primary school teachers and Syrian immigrant parents—many of whom fled the Syrian war—is frequently ineffective, and there is limited scholarly attention to this issue. Migration studies highlight that the nature of migration strongly influences migrants' experiences in the host country: while some individuals move voluntarily, others are displaced suddenly and without preparation. This study focuses on the latter group, whose unmet educational needs can have lasting effects, as these students often encounter difficulties in local schools that hinder their academic achievement (Amthor, 2019; Rong & Preissle, 2008, p. 205). These difficulties also impact society more broadly, since higher levels of education are associated with lower crime rates, stronger economic performance, and better living conditions (Barro, 2013; Duman, 2019; Zgaga, 2005; Seetanah, 2009; Bhardwaj, 2016). Given that 3.76 million of Türkiye's 5.5 million immigrants are Syrian (Ministry of Interior, 2023), Syrian students constitute a substantial proportion of the school population, making

Syrian immigrant families a central focus of this research (Kiremit, Akpınar, & Akcan, 2018; Ergen & Şahin, 2019).

Parental involvement, understood as parents and teachers working together to support children's learning, is widely recognised as essential to students' academic development (Đurišić & Bunijevac, 2017). This cooperation is especially important for children from migrant backgrounds, who frequently encounter obstacles such as language differences, unfamiliarity with the education system, and cultural mismatches (García, Pujol-Ferran, & Reddy, 2013). Because primary school represents the foundation of formal education, parental engagement at this stage influences not only children's academic success but also the overall well-being of the wider community (Driessen, Smith, & Sleegers, 2005).

In Türkiye, where primary education is compulsory and native and immigrant students learn together, Syrian students often require extra support; many experience delays in literacy development, lower academic performance, and behavioural issues that cannot be resolved solely through teachers' efforts. Research consistently highlights the importance of parental engagement, particularly ongoing communication and collaboration with teachers through regular meetings, in addressing these needs (Aykırı, 2017; Bulut, Soysal, & Gülçiçek, 2018; Kiremit, Akpınar, & Akcan, 2018; Ergen & Şahin, 2019). Yet language barriers frequently prevent Syrian parents from participating effectively (Tümkaya & Çopur, 2020), underscoring the need for targeted strategies to enhance communication, boost student outcomes, and foster long-term community well-being.

Within this context, a range of established approaches exists for addressing language barriers, each varying in its suitability depending

on the situation. Interpreter services involve professional interpreters converting spoken language in real time (Wadensjö, 2014, pp. 4–12), while VRI provides similar services remotely through video technologies such as webcams or videophones. Complementing these, mobile applications, designed for smartphones and tablets (Liao & Ho, 2021), facilitate multilingual communication and offer flexible, cost-effective alternatives to human interpretation. Pictorial booklets, which combine text and illustrations to convey information (Talhouk et al., 2016), enhance comprehension by supporting communication visually. Together, these tools form the basis for the investigation, which is structured around case studies drawn from diverse contexts to assess their effectiveness and applicability in educational settings.

Ultimately, this paper explores how different communication tools facilitate or hinder meaningful dialogue, and how strategic channel selection forms the baseline for participatory engagement between displaced families and school systems. The central question guiding this analysis is: which communication approaches best respond to the contexts, and support effective communication between parents and teachers, taking into account the realities of these groups (e.g., limited social inclusion, limited language capacity, relatively low education level) (Tümkaya& Çopur, 2020). In line with this objective, this study is structured into five sections in total. Following the background presented in this introduction, the next section outlines the methodological approach, followed by the findings and discussion in Section 3. Section 4 then briefly summarises the study in the conclusion, and the final section is devoted to future research.

2. Method

The methodology employed a Human-Centred Touchpoint Evaluation (using SWOT analysis) to systematically critique existing communication channels — apps, VRI, booklets, and interpreters — based on their ability to support active two-way participation. This evaluation establishes the baseline information for the Inspiration phase, as shown in Figure 1 below. The Inspiration phase, as defined by IDEO (2015), focuses in this research on developing a comprehensive understanding of the target group — Syrian immigrant parents and as well as investigating potentially useful communication solutions accordingly. that could mitigate these problems, including language barriers at school.

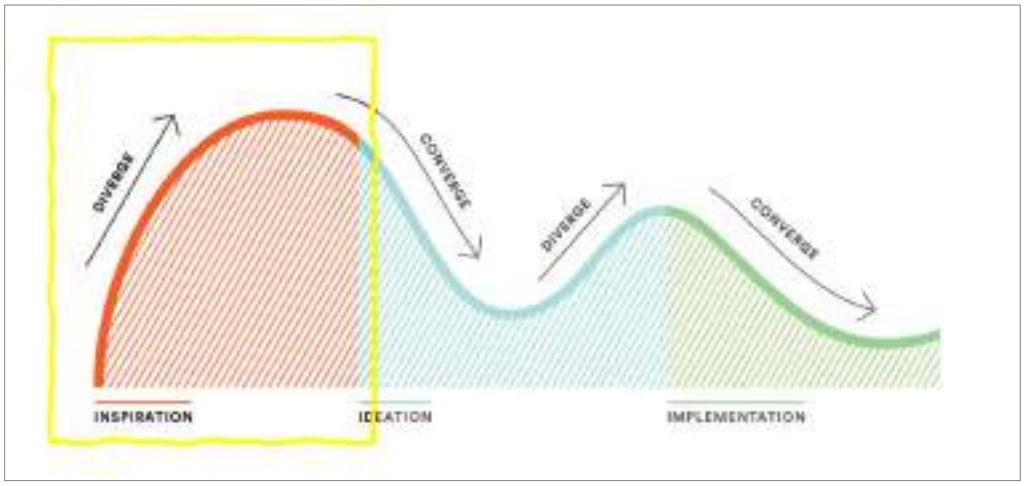


Figure 5Employment of HCD in the Inspiration stage to explore potential solutions for enhancing communication between immigrant parents and Turkish primary school teachers.

The investigation is organised around two primary sub-topics to provide a comprehensive examination of both practical implementation and theoretical foundations: (1) Case Studies from Practice, which focus on example applications, and (2) Research-Based Case Studies, based on certain criteria. Case studies, both practice and research-based, were selected using parallel eligibility criteria. Inclusion required that cases from practice: explicitly focused

on mitigating language barriers, offered practical solutions applicable to real-life contexts, and demonstrated adaptability across diverse settings. Conversely, cases were excluded if they focused on issues other than language barriers, remained purely conceptual without actionable solutions, or presented single-use solutions that could not be modified. Inclusion required that research-based cases: prioritised reducing language barriers, proposed practical solutions suitable for real-world implementation, and demonstrated adaptability across multiple contexts. Excluded were studies that lacked a focus on language barriers, remained strictly theoretical without offering practical solutions, or offered inflexible solutions restricted to a single context.

The literature review was conducted primarily through Google Scholar, using the keyword 'language barriers.' This term was deliberately kept broad, rather than narrowed to education- or migration-specific phrasing, in order to capture the full range of strategies developed across disciplines for addressing language barriers, rather than only those already framed around schools or displaced populations. Sources were reviewed in reverse chronological order, from the most recent to the oldest, with the search conducted in 2024. Saturation was reached after approximately 18 sources, beyond which no newcommunication strategies emerged; the case studies included in the final analysis are presented in Tables 1 and 2.

Data were analysed using SWOT analysis — a technique for identifying Strengths, Weaknesses, Opportunities, and Threats (Teoli, Sanvictores and An, 2019) — applied here based on the thematic relevance of each case to the target group. SWOT was selected for its

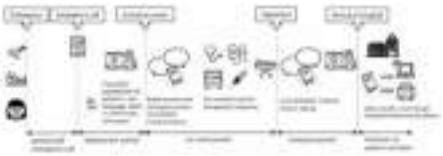
capacity to synthesise heterogeneous practice- and research-based case studies into a consistent comparative structure, without requiring primary data collection at this stage of the project. The findings from this analysis are presented in the following section, following the presentation of the reviewed case studies.

Notably, the research will proceed to the Ideation stage by incorporating expert insights, before translating the integrated findings from both primary and secondary data into practical outputs for school administrators, as further elaborated within the final section, Future Research. These outputs will take the form of a structured guideline designed to facilitate more effective communication between parents and teachers, thereby fulfilling the Implementation stage of the HCD process.

2.1 Review of Example Applications (Case studies from Practice)

These examples are particularly valuable, as they providedetailed insights into the practical application of these methods within specific settings, illustrating their processes, challenges, and outcomes. The analysis included a total of nine practice-based cases as provided in Table 1. Inclusion criteria required that the cases focus on mitigating language barriers, offer practical solutions applicable in real-life contexts, and be adaptable across different settings. Conversely, cases are excluded if their focus did not address language barriers, whether they offered only conceptual rather than practical solutions, or if their solutions were restricted to a single, non-transferable context.

Table 1 Reviewed Practice-Based Case Studies

Research title	Context & Tool	Relevant image
Designing an App to Overcome Language Barriers in the Delivery of Emergency Medical Services: Participatory Development Process (Noack et al., 2021)	**Healthcare settings** **App**	 
Beyond the language barrier: Recommendations for working with interpreters in individual psychotherapy (Martin et al., 2020)	**Healthcare settings** **Interpreter service**	***Not given***
Overcoming language barriers in paramedic care: a study protocol of the interventional trial 'DICTUM rescue' evaluating an app designed to improve communication between paramedics and foreign-language patients (Noack et al., 2021)	**Healthcare settings** **App**	
Inclusive Co-design Toolkit (Bridgeable, 2019)	**General use** **Pictorial booklet**	 
Better communication, better care. A provider toolkit for	**Healthcare settings**	

serving diverse populations (L.A. Care Health Plan, 2018)	**Pictorial booklet**	 
Strategies for overcoming language barriers in healthcare (Squires, 2018)	**Healthcare settings** **Interpreter service**	***Not given***
Beyond the Language Barrier 'Speak','See','Help Me' (Badruddin & Arif, 2017)	**Healthcare settings** **Pictorial booklet**	
Overcoming the language barrier in mobile user interface design: A case study on a mobile health app (Ross & Gao, 2016)	**Healthcare settings** **App**	 

2.2 Review of Empirical Examples (Research-based Case Studies)

The examination of research-based case studies provides an opportunity to gain in-depth insights from studies conducted with clearly defined target groups, offering a nuanced understanding of the effectiveness and limitations of various communication solutions in practice. A total of nine research-based case studies were examined,

as detailed in Table 2, with inclusion criteria requiring that the primary focus of each study address language barriers, while studies outside the scope of language-related issues are excluded.

Table 2 Reviewed Research-Based Case Studies

Research title	Context	The mechanism assessed
Language barriers in multilingual Saudi hospitals: causes, consequences, and solutions (Alhamami, 2022)	**Healthcare settings**	**Interpreter service**
Enhancing patient safety through the quality assured use of a low-tech video interpreting system to overcome language barriers in healthcare settings (Kletečka-Pulker et al., 2021)	**Healthcare settings**	**VRI**
Successful Verbal Communication Using Google Translate to Facilitate Awake Intubation of a Patient with a Language Barrier: A Case Report (Kapoor et al., 2020)	**Healthcare settings**	**App**
The "Battle" of Managing Language Barriers in Health Care (Steinberg et al., 2016)	**Healthcare settings**	**Interpreter service**
Language barriers and patient safety risks in hospital care-A mixed methods study (van Rosse et al., 2016)	**Healthcare settings**	**Interpreter service**
Using mobile technology to overcome language barriers in medicine (Chang et al., 2014)	**Healthcare settings**	**App**

Prevention is the Best Medicine: Development of a work and health toolkit for new immigrants using settlement services in Ontario (Kosny et al., 2014)	**General use**	**Booklet (Toolkit)**
The effects of a language barrier in a South African district hospital (Schlemmer and Mash, 2006)	**Healthcare settings**	**Interpreter service**
Bridging the language barrier: the use of interpreters in primary care nursing (Gerrish, et al., 2004)	**Healthcare settings**	**Interpreter service**

3. Findings and Discussion

The analysis of the case studies suggests that interpreter services constitute highly effective channels for mitigating language barriers, with multiple studies underscoring their practicality and reliability. For example, Alhamami (2022) identify interpreter services as among the most efficient solutions, and Van Rosse et al. (2016) emphasie professional interpreters as the most effective mediators. Video remote interpreting (VRI) offers additional advantages, including rapid accessibility, compliance with data protection regulations, suitability when in-person meetings are impractical, the absence of external influences, legal assurance, and cost efficiency (Kletečka-Pulker et al., 2021). Despite these benefits, challenges such as high costs and time constraints have been reported (Schlemmer & Mash, 2006; Steinberg et al., 2016); nevertheless, the overall advantages of interpreter services justify their prioritisation where feasible. Their effectiveness can be further enhanced by applying insights from case

studies, including the collection of regular feedback from diverse stakeholders, the development of context-specific solutions such as optimised service schedules, and the provision of cultural competency training for interpreters (Squires, 2018; Martin et al., 2020). Key recommendations also include fostering a triadic relationship that positions interpreters as integral team members, offering targeted cultural and contextual training, and establishing clear termination policies and operational guidelines (ibid).

The review of case studies on interpreter services and video remote interpreting (VRI) demonstrates that this option is widely preferred because it ensures smooth interaction and enhances engagement between parties. However, these services can impose a significant economic burden on institutions, and strategies should therefore be considered to maximise their benefit where their use is feasible — for instance, guidelines that could enhance service effectiveness and maximise benefits within limited timeframes (e.g., Squires, 2018; Martin et al., 2020). Key insights from these practical examples highlight the importance of: (1) structured planning of the entire conversation, including preparatory requirements (e.g., introducing meeting processes), technical considerations to improve service effectiveness (e.g., using concise statements), and concluding protocols (e.g., final questions before closing the session); and (2) considering all stakeholders involved (e.g., service providers, clients, and interpreters) and providing guidance tailored to their respective roles. Drawing on these insights, similar guidelines could be developed to address the needs of school staff and parents, with these case studies serving as inspiration for designing strategies to improve communication within educational settings.

The reviewed case studies on apps indicate that such tools are effective in reducing language barriers across diverse contexts, offering key advantages - including practicality, temporal flexibility, and cost efficiency - as they enable communication in multiple languages without reliance on interpreter availability, thereby providing a more economical alternative to human translation or interpretation (Chang et al., 2014; Noack et al., 2020). Building on this, Noack et al. (2021) identify additional strategies relevant to educational settings, including the adaptation of fixed phrases, the incorporation of rapid-communication features such as audio playback and supplementary text displays, and the systematic maintenance of communication records to support future interactions. Complementing these insights, Ross and Gao (2016) emphasise the value of integrating visual elements, such as national flags, with textual supports, demonstrating how visual–textual combinations can further strengthen communication effectiveness.

With regard to the use of pictorial booklets, the examined case studies mostly highlight the limitations. While image-only booklets, such as those produced by international companies, can effectively convey procedural information, they are less suitable for facilitating nuanced communication. Case examples specifically designed for communication support, including the Inclusive Co-design Toolkit (2019) and L.A. Care Health Plan (2018), demonstrate that effective pictorial booklets combine widely used phrases and context-specific terminology in multiple languages with images that clarify actions or behaviours. These resources offer advantages such as portability, ease of use, support for direct communication through fixed phrases, and cost-effectiveness due to low production and distribution costs. However, their predefined content limits flexibility, constraining

spontaneous dialogue, and they require regular updates to remain relevant, with delays potentially leading to user dissatisfaction. Consequently, while pictorial booklets can serve as valuable supplementary tools for reducing language barriers, they are insufficient as standalone communication mediums.

Table 3 subsequently presents a comparison of widely used communication tools. Interpreter services facilitate direct interaction and, when conducted in person, can strengthen parent–teacher relationships within this research context, making them a priority where feasible. This is consistent with the Human-Centred Touchpoint Evaluation (using SWOT analysis), given that Syrian parents are often socially isolated, meaning that encouraging their presence in schools may be particularly valuable. Although this evaluation is grounded in the context of Syrians in Türkiye, it could equally be applied to other groups facing similar challenges of social isolation, where comparable inclusion strategies may be required. However, their implementation can be expensive for schools, underscoring the need for viable alternative solutions.

Among the other viable solutions, mobile applications may serve as a supplementary tool, facilitating communication in contexts where interpreters or video remote interpretation are unavailable. On the other hand, pictorial booklets are comparatively less effective, as their dependence on highly restricted phrases constrains meaningful dialogue. Building on these assessments, practical examples offer additional guidance for implementation. For instance, interpreters should possess familiarity with educational terminology and sensitivity to cultural nuances, and their integration as collaborative staff members within schools can enhance service effectiveness. Dedicated guidance, such as collections of recommendations for

optimising interpreter use, can further support their role. Similarly, the adoption of apps can draw on insights from case studies, addressing the needs of both school staff and parents - for example, incorporating features to track previous conversations or schedule meetings. The design of these tools should also consider usability principles, including the use of intuitive icons, symbols, and differentiated colours, in alignment with best practices identified in the reviewed examples.

Table 3 Analysis of the communication tools

Key elements	Mood of communication		Potential time constraints		Reliance for external facilitators	
	Mostly direct	Mostly indirect	Mostly limited	Unrestricted by temporal constraints	Generally necessary	May not be required
Interpreter services/VRI		X	X		X	
Apps	X			X		X
Pictorial Booklets	X			X		X

Taken together, analysing these cases through the lens of Human-Centred Design (HCD) fostered an empathy-driven understanding of Syrian parents' circumstances, extending beyond the Inspiration stage's typical positioning (IDEO, 2015). By adapting SWOT analysis into a design-relevant framework — assessing each communication tool against criteria drawn from Syrian parents' documented

circumstances, such as limited social inclusion, which potentially requires more in-person interaction to diminish it — this study ensured a structured comparative evaluation as its core analytical tool. In doing so, this comparative evaluation echoes Bason's (2014) characterisation of the 'insight' stage of design-for-policy, wherein design research methods are used to surface user needs and constraints prior to ideation.

Overall, this design research makes a distinct contribution by identifying translation as a priority need for enhancing communication between immigrant parents and teachers in Turkish schools, while also surfacing the contextual considerations required to provide it appropriately within the school setting. Through this process, in-person communication supported by a professional translator emerged as potentially the most effective approach, enabling direct and meaningful interaction. Yet the research also brought into focus practical constraints, such as limited staff availability and financial resources, that may restrict this option's implementation. Rather than positioning translation as a single fix, the design research's contribution is in reframing it as part of a broader, adaptable toolkit, pointing schools toward complementary tools such as translation applications where in-person interpretation is unavailable or impractical. In doing so, the research moves beyond simply identifying a priority need to demonstrate how that need can be met feasibly and appropriately across varying school contexts.

4. Conclusion

This research addressed the Inspiration stage of Human-Centred Design, following the framework proposed by IDEO (2015), thereby identifying suitable practical communication tools for marginalised

groups that can help enhance immigrant parent–teacher interactions in schools, based on case-study research. The review of practical case studies and research-based examples provided insights into the effectiveness, advantages, and limitations of various communication tools for the target research group, while also identifying potential strategies to enhance their utility in school settings. The analysis suggests that interpreter services represent the most effective and convenient option for facilitating parent–teacher communication. However, in contexts where these services are unavailable, supportive tools such as translation applications may serve as complementary channels, with features specifically designed to support parent–teacher interactions incorporated into a dedicated app if developed. In contrast, pictorial booklets appear to offer limited communicative value and are therefore not recommended as an alternative solution.

5. Future research

Primary research is also needed to identify the most suitable communication channels for the target group and to inform strategies for enhancing their use. Methods such as card sorting and semi-structured interviews will gather input from key stakeholders and experts, aligning with the 'Exploration' stage of HCD. Findings from both the primary and secondary data will be synthesised into a guideline for school managers, providing practical recommendations to reduce language barriers. As a final outcome of the study, the guideline reflects the implementation stage of the Human-Centred Design process through an inclusive intervention.

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APPENDICES

A.1 Databases and Search Details

Table A. 1: Databases and search details

ACM	**[[Title: "automated chat agent"] OR [Title: "chatbot"] OR [Title: "conversation agent"] OR [Title: "conversational agent"] OR [Title: "conversational ai"] OR [Title: "conversational assistant"] OR [Title: "conversational interface"] OR [Title: "conversational user interface"] OR [Title: "digital personal assistant"] OR [Title: "embodied agent"] OR [Title: "intelligent agent"] OR [Title: "intelligent assistant"] OR [Title: "personal assistant"] OR [Title: "personal digital assistant"] OR [Title: "smart assistant"] OR [Title: "smart speaker"] OR [Title: "virtual agent"] OR [Title: "virtual assistant"] OR [Title: "voice assistant"] OR [Title: "voice interface"] OR [Title: "voice user interface"]] AND [[Abstract: "ageing"] OR [Abstract: "aging"] OR [Abstract: "old"] OR [Abstract: "older"] OR [Abstract: "older adult"] OR [Abstract: "older adults"] OR [Abstract: "elder"] OR [Abstract: "elders"] OR [Abstract: "elderly"] OR [Abstract: "senior"] OR [Abstract: "seniors"] OR [Abstract: "geriatric"] OR [Abstract: "geriatry"] OR [Abstract: "geriatrics"]] OR [[Title: "ageing"] OR [Title: "aging"] OR [Title: "old"] OR [Title: "older"] OR [Title: "older adult"] OR [Title: "older adults"] OR [Title: "elder"] OR [Title: "elders"] OR [Title: "elderly"] OR [Title: "senior"] OR [Title: "seniors"] OR [Title: "geriatric"] OR [Title: "geriatry"] OR [Title: "geriatrics"]] AND [[Abstract: "automated chat agent"] OR [Abstract: "chatbot"] OR [Abstract: "conversation agent"] OR [Abstract: "conversational agent"] OR [Abstract: "conversational ai"] OR [Abstract: "conversational assistant"] OR [Abstract: "conversational interface"] OR [Abstract: "conversational user interface"] OR [Abstract: "digital personal assistant"] OR [Abstract: "embodied agent"] OR [Abstract: "intelligent agent"] OR [Abstract: "intelligent assistant"] OR [Abstract: "personal assistant"] OR [Abstract: "personal digital assistant"] OR [Abstract: "smart assistant"] OR [Abstract: "smart speaker"] OR [Abstract: "virtual agent"] OR [Abstract: "virtual assistant"] OR [Abstract: "voice assistant"] OR [Abstract: "voice interface"] OR [Abstract: "voice user interface"]]**

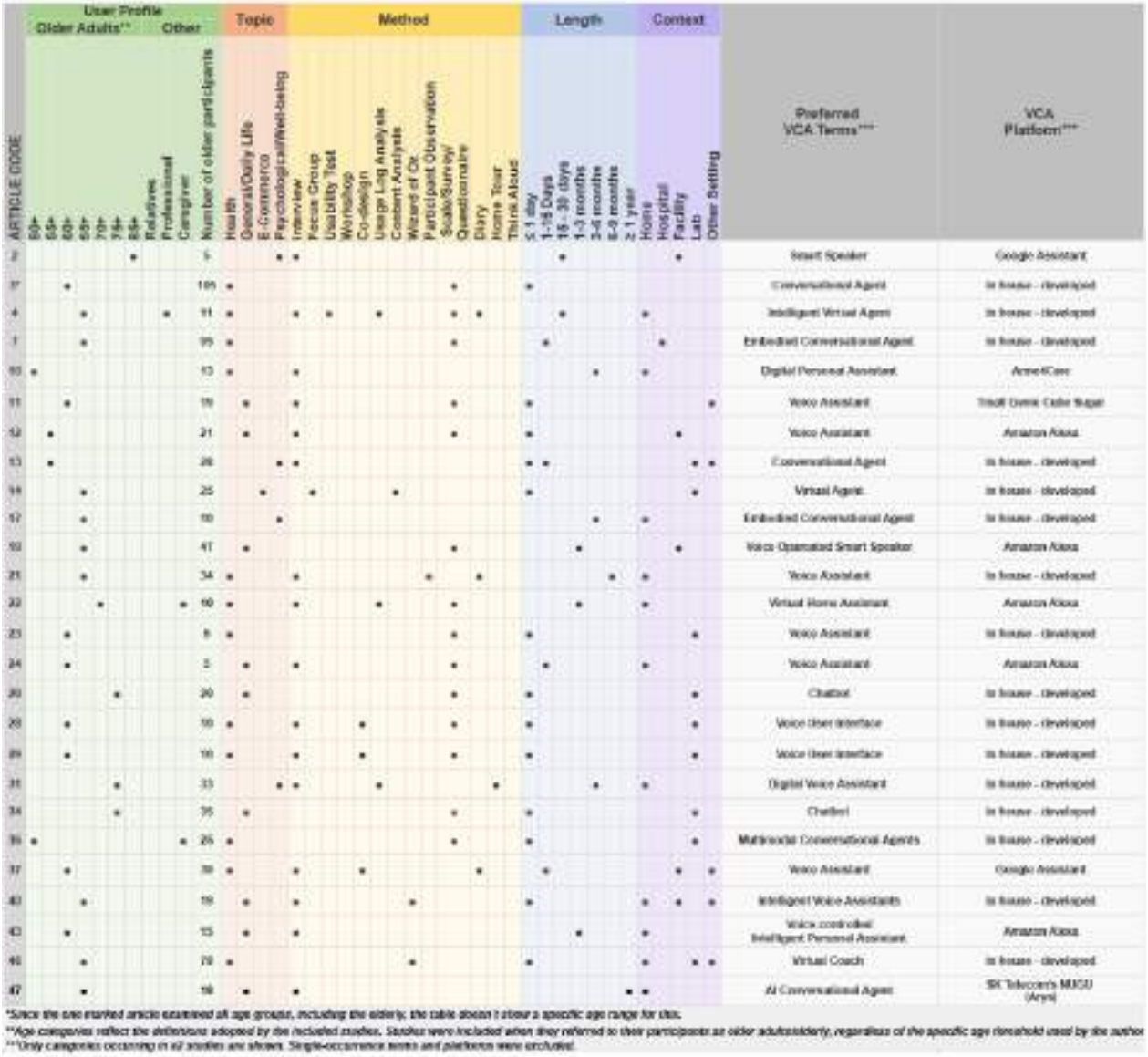
Scopus	**(TITLE-ABS-KEY ("Automated chat agent" OR "Chatbot" OR "conversation agent" OR "Conversational agent" OR "Conversational AI" OR "Conversational assistant" OR "Conversational interface" OR "Conversational User Interface" OR "digital personal assistant" OR "embodied agent" OR "Intelligent agent" OR "intelligent assistant" OR "personal assistant" OR "Personal Digital Assistant" OR "smart assistant" OR "smart speaker" OR "virtual agent" OR "virtual assistant" OR "voice assistant" OR "voice interface" OR "voice user interface") AND TITLE-ABS-KEY ("ageing" OR "aging" OR "old" OR "older" OR "older adult" OR "older adults" OR "elder" OR "elders" OR "elderly" OR "senior" OR "seniors" OR "geriatric" OR "geriatry" OR "geriatrics")**
IEEE Xplore	**("All Metadata":"Automated chat agent" OR "All Metadata":"Chatbot" OR "All Metadata":"conversation agent" OR "All Metadata":"Conversational agent" OR "All Metadata":"Conversational AI" OR "All Metadata":"Conversational assistant" OR "All Metadata":"Conversational interface" OR "All Metadata":"Conversational User Interface" OR "All Metadata":"digital personal assistant" OR "All Metadata":"embodied agent" OR "All Metadata":"Intelligent agent" OR "All Metadata":"intelligent assistant" OR "All Metadata":"personal assistant" OR "All Metadata":"Personal Digital Assistant" OR "All Metadata":"smart assistant" OR "All Metadata":"smart speaker" OR "All Metadata":"virtual agent" OR "All Metadata":"virtual assistant" OR "All Metadata":"voice assistant" OR "All Metadata":"voice interface" OR "All Metadata":"voice user interface") AND ("All Metadata":"ageing" OR "All Metadata":"aging" OR "All Metadata":"old" OR "All Metadata":"elder*" OR "All Metadata":"senior" OR "All Metadata":"geriatr*")** **"Automated chat agent" OR "Chatbot" OR "conversation agent" OR "Conversational agent" "Conversational AI" OR "Conversational assistant" OR "Conversational interface" OR "Conversational User Interface" OR "digital personal assistant" OR "embodied agent" OR"Intelligent agent" OR "intelligent assistant" OR "personal assistant" OR "Personal Digital Assistant" OR "smart assistant" OR "smart speaker" OR "virtual agent" OR "virtual assistant" OR "voice assistant" OR "voice interface" OR "voice user interface") AND ("ageing" OR :"aging" OR "old" OR "elder*" OR "senior" OR "geriatr*")**

WoS	**"Automated chat agent" OR "Chatbot" OR "conversation agent" OR "Conversational agent" OR "Conversational AI" OR "Conversational assistant" OR "Conversational interface" OR "Conversational User Interface" OR "digital personal assistant" OR "embodied agent" OR "Intelligent agent" OR "intelligent assistant" OR "personal assistant" OR "Personal Digital Assistant" OR "smart assistant" OR "smart speaker" OR "virtual agent" OR "virtual assistant" OR "voice assistant" OR "voice interface" OR "voice user interface" (Title) and "ageing" OR "aging" OR "old" OR "elder*" OR "senior" OR "geriatr*" (Abstract) or "ageing" OR "aging" OR "old" OR "elder*" OR "senior" OR "geriatr*" (Title) and "Automated chat agent" OR "Chatbot" OR "conversation agent" OR "Conversational agent" OR "Conversational AI" OR "Conversational assistant" OR "Conversational interface" OR "Conversational User Interface" OR "digital personal assistant" OR "embodied agent" OR "Intelligent agent" OR "intelligent assistant" OR "personal assistant" OR "Personal Digital Assistant" OR "smart assistant" OR "smart speaker" OR "virtual agent" OR "virtual assistant" OR "voice assistant" OR "voice interface" OR "voice user interface" (Abstract)**
EBSCO HOST	**[[Title: "ageing"] OR [Title: "aging"] OR [Title: "old"] OR [Title: "older"] OR [Title: "older adult"] OR [Title: "older adults"] OR [Title: "elder"] OR [Title: "elders"] OR [Title: "elderly"] OR [Title: "senior"] OR [Title: "seniors"] OR [Title: "geriatric"] OR [Title: "geriatry"] OR [Title: "geriatrics"]] AND [[Abstract: "automated chat agent"] OR [Abstract: "chatbot"] OR [Abstract: "conversation agent"] OR [Abstract: "conversational agent"] OR [Abstract: "conversational ai"] OR [Abstract: "conversational assistant"] OR [Abstract: "conversational interface"] OR [Abstract: "conversational user interface"] OR [Abstract: "digital personal assistant"] OR [Abstract: "embodied agent"] OR [Abstract: "intelligent agent"] OR [Abstract: "intelligent assistant"] OR [Abstract: "personal assistant"] OR [Abstract: "personal digital assistant"] OR [Abstract: "smart assistant"] OR [Abstract: "smart speaker"] OR [Abstract: "virtual agent"] OR [Abstract: "virtual assistant"] OR [Abstract: "voice assistant"] OR [Abstract: "voice interface"] OR [Abstract: "voice user interface"]] OR [[Title: "automated chat agent"] OR [Title: "chatbot"] OR [Title: "conversation agent"] OR [Title: "conversational agent"] OR [Title: "conversational ai"] OR [Title: "conversational assistant"] OR [Title: "conversational interface"] OR [Title: "conversational user interface"] OR [Title: "digital personal assistant"] OR [Title: "embodied agent"] OR [Title: "intelligent agent"] OR [Title: "intelligent assistant"] OR [Title: "personal**

	assistant"] OR [Title: "personal digital assistant"] OR [Title: "smart assistant"] OR [Title: "smart speaker"] OR [Title: "virtual agent"] OR [Title: "virtual assistant"] OR [Title: "voice assistant"] OR [Title: "voice interface"] OR [Title: "voice user interface"]] AND [[Abstract: "ageing"] OR [Abstract: "aging"] OR [Abstract: "old"] OR [Abstract: "older"] OR [Abstract: "older adult"] OR [Abstract: "older adults"] OR [Abstract: "elder"] OR [Abstract: "elders"] OR [Abstract: "elderly"] OR [Abstract: "senior"] OR [Abstract: "seniors"] OR [Abstract: "geriatric"] OR [Abstract: "geriatry"] OR [Abstract: "geriatrics"]]
ScienceDirect	**("ageing" OR "aging" OR "old" OR "older" OR "older adult" OR "older adults" OR "elder" OR "elders" OR "elderly" OR "senior" OR "seniors" OR "geriatric" OR "geriatry" OR "geriatrics") AND ("Automated chat agent" OR "Chatbot" OR "conversation agent" OR "Conversational agent" OR "Conversational AI" OR "Conversational assistant" OR "Conversational interface" OR "Conversational User Interface" OR "digital personal assistant" OR "embodied agent" OR "Intelligent agent" OR "intelligent assistant" OR "personal assistant" OR "Personal Digital Assistant" OR "smart assistant" OR "smart speaker" OR "virtual agent" OR "virtual assistant" OR "voice assistant" OR "voice interface" OR "voice user interface")**

A.2 Descriptive Information Matrix

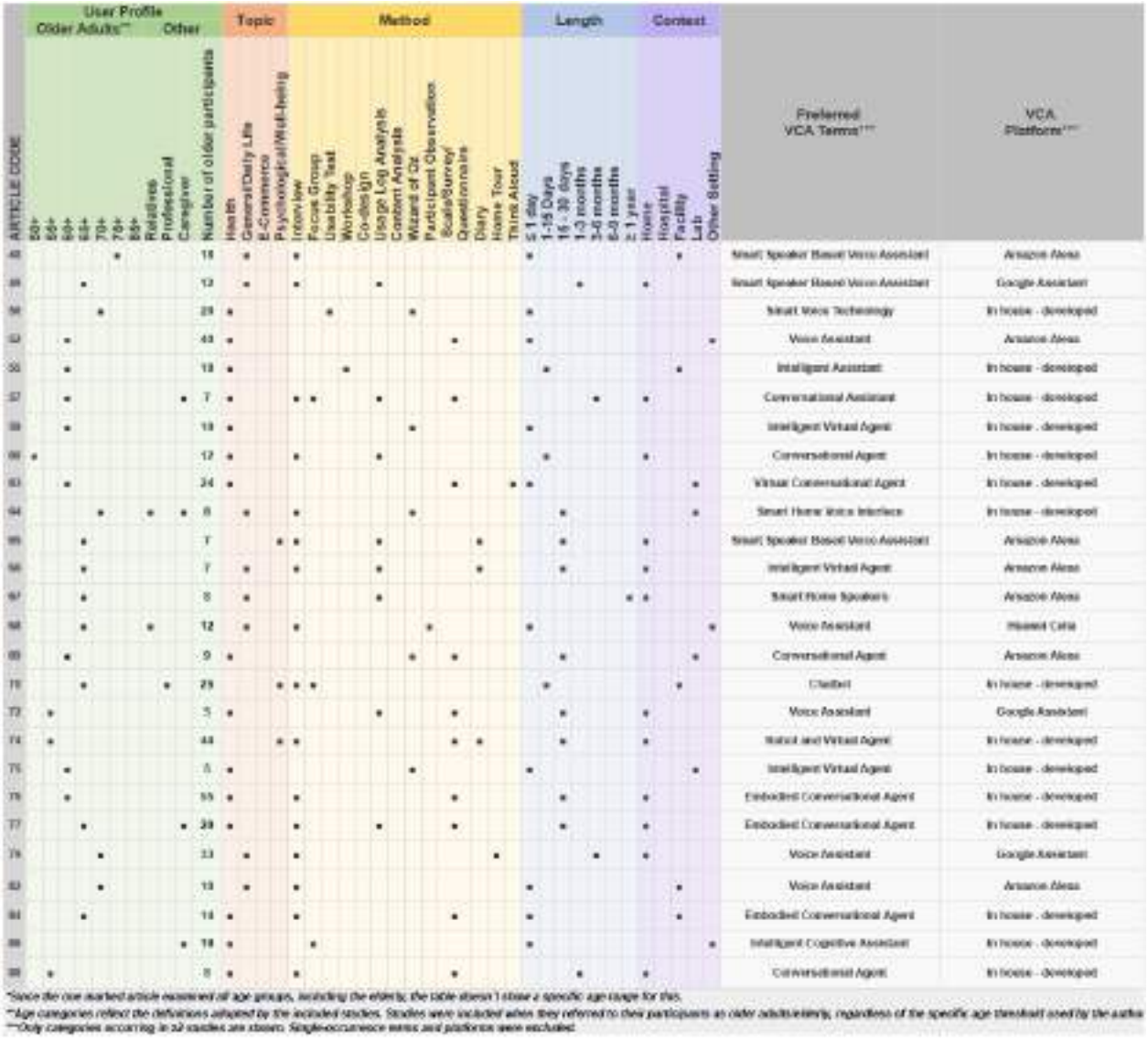
Table A. 2: Descriptive information about the studies included



ARTICLE CODE	User Profile: Older Adults** 60+	65+	69+	69+	70+	75+	85+	Relatives	Professional Caregiver	Number of older participants	Topic: Health	Device/Daily Life	E-Commerce	Psychological/Well-being	Method: Interview	Focus Group	Usability Test	Workshop	Co-design	Usage Log Analysis	Content Analysis	Wizard of Oz	Participant Observation	Scale/Survey/ Questionnaire	Diary	Home Tour	Think Aloud	Length: ≤ 1 day	1-15 Days	16 - 30 days	1-3 months	3-6 months	6-9 months	≥ 1 year	Context: Home	Hospital	Facility	Lab	Other Setting	Preferred VCA Terms***	VCA Platform***
2							•			5				•	•									•					•							•			Smart Speaker	Google Assistant
3			•							105	•													•				•										Conversational Agent	In house - developed
4				•					•	11	•				•		•			•				•	•				•				•					Intelligent Virtual Agent	In house - developed
7				•						35	•													•				•						•				Embodied Conversational Agent	In house - developed
10	•									13	•				•															•			•					Digital Personal Assistant	AmeliCare
11			•							19		•			•									•				•									•	Voice Assistant	Triall Omni Cube Sugar
12		•								21		•			•									•				•							•			Voice Assistant	Amazon Alexa
13		•								26				•	•													•	•							•	•	Conversational Agent	In house - developed
14				•						25			•			•					•							•								•		Virtual Agent	In house - developed
17				•						10				•																	•		•					Embodied Conversational Agent	In house - developed
18				•						47		•												•						•					•			Voice Operated Smart Speaker	Amazon Alexa
21				•						34	•				•							•			•						•	•						Voice Assistant	In house - developed
22					•				•	10	•				•					•				•						•			•					Virtual Home Assistant	Amazon Alexa
23			•							5	•													•				•								•		Voice Assistant	In house - developed
24			•							5		•			•									•				•						•				Voice Assistant	Amazon Alexa
30					•					20		•												•				•								•		Chatbot	In house - developed
29			•							10	•				•				•					•				•								•		Voice User Interface	In house - developed
29			•							10	•				•				•					•				•								•		Voice User Interface	In house - developed
31					•					33				•	•					•						•				•			•					Digital Voice Assistant	In house - developed
34					•					35		•												•				•								•		Chatbot	In house - developed
35	•								•	26	•													•				•								•		Multimodal Conversational Agents	In house - developed
37			•							30	•				•				•						•			•								•	•	Voice Assistant	Google Assistant
40				•						19		•			•						•							•					•		•	•	•	Intelligent Voice Assistants	In house - developed
43			•							15		•			•													•					•					Voice controlled Intelligent Personal Assistant	Amazon Alexa
46				•						29	•										•							•					•				•	Virtual Coach	In house - developed
47				•						18		•			•																	•	•					AI Conversational Agent	SK Telecom's MADU (Aryn)

*Since the one started article examined all age groups, including the elderly, the table doesn't show a specific age range for this.
**Age categories reflect the definitions adopted by the included studies. Studies were included when they referred to their participants as older adults/elderly, regardless of the specific age threshold used by the author
***Only categories occurring in all studies are shown. Single-occurrence terms and platforms were excluded.

Table A. 3: Descriptive information about the studies included (continued)



ARTICLE CODE	User Profile: Older Adults** 50+	55+	60+	65+	70+	75+	80+	Relatives	Professional Caregiver	Number of older participants	Topic: Health	General/Daily Life	E-Commerce	Psychological/Well-being	Method: Interview	Focus Group	Usability Test	Workshop	Co-design	Usage Log Analysis	Content Analysis	Wizard of Oz	Participant Observation	Scale/Survey	Questionnaire	Diary	Home Tour	Think Aloud	Length: ≤ 1 day	1-15 Days	16 - 30 days	1-3 months	3-6 months	6-9 months	≥ 1 year	Context: Home	Hospital	Facility	Lab	Other Setting	Preferred VCA Terms***	VCA Platforms***
43					•					14	•				•													•								•				Smart Speaker Based Voice Assistant	Amazon Alexa
49				•						12	•				•					•										•				•				Smart Speaker Based Voice Assistant	Google Assistant
50					•					29	•						•				•							•											Smart Voice Technology	In house - developed
52			•							43	•													•				•										•	Voice Assistant	Amazon Alexa
55			•							18	•							•										•								•			Intelligent Assistant	In house - developed
57			•						•	7	•				•	•				•				•							•			•					Conversational Assistant	In house - developed
59			•							19	•										•							•											Intelligent Virtual Agent	In house - developed
60	•									12	•				•					•									•					•					Conversational Agent	In house - developed
63			•							24	•													•				•	•								•		Virtual Conversational Agent	In house - developed
64				•			•		•	6		•			•							•								•							•		Smart Home Voice Interface	In house - developed
65			•							7				•	•					•					•					•					•					Smart Speaker Based Voice Assistant	Amazon Alexa
66			•							7	•				•					•					•					•					•					Intelligent Virtual Agent	Amazon Alexa
67			•							6	•									•														•	•					Smart Home Speakers	Amazon Alexa
68			•					•		12	•				•							•							•									•	Voice Assistant	Huawei Celia
69		•								9	•										•			•					•								•			Conversational Agent	Amazon Alexa
70			•				•			29				•	•	•													•								•			Chatbot	In house - developed
72	•									5	•									•				•						•					•					Voice Assistant	Google Assistant
74	•									44				•	•									•	•					•					•					Robot and Virtual Agent	In house - developed
75		•								5	•										•							•										•		Intelligent Virtual Agent	In house - developed
76		•								55	•				•									•						•					•					Embodied Conversational Agent	In house - developed
77			•						•	29	•				•					•				•						•					•					Embodied Conversational Agent	In house - developed
78				•						33		•			•												•				•				•					Voice Assistant	Google Assistant
83				•						19		•			•													•									•			Voice Assistant	Amazon Alexa
84				•						14	•				•									•					•									•			Embodied Conversational Agent	In house - developed
86							•			19	•					•													•										•		Intelligent Cognitive Assistant	In house - developed
88	•									5	•				•									•							•				•					Conversational Agent	In house - developed

*Since the one marked article examined all age groups, excluding the elderly, the table doesn't show a specific age range for this.
**Age categories reflect the definitions adopted by the included studies. Studies were included when they referred to their participants as older adults/elderly, regardless of the specific age threshold used by the author
***Only categories occurring in ≥2 studies are shown. Single-occurrence terms and platforms were excluded.



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Research Interests: Responsible design; visual communication design; health communication; health literacy; short-video communication; ageing and older adults

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Responsible Commercial Transparency in Health Short Videos for Older Adults: A Cross-Platform Case Study

Yufan Guo

Abstract

Health-related short videos increasingly combine health education, personal experience and product promotion within the same compressed media format. This is particularly visible in supplement-related content, where claims about nutrition, bodily function and everyday health management may appear alongside product display, shopping links, influencer endorsement or expert-style explanation. This article examines commercial transparency in supplement-related short videos as a responsible design issue.

The article presents a literature-informed cross-platform case study of selected videos from Douyin, Kuaishou, Xiaohongshu, TikTok, Instagram and YouTube Shorts. Drawing on literature on health-related claims, supplement advertising, short-video persuasion, advertising disclosure and influencer marketing, it develops a Responsible Commercial Transparency Framework with three dimensions: commercial identity disclosure, the education–promotion boundary, and risk and limitation communication. The framework is applied to six selected cases representing doctor-led explanation, product-focused promotion, structured product information, personal testimony, paid partnership content and risk-aware health advice.

Questionnaire findings from older Chinese adults are used as audience-related contextual evidence. The article argues that commercial transparency should not be treated only as a regulatory or marketing issue. It should also be understood as a responsible design concern, because visual hierarchy, source cues, platform selling functions and risk information shape how older viewers may interpret the boundary between health advice and commercial persuasion.

Keywords: ***commercial transparency; health short videos; dietary supplements; responsible design; older adults; advertising disclosure; visual communication design***

1. Introduction

Short-video platforms have become important spaces for everyday health communication, where health information is increasingly encountered through influencer recommendations, personal stories, product demonstrations and platform-based shopping functions rather than only through hospitals, public health campaigns or long-form educational materials (Tripathi, de Vries and Lemke, 2022; Park, Lee and Lazenby, 2026). In dietary-supplement-related content, health education, personal experience, product recommendation and commercial promotion may therefore appear within the same short video (Iye et al., 2021; Park, Lee and Lazenby, 2026). In this article, dietary supplements are defined as non-prescription products intended to supplement the normal diet and containing vitamins, minerals, herbs, amino acids or other substances with nutritional or

physiological effects; they are presented as supporting nutrition, health or bodily function rather than diagnosing or treating disease (European Parliament and Council, 2006; Iye et al., 2021).

Dietary supplements occupy an ambiguous position between food, everyday health management and medical expectation. The scale of the sector increases the significance of how these products are communicated: one recent industry estimate valued the global dietary supplements market at USD 100.92 billion in 2025 and projected continued growth to USD 219.31 billion by 2034 (Fortune Business Insights, 2026). Although dietary supplements are not medicines, they are frequently promoted through health-related claims that associate products with bodily improvement, risk reduction or general wellbeing (European Parliament and Council, 2006; Muela-Molina, Perelló-Oliver and García-Arranz, 2021). Such claims commonly relate products to fatigue, immunity, bone health, digestion, sleep, ageing and weight control, making promotion appear educational by presenting products through recognisable health concerns rather than through direct selling alone (Iye et al., 2021; Muela-Molina, Perelló-Oliver and García-Arranz, 2021). Short-video formats may strengthen these claims through presenter identity, subtitles, personal testimony, product display and direct purchasing links, guiding viewers from attention and engagement towards product-related action (Iye et al., 2021; Tripathi, de Vries and Lemke, 2022).

This creates a problem of commercial transparency, which refers to the extent to which audiences can recognise the commercial purpose of a message and understand the relationship between the presenter, the product, the brand and the purchasing pathway (Wojdynski and Evans, 2016; Boerman, Willemsen and Van Der Aa, 2017). Previous research has shown that advertising disclosure influences audiences'

recognition of persuasive intent, while source credibility and influencer marketing shape how branded health content is perceived and trusted (Lou and Yuan, 2019; Boerman, 2020). However, commercial cues may still be integrated with expert explanation, personal testimony and health advice, making the boundary between education and promotion difficult to identify.

This issue is particularly relevant to older viewers because dietary supplement promotion frequently addresses concerns associated with later life, including fatigue, blood pressure, sleep, immunity and bone health (Iye et al., 2021; Wierzejska et al., 2022). Older viewers may rely on professional identity, visible titles, familiar examples and source-related cues when judging credibility (Friemel, 2016). Where commercial purpose, product limitations or risk information are unclear, health advice and product promotion may become difficult to distinguish (Boerman, 2020; Lou and Yuan, 2019).

2. Literature Review and Analytical Framework

Building on the concepts introduced in the Introduction, this section reviews previous research on dietary-supplement-related health claims, short-video persuasion and commercial transparency. It then develops the Responsible Commercial Transparency Framework used in the subsequent case study analysis, focusing on commercial identity disclosure, the education–promotion boundary, and risk and limitation communication.

2.1 Health-related claims in supplement promotion

Video-based supplement advertising often blurs the boundary between health education and commercial promotion. Iye et al. (2021) found that YouTube dietary supplement advertisements often used "health concerns" and "easy solutions" as persuasive themes.

Recent research on TikTok gut-health supplement videos similarly shows that health claims are often presented through positive benefit framing, while creator credentials and disclosure may be limited (Park, Lee and Lazenby, 2026). Therefore, health-related claims provide a useful entry point for analysing how supplement short videos connect health benefits, source credibility and commercial intention, and whether viewers can recognise the evidence, purpose and limitations of such claims.Previous research has also shown that health-product advertising often gives greater visual and narrative emphasis to product benefits than to risks or limitations. Risk information may receive less prominence through its placement, presentation or organisation, making it more difficult for audiences to recognise important limitations or make informed judgements, particularly among older viewers (Sullivan et al., 2019; O'Donoghue et al., 2019). This suggests that the communication of risk and limitation information should be considered an important dimension when analysing commercial transparency in supplement-related short videos.

1.2 Packaging health claims through short-video persuasion

Short-video platforms do not simply present health-related claims; they package these claims through visual, narrative and interactive cues. A supplement claim may become more persuasive when it is delivered by a confident presenter, supported by subtitles or data, connected to personal experience, and placed close to a visible product or purchase link. In this way, viewers encounter the claim not as an isolated advertising statement, but as part of a short health narrative. Tripathi, de Vries and Lemke (2022), in their grounded

theory study of 60 YouTube protein supplement videos, describe this process through a three-step persuasion model: reaching the message, staying on the message and performing the desired action.

This model is useful for understanding supplement short videos because it shows how attention, engagement and action can be organised within a single clip. A symptom, question or eye-catching title may first attract viewers. Credibility cues, such as professional identity, personal testimony, research references, subtitles or product demonstrations, may then keep viewers engaged. Finally, product display, brand mention, shopping links or discount codes may guide viewers towards trust, trial or purchase.

The problem is not that every such video is necessarily misleading, but that short-video design can make commercial direction appear continuous with health education. Recent TikTok research on gut-health supplement promotion also shows that health claims are often framed through positive bodily benefits, while creator credentials and advertising disclosure may remain limited (Park, Lee and Lazenby, 2026). Therefore, this article examines how supplement short videos arrange health concerns, credibility cues and action prompts in ways that may blur the boundary between health information and product promotion.

Figure 1: Simplified Three-Step Persuasion Model in Supplement-Related Video Content



Source:Adapted from Tripathi, de Vries and Lemke (2022).

Note: The model is used here to explain how supplement short videos may first attract viewers, then keep them engaged through credibility cues or personal narratives, and finally guide them towards trust, trial or purchase-related action.

1.3 Commercial Transparency as a Responsible Design Concern

This is especially important in supplement-related short videos because commercial intent may be embedded within health narratives. A creator may discuss symptoms, explain a nutrient, share personal experience, display a product and provide a purchase link within the same short clip. Research on native advertising shows that audiences may fail to recognise persuasive content when disclosures are unclear, visually weak or poorly positioned (Wojdynski and Evans, 2016). Similarly, studies of influencer marketing suggest that source credibility, message value and sponsorship disclosure shape how audiences trust and interpret branded content (Lou and Yuan, 2019; Boerman, 2020).

Commercial transparency provides the general analytical starting point for this study: whether commercial purpose and the relationships among the presenter, product, brand and purchasing pathway are visible and understandable. In this article, commercial transparency refers to this general recognisability of commercial purpose, whereas Responsible Commercial Transparency refers to the design-oriented concept developed in this study, which additionally considers whether health education can be distinguished from product promotion and whether risk and limitation information is sufficiently visible. The selected videos are therefore examined not for clinical accuracy, but for how commercial purpose, educational framing and product-related limitations are visually organised. From

a responsible design perspective, transparency depends not only on whether information is technically present, but also on its placement, emphasis and relationship to platform functions such as shopping links and recommendation interfaces. These choices can support or obstruct viewers' recognition of persuasive intent and their ability to make informed decisions (Friedman and Hendry, 2019).

2.4 Responsible Commercial Transparency Framework

Based on the literature reviewed above, this article develops a Responsible Commercial Transparency Framework for the cross-platform case study. The three dimensions synthesise three recurring concerns identified in the literature: the recognisability of commercial identity, the blending of health education with product promotion, and the relative visibility of benefits, risks and limitations. The framework is not designed to assess the medical accuracy of each video. Instead, it provides a literature-informed structure for examining how visual and platform-based communication makes commercial purpose, health information and product-related limitations visible, prominent, secondary or obscured in supplement-related short videos.

(1) Commercial Identity Disclosure

This dimension examines whether the video clearly communicates its commercial status, including advertising, sponsorship, affiliate promotion, brand collaboration, product recommendation or platform shopping functions. Disclosure research suggests that audiences are more likely to recognise persuasive intent when commercial cues are explicit, visible and easy to interpret (Wojdynski and Evans, 2016; Boerman, Willemsen and Van Der Aa, 2017; Boerman, 2020).From a

visual communication perspective, this involves how disclosure cues are designed through visual elements such as labels, typography, colour, placement and visual emphasis, enabling viewers to recognise commercial identity more easily.

(2) Education–Promotion Boundary

This dimension examines whether health education, personal experience, expert explanation and product recommendation are clearly separated or blended within the same video. Supplement videos may connect everyday health concerns with product use, while short-video persuasion can strengthen such claims through speaker identity, personal testimony, subtitles, product demonstrations and action prompts (Iye et al., 2021; Tripathi, de Vries and Lemke, 2022; Park, Lee and Lazenby, 2026).From a visual communication perspective, this boundary can be reinforced through the visual separation of educational and promotional content, for example by distinguishing informational explanations from product recommendations through layout, sequencing, labelling and other visual cues.

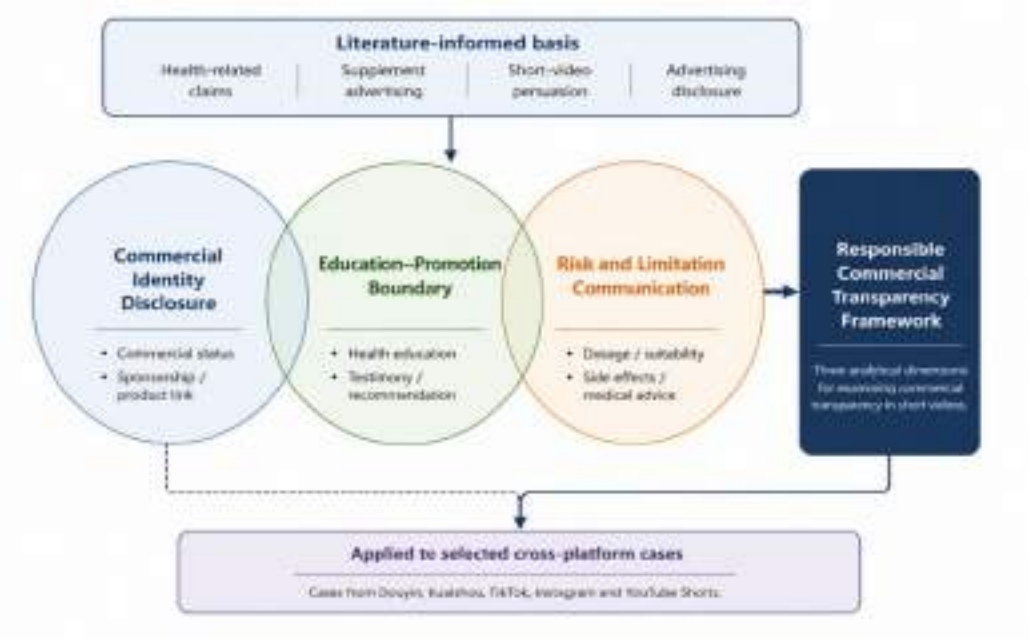
(3) Risk and Limitation Communication

This dimension examines whether benefit claims are accompanied by caution, uncertainty or qualifying information, such as dosage, suitability, side effects, contraindications, testing needs or professional medical advice. This is important because supplement-related videos may present product use as simple and beneficial while making risks or limitations less visible than positive claims (Iye et al.,

2021; Park, Lee and Lazenby, 2026).From a visual communication perspective, responsible communication requires risk and limitation information to be presented with sufficient visual prominence, allowing viewers to recognise cautions, conditions and uncertainties alongside benefit claims.

Together, these three dimensions guide the analysis of the selected cases by asking how commercial identity, promotional framing and product-related limitations are designed, disclosed or obscured. The three dimensions are analytically distinct but interdependent. Commercial identity disclosure may remain difficult to recognise when professional authority or educational framing dominates, while weak risk information may further reinforce an overly positive interpretation of the product.

Figure 2: Responsible Commercial Transparency Framework for Supplement-Related Short Videos



Source: Author's own creation

Note: The framework is developed from literature on health-related claims, supplement advertising, short-video persuasion and advertising disclosure. It consists of three analytical dimensions—commercial identity disclosure, the education–promotion boundary, and risk and limitation communication—which guide the analysis of selected cross-platform cases.

2.5 Research Aim and Research Questions

The literature reviewed above shows that health-related claims, supplement advertising, advertising disclosure, short-video persuasion and influencer marketing have been widely examined (Wojdynski and Evans, 2016; Lou and Yuan, 2019; Boerman, 2020; Iye et al., 2021; Tripathi, de Vries and Lemke, 2022). However, less attention has been paid to how Responsible Commercial Transparency is communicated through visual communication design in supplement-related short videos across different platforms. This gap provides the rationale for the present study.

The aim of this article is to examine how Responsible Commercial Transparency is visually and narratively communicated in supplement-related short videos through visual communication design. Its objectives are to develop a literature-informed Responsible Commercial Transparency Framework, apply the framework to selected cases across six platforms, and use questionnaire findings from older Chinese adults to contextualise the case analysis and identify responsible design implications.

The article addresses the following research questions:

- **RQ1: How is commercial identity disclosed or obscured in supplement-related health short videos across platforms?**

- **RQ2: How is the boundary between health education and product promotion visually and narratively constructed or blurred?**
- **RQ3: How is risk and limitation information presented, minimised or omitted in these videos?**

These research questions correspond directly to the three dimensions of the Responsible Commercial Transparency Framework presented above and guide the subsequent cross-platform case analysis.

The article contributes by positioning Responsible Commercial Transparency as a visual communication design concern rather than solely as a marketing or regulatory issue.

The overall structure and progression of the study are summarised in Figure 3.

Figure 3: Overview of the Article Structure and Research Process



Source: Author's own creation.

3. Methodology

This section explains the qualitative cross-platform case study, including case selection, analytical procedure and the supporting questionnaire involving older Chinese adults. The case study is the primary method, while the questionnaire provides audience-related contextual evidence for interpreting how Responsible Commercial Transparency is communicated through visual design.

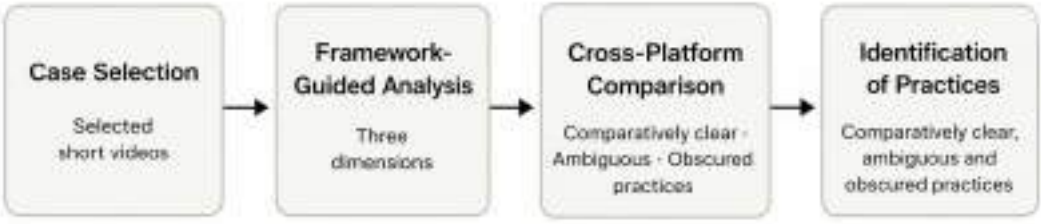
3.1 Research design

This article adopts a qualitative cross-platform case study design. The purpose is not to produce a statistically representative account of all health-related short videos, but to examine information-rich cases that reveal contrasting ways in which health claims, persuasive presentation and commercial cues are visually and narratively organised. Comparing doctor-led explanation, personal testimony, product-focused promotion and paid-partnership content enables the study to identify comparatively clear, ambiguous and obscured practices of Responsible Commercial Transparency without classifying the platforms themselves.

The case study analysis examined publicly available short-video content only and did not involve interaction with content creators, platform users, or access to private data. Therefore, no additional participant recruitment or separate ethical approval was required for the case analysis. Ethical approval was obtained for the questionnaire research involving older adults (BREO Approval Reference: 51246-LR-Apr/2026-55172-2).

The study applies the Responsible Commercial Transparency Framework developed in Section 2. As shown in Figure 4, the process moves from case selection to framework-guided analysis and cross-case comparison, leading to the identification of contrasting communication practices. The three dimensions—commercial identity disclosure, the education–promotion boundary, and risk and limitation communication—guide the examination of how commercial purpose is made visible, ambiguous or obscured.

Figure 4: Application of the Case Study Approach



Source:Author's own creation

3.2 Case Selection

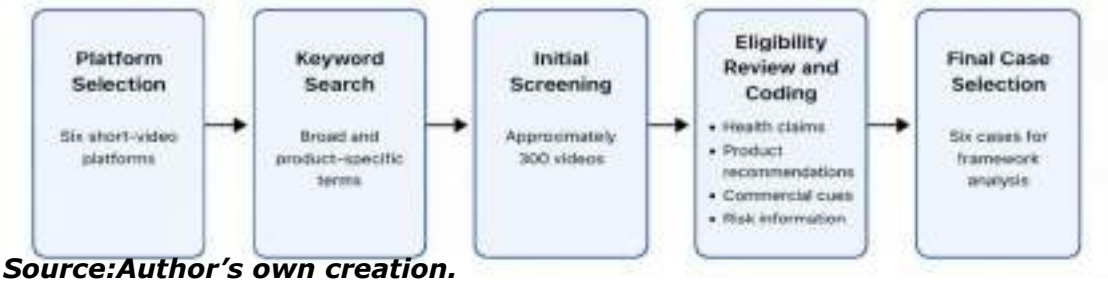
The case selection followed a two-level purposive strategy comprising platform selection and video-case selection. At the platform level, Douyin, Kuaishou, Xiaohongshu, TikTok, Instagram and YouTube Shorts were selected because of their substantial user reach and relevance to health-related and commercially embedded short-video communication (TikTok, 2021; YouTube, 2023; Vogue Business, 2024; Statista, 2025; Reuters, 2025; Kuaishou Technology, 2026). Platform scale was used to justify inclusion rather than to claim that the selected videos were statistically representative.

As shown in Figure 5, an iterative keyword search was conducted across the six platforms between April and July 2026. English and Chinese search terms were used where relevant, and approximately 300 supplement-related short videos were screened by the author

through platform search results and related-content recommendations. Duplicate or repeatedly recommended videos were counted only once.

Search terms were selected based on a preliminary exploration of the six platforms and were retained because they consistently returned a substantial volume of supplement-related videos. Both generic search terms, including dietary supplements, health supplements, health products and healthy ageing, and ingredient-specific terms, including iron supplements, vitamin D, collagen and calcium supplements, were used to capture a broad range of health claims, product recommendations and commercial communication. Videos were included when they contained health-related claims, product recommendations, expert explanation, personal testimony, product display or identifiable commercial cues. Duplicate videos, unrelated health content, long-form videos and videos without identifiable supplement-related information were excluded. During screening, videos were coded according to presenter identity, product visibility, commercial identity disclosure and risk and limitation communication. This process enabled the identification of information-rich and contrasting cases suitable for qualitative cross-case analysis (Schreier, 2012; Yin, 2018).

Figure 5: Case Selection Process



Source:Author's own creation.

The final six cases, presented in Table 1, were purposively selected because they represented contrasting combinations of presenter

identity, product visibility, commercial identity disclosure and risk and limitation communication. They included doctor-led explanation, supplement-focused promotion, structured product information, personal testimony, paid-partnership content and risk-aware health communication. Together, these cases provided sufficient variation for applying the Responsible Commercial Transparency Framework across its three analytical dimensions: commercial identity disclosure, the education–promotion boundary, and risk and limitation communication.

Table 1: Case Profile Matrix of the Selected Cases

Evaluation Criteria	C1	C2	C3	C4	C5	C6
Screenshot						
Platform	Douyin	Kuaishou	Xiaohongshu	TikTok	Instagram	YouTube Shorts
Presenter identity	Doctor	Influencer	Nutrition expert	Consumer	Influencer	Doctor
Primary communication style	Health education	Product promotion	Product explanation	Personal testimony	Paid partnership	Risk-aware education
Product visibility	Low	High	High	Medium	High	Low
Commercial Identity Disclosure	None	None	Partial	None	Clear	Clear
Risk and Limitation Communication	Present	Absent	Limited	Absent	Limited	Present
Contribution to cross-case comparison	Professional educational communication	Highly promotional commercial content	Structured product information	Testimonial-based persuasion	Sponsored influencer marketing	Responsible Commercial Transparency

Evaluation Criteria	C1	C2	C3	C4	C5	C6
Video link	View video	View video	View video	View video	View video	View video

Source: Author's own creation using screenshots from the selected videos. Video links are provided beneath each case.

Note: This table provides an overview of the six selected cases used for close analysis. The cases are presented to support case organisation rather than to rank, evaluate or medically assess the videos.

3.3 Analytical Procedure

The selected cases were analysed through repeated viewing and close reading of their visual, verbal and platform-based features. Observable elements, including titles and thumbnails, presenter identity, spoken health claims, subtitles, text overlays, product display, brand references, shopping links, paid-partnership labels, disclaimers and risk-related information, were systematically recorded and coded according to their communicative functions. The overall analytical procedure is illustrated in Figure 6.

Figure 6: Analytical Procedure: From Observable Video Features to Responsible Commercial Transparency Dimensions



Source:Author's own creation

To operationalise the Responsible Commercial Transparency Framework, a framework-based checklist was developed to establish explicit links between the three analytical dimensions and the observable visual and communicative elements examined in each case. As shown in Table 2, the checklist was applied consistently across all six cases to ensure a systematic and comparable analysis.

Table 2. Framework-Based Checklist for Case Analysis

Framework Dimension	Observable Elements
Commercial Identity Disclosure	**Product display; brand references; shopping links; paid-partnership labels**
Education–Promotion Boundary	**Presenter identity; health claims; expert explanation; personal testimony; recommendation language**
Risk and Limitation Communication	**Dosage; side effects; contraindications; disclaimers; professional advice**

Note: The checklist was applied consistently across all six selected cases.

The purpose of this procedure was not to assess the clinical accuracy of individual health claims, but to examine how commercial transparency was designed and communicated within the short-video format. Using the checklist, the six cases were compared across platforms to identify recurring patterns and contrasting practices in how commercial purpose, health information and product-related risks or limitations were made visible, rendered ambiguous or obscured.

3.4 Questionnaire design and contextual grounding

The supporting questionnaire was used to provide audience-related contextual evidence for the qualitative case study. It explored older Chinese adults' experiences of viewing health-related short videos and supported the interpretation of the Responsible Commercial Transparency Framework. A summary of the questionnaire design is

presented in Table 3.The questionnaire was completed by 40 older Chinese participants during the fieldwork. The findings are used as audience-related contextual evidence to support the interpretation of the case analysis rather than as an independent evaluation of the framework.

Table 3: Summary of the Supporting Questionnaire

Component	Description
Purpose	**To provide audience-related contextual evidence for the qualitative case study and support the interpretation of the Responsible Commercial Transparency Framework.**
Instrument Design	**A structured questionnaire comprising multiple-choice, rating and preference-based questions on viewing habits, source credibility, commercial promotion and risk information. Responses were summarised descriptively using frequencies and percentages.**
Sample Selection	**Chinese adults aged 60 years or above. Individuals under 60, responses without informed consent and substantially incomplete questionnaires were excluded.**
Participant Recruitment & Ethics	**Participants were recruited with the assistance of the Jiuxian Town Community, Yanqing District, Beijing, where the questionnaire activities were conducted at the local cultural centre. Participation was voluntary, informed consent was obtained before participation, and ethical approval was granted by Brunel University London (BREO Approval Reference: 51246-LR-Apr/2026-55172-2).**

Source:Author's own creation.

The questionnaire findings were used to contextualise, rather than validate, the case study analysis. They helped interpret how observable video features, such as presenter identity, product visibility and commercial identity disclosure, might be understood by older viewers. This use of audience-related contextual evidence is

consistent with qualitative case study and mixed-methods research (Bryman, 2016; Creswell and Plano Clark, 2018; Yin, 2018).

4. Cross-Platform Case Analysis

This section applies the Responsible Commercial Transparency Framework to the six selected cases to address the three research questions. Rather than describing each case individually, the analysis identifies recurring cross-case patterns concerning commercial identity, the boundary between education and promotion, and the communication of risks and limitations. It examines how these patterns are shaped by presenter identity, disclosure practices, educational framing and the visibility of risk-related information (Hsieh and Shannon, 2005; Schreier, 2012; Yin, 2018).

The findings are presented in four sections. Sections 4.1–4.3 report the case study results across the three framework dimensions, while Section 4.4 draws on the questionnaire findings to provide audience-related context for the case analysis rather than serving as an independent evaluation of the framework.

4.1 Commercial Identity Disclosure

To address RQ1, the cases were compared according to disclosure labels, presenter identity, product visibility and purchasing cues. Three disclosure patterns emerged. First, C5 used Instagram's paid-partnership label, making the creator–brand relationship explicit and immediately visible. This supports previous findings that standardised and prominent disclosure can improve recognition of sponsored content (Boerman, 2020; Wojdynski and Evans, 2016).

Second, C2–C4 communicated commercial intent mainly through product display, recommendation language and product-centred presentation. These cues suggested promotion but did not clearly explain whether the presenter was sponsored, affiliated with the brand, acting as a seller or recommending independently. Viewers therefore had to infer the commercial relationship from the surrounding visual and narrative context (Lou and Yuan, 2019). Third, C1 foregrounded professional authority: the white coat and doctor-led explanation were more visible than any possible commercial role. Here, expert identity could strengthen credibility while making persuasive intent less noticeable (Muela-Molina, Perelló-Oliver and García-Arranz, 2021). C6 provided a non-commercial contrast, with no central product, brand or purchasing pathway.

Overall, the cases show that commercial identity is not communicated by disclosure labels alone. It is produced through the relationship between disclosure, presenter identity, product prominence and platform-selling features. When these cues are incomplete or visually unbalanced, commercial purpose becomes more difficult to recognise.

4.2 Education–Promotion Boundary

To address RQ2, the analysis examined how health explanation, personal experience and product recommendation were organised within each video. Three recurring patterns were identified. In C1 and C5, educational formats were combined with product-related content: C1 used doctor-led explanation, while C5 used a myth-busting format within a disclosed partnership. Although their commercial status differed, both integrated educational authority and promotional direction within the same short-video sequence.

A second pattern appeared in C2 and C3, where product-centred information was presented as health explanation. C2 relied on direct promotion and benefit-related claims, whereas C3 used a more structured informational format. In both cases, the product remained visually central, and the movement from explanation to recommendation was not clearly separated. A third pattern appeared in C4, where personal testimony connected individual experience with product recommendation. The experiential narrative made the recommendation appear informal and relatable, but did not clearly distinguish personal experience from persuasive communication. C6 again provided a contrast by discussing vitamin D risk without directing viewers towards a particular product or purchase.

Across the cases, the education–promotion boundary was shaped mainly through sequencing, presenter role and product visibility. Where educational explanation and recommendation were visually continuous, promotion could appear to be a natural extension of health information rather than a distinct commercial message.

4.3 Risk and Limitation Communication

To address RQ3, the cases were compared according to the visibility of dosage, suitability, side effects, contraindications, uncertainty and professional advice. Two main patterns emerged. Across C1–C5, benefit-related explanation and product recommendation generally received greater visual and narrative emphasis than risk or limitation information. The iron-related cases, for example, discussed potential benefits without giving equivalent prominence to individual suitability, dosage or the need for assessment. Similarly, C2–C5 emphasised product benefits, structured information, personal

experience or myth-busting, while cautions remained limited or secondary.

Where qualifying information appeared, it was usually shorter, less prominent or positioned after the main benefit message. This imbalance is consistent with previous research showing that supplement promotion often presents products as accessible responses to health concerns while giving less attention to possible limitations or adverse effects (Iye et al., 2021; Wierzejska et al., 2022). C6 represented the contrasting pattern. Rather than centring product benefits, it placed excessive vitamin D intake and possible toxicity at the centre of the message, making risk communication the primary content rather than a minor qualification.

Overall, responsible risk and limitation communication depends not only on whether cautionary information is technically present, but also on whether it is visible and proportionate to the benefit claims. In these cases, the strongest promotional framing was generally associated with the weakest presentation of risks and limitations.

4.4 Questionnaire-Supported Contextualisation

As shown in Figure 7, the questionnaire was administered face-to-face with older participants during the fieldwork. This approach allowed the researcher to explain unfamiliar questions and visual materials where necessary, particularly because regular mobile-phone use did not always indicate confidence in interpreting digital or platform-based commercial cues. Accordingly, the questionnaire findings are organised around the same three analytical dimensions to provide audience-related context for the case analysis, rather than serving as an independent evaluation of the framework.

Figure 7: Face-to-Face Questionnaire with Older Participants



Source: Photograph taken by the author during fieldwork.

The questionnaire findings provide contextual support for the cross-case analysis, particularly in relation to commercial identity disclosure. Although 92.5% of participants usually watched videos on mobile phones and 60% had encountered health-related content, only 25% considered mobile-phone use very convenient. This suggests that frequent access to short-video platforms did not necessarily mean that disclosure labels, shopping functions or purchasing pathways were easy to recognise, reinforcing the need for clear commercial identity disclosure for older viewers (Friemel, 2016).

The findings also help contextualise the education–promotion boundary. Health concerns such as blood pressure, sleep and joint pain attracted 60% of participants, while 42.5% identified doctors, experts or white-coat presenters as reasons for continuing to watch. In addition, 87.5% had encountered health talks offering eggs or small gifts, and 70% knew someone who had purchased health products after such activities. These results show how educational settings and professional appearance may strengthen credibility while making commercial promotion less immediately apparent.

Finally, the questionnaire findings reinforce the importance of risk and limitation communication. Participants' familiarity with promotional activities suggests that product messages may be persuasive when presented through apparently educational or authoritative formats. This supports the need to present risk, suitability and limitation information alongside product benefits. Taken together, the questionnaire findings provide an audience-related basis for the responsible design implications discussed in the following section.

5. Discussion

The findings indicate that commercial transparency in supplement-related short videos is not secured by disclosure alone. Instead, it depends on the relative visibility of commercial cues within the wider visual and communicative context. This supports previous research showing that advertising recognition is shaped by disclosure design, source credibility and message context (Wojdynski and Evans, 2016; Lou and Yuan, 2019; Boerman, 2020). The present study extends this work by showing that a disclosure label may be technically present yet remain less noticeable than professional authority, personal testimony or an educational format.

The three dimensions of the Responsible Commercial Transparency Framework are therefore interdependent rather than separate criteria. Explicit sponsorship disclosure can identify a commercial relationship, but it does not necessarily clarify where health explanation ends and product promotion begins. Similarly, professional presentation may increase perceived credibility while dosage, suitability and uncertainty remain visually secondary. The

questionnaire findings provide relevant audience context rather than causal confirmation: older participants reported attending to professional identity and visible health concerns, while many did not find mobile-platform use fully convenient. This suggests that transparency should be designed for practical recognition during viewing, rather than assumed from the technical presence of information.

The proposed conceptual illustration, presented in Figure 8, translates these findings into a short-video interface informed by the three analytical dimensions. Its elements are derived directly from the recurring problems identified in the cases: unclear commercial relationships, visual continuity between education and promotion, and weak prominence of risk information. The illustration is not presented as a tested interface or a universal solution. Instead, it makes the framework's design implications visible and provides a proposition for later evaluation with users, designers and platform stakeholders.

Three implications follow. First, commercial identity should be recognisable at the point of exposure and remain sufficiently visible throughout the message, rather than appearing only in a caption, profile or brief label. Clear and prominent disclosure improves recognition of sponsored content, whereas weak placement may reduce awareness of persuasive intent (Boerman, Willemsen and Van Der Aa, 2017; Federal Trade Commission, 2023).

Second, health education and product promotion should be differentiated through sequencing, labelling and visual hierarchy. Expert explanation and personal testimony may support engagement, but a visible transition is needed when communication moves from

information to recommendation (Tripathi, de Vries and Lemke, 2022; Borchers and Enke, 2022).

Third, risk and limitation information should receive prominence proportionate to benefit claims. Dosage, suitability, contraindications and uncertainty should not function as minor qualifications after the main persuasive message (Iye et al., 2021; Wierzejska et al., 2022; Federal Trade Commission, 2022).

The contribution of the framework is therefore not a new disclosure label or a fixed screen layout. It is an integrated way of examining whether viewers can recognise who is communicating commercially, distinguish advice from promotion, and consider benefits alongside limitations. This shifts commercial transparency from a narrow compliance question towards a responsible visual communication problem involving creators, designers and platforms. However, because each platform is represented by one purposively selected case, the findings should not be interpreted as platform-level comparisons or claims about typical practice. The framework and Figure 8 should instead be treated as analytically grounded propositions that require further testing across additional content, audiences and platform environments.

Figure 8: Conceptual Illustration of Responsible Commercial Transparency in a Supplement-Related Short Video



Source: Author's own creation.

Note: This figure is a conceptual illustration of how the three dimensions of the Responsible Commercial Transparency Framework may be reflected in a short-video interface. It does not prescribe a fixed layout and may require adaptation to different platforms, content types and audience needs.

6. Conclusion

This study examined how Responsible Commercial Transparency is communicated in supplement-related short videos across six social media platforms. Using a literature-informed case study supported by questionnaire findings from older Chinese adults, it showed that commercial transparency depends not only on disclosure labels, but also on how commercial identity, educational framing and risk

information are visually organised within short-video communication. Together, the findings address the three research questions by demonstrating how these three dimensions are disclosed, blended or minimised across different communication contexts.

The principal contribution of this study is not simply the development of the Responsible Commercial Transparency Framework, but its repositioning of commercial transparency as a visual communication design issue. Previous studies have primarily examined disclosure, influencer marketing and persuasive intent from regulatory or marketing perspectives (Wojdynski and Evans, 2016; Lou and Yuan, 2019; Boerman, 2020). By bringing together commercial identity disclosure, the education–promotion boundary and risk and limitation communication within a single analytical framework, this study shows how visual communication design influences audiences' ability to recognise commercial purpose and interpret health-related information. Rather than proposing a universal design solution, the framework offers a design-oriented approach for analysing and supporting responsible commercial transparency in health-related short videos.

This study has several limitations. The analysis was based on six purposively selected cases and therefore aims for analytical rather than statistical generalisation. In addition, the questionnaire provides audience-related contextual evidence rather than validation of the proposed framework, while the conceptual illustration presented in the Discussion has not yet been empirically evaluated. These limitations also indicate directions for future research.

Future studies could evaluate the framework through prototype development, user testing and co-design with older adults, as well as

comparative research across different platforms and cultural contexts. Such work would help examine how visual communication design can further support transparent and responsible health communication for older audiences.

Reference:

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Biomimetic Design for Academic Workspaces: Enhancing Staff Well-Being and Productivity in UK University Offices

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Abstract

Academic office environments profoundly shape the intellectual, emotional, and professional lives of university staff, yet many remain standardised, inflexible, and ecologically disconnected from the natural systems that support human well-being. This study investigates how biomimetic design principles can address the lived workspace challenges of UK academic staff and translates user-identified needs into evidence-based design strategies. Employing a qualitative, interpretive methodology, semi-structured interviews were conducted with thirty academic staff from six disciplinary departments across multiple UK universities. Reflexive thematic analysis identified five cross-cutting barriers to well-being and productivity: inadequate acoustic privacy, environmental discomfort, spatial inflexibility, limited personal control, and the absence of natural or restorative elements. These findings are synthesised into a Biomimetic Design Translation Framework — the primary contribution of this paper — which maps empirically derived user challenges onto

nature-inspired design strategies operating at the form, process, and ecosystem levels of biomimetic application. Reframed through a responsible design lens, these findings suggest that access to acoustically private, thermally comfortable, and restorative working conditions is unevenly distributed across academic roles and institutions, positioning staff well-being as a matter of institutional responsibility and equity rather than design optimisation alone. The study contributes empirical grounding for subsequent design framework development in academic settings and offers practical implications for institutional workspace planning that supports dignity and equitable access to restorative space.

Keywords: ***biomimicry, biophilic design, interior design, academic workspace, well-being, qualitative research, UK universities, thematic analysis, responsible design, institutional equity***

Introduction

Academic office environments are pivotal sites of intellectual labour. They host a dense and shifting repertoire of activities focused research, teaching preparation, student meetings, and interdisciplinary collaboration, which impose competing spatial and sensory demands. Despite their centrality to academic life, many contemporary university offices are shaped by standardised, efficiency-driven design models that prioritise spatial economy over human well-being, contributing to heightened stress, reduced concentration, and diminished long-term productivity (Kim and de Dear 2013; De Croon et al. 2005; Haapakangas et al. 2011).

Understood in this way, the design of academic office space is not simply a matter of spatial economy or aesthetic preference; it is a question of institutional responsibility. Who is afforded a quiet, comfortable, and restorative place to work, and who is not, is shaped by decisions over which individual staff have little influence, including capital budgets, estates standards, and space allocation policies, which determine whose working conditions support dignity, sustained attention, and professional well-being, and whose do not. Reframing academic workspace design as a responsible design problem foregrounds these questions of access and equity alongside questions of performance and comfort, situating the present study within a broader concern for designing physical environments that support social connection, dignity, and belonging in institutional life.

Responses to this problem have largely proceeded along two parallel tracks. The first, activity-based working (ABW), reconfigures office space into functionally differentiated zones to support varied work modes (Appel-Meulenbroek, Groenen, and Janssen 2011). The second, biophilic design, introduces natural sensory stimuli, plants, daylight, natural materials, and outdoor views based on an evolved human affinity with nature (Kellert, Heerwagen, and Mador 2008; Wilson 1984). Neither framework, however, provides the integrated, systems-level logic needed to address multiple, interrelated workspace challenges simultaneously, that is, a design approach capable of treating acoustic performance, thermal comfort, spatial adaptability, and restorative quality as interdependent properties of a whole environment rather than isolated problems to be solved separately (Pedersen Zari 2018; Pawlyn 2011). It is here that biomimicry (or biomimetic design) offers a distinctive contribution.

Biomimicry refers to design that emulates the functional processes and systemic relationships of natural systems, not merely their visual forms (Benyus 1997; Vincent et al. 2006). Pedersen Zari (2018) proposes a hierarchical model of biomimetic application operating at three levels: form (the emulation of natural structures and materials), process (the emulation of natural functions such as thermoregulation, sound attenuation, and light distribution), and ecosystem (the emulation of systemic, adaptive, and self-regulating relationships among components). This conceptual architecture distinguishes biomimicry from biophilic design, which foregrounds sensory and experiential contact with nature (Browning, Ryan, and Clancy 2014; Kellert et al. 2008), and from ABW, which foregrounds spatial reconfiguration. This paper uses 'biomimicry' and 'biomimetic design' consistently to refer to design that emulates natural processes and systems, not merely natural forms. Where biophilic design is discussed, this distinction is maintained.

Academic workspaces have received comparatively minimal direct attention in the built environment literature. Most empirical work on workplace design focuses on generic commercial or open-plan office settings (Kim and de Dear 2013; Bernstein and Turban 2018), and studies of educational environments typically examine learning spaces such as lecture theatres, studios, and libraries rather than the offices occupied by academic staff (Heerwagen 2000). The academic workspace thus represents a distinct and underexplored typology, one in which the demands of solitary research, student-facing interaction, and confidential professional exchange create spatial and environmental requirements that generic office design models poorly serve.

This paper addresses that gap, guided by two research questions: (1) What are the primary spatial and environmental challenges experienced by UK academic staff in their office environments? (2) How can biomimetic design principles be systematically mapped onto these empirically identified challenges to inform future workspace redesign? The paper makes its primary contribution through a Biomimetic Design Translation Framework (Table 3), an empirically grounded instrument that links user-identified needs to nature-inspired design strategies across Pedersen Zari's (2018) three levels of biomimetic application. This framework constitutes the evidential and conceptual foundation for subsequent design framework and guideline development, and for institutional efforts to distribute the conditions for dignified, restorative work more equitably across academic roles and spaces.

The paper proceeds as follows: Background establishes the theoretical context; Methodology describes the research design and framework development process; Findings presents the five thematic patterns; Discussion presents the framework, situates findings in the literature, and appraises the study; and the Conclusion summarises contributions, limitations, and future directions.

Background

The relationship between built environments and human well-being has been theorised through complementary frameworks: Ulrich's (1983) stress recovery theory and Kaplan and Kaplan's (1989) attention restoration theory, which together hold that natural environments support psychological and physiological recovery from cognitive and emotional stress. These frameworks underpin biophilic design interventions and the demand for natural elements

consistently reported in workplace studies (Browning et al. 2014; Kellert et al. 2008).

Empirical research on open-plan offices documents persistent trade-offs between collaborative affordances and the cognitive and privacy costs of shared space (Kim and de Dear 2013). Bernstein and Turban (2018) found open office configurations reduced face-to-face interaction while increasing digital communication, complicating the institutional rationale for open-plan academic workspaces. Appel-Meulenbroek et al. (2011) show activity-based working can mitigate some of these costs, though effective implementation requires genuine user involvement (Sanders and Stappers 2008).

Within biomimetic design scholarship, Pawlyn (2011) and Pedersen Zari (2018) established the theoretical architecture for applying natural system principles to buildings at multiple scales. Pedersen Zari's three-level model of form, process, and ecosystem provides the framework against which this paper's findings are mapped. Prior applications have concentrated on building skins, ventilation systems, and urban-scale ecology, with interior workspace design in educational settings remaining unexplored — the gap this study occupies.

The application of biomimetic principles to interior design specifically is an emerging area. Kellert et al. (2008) and Browning et al. (2014) provide extensive biophilic interior frameworks addressing sensory responses to natural stimuli, distinct from biomimetic application's focus on functional emulation. More directly relevant are Gruber (2011), who treats biomimetics as a design methodology grounded in biological principles, and Hwang, Kim, and Kim (2017), who demonstrate biomimetic surface strategies for interior acoustic and thermal performance; Pedersen Zari (2012) applies the ecosystem-

services model to buildings as a whole. Applications to date include honeycomb-patterned partitions for acoustic attenuation (Vincent et al. 2006), termite-inspired passive ventilation (Turner and Soar 2008), and canopy-inspired ceiling panels (Pawlyn 2011), confirming technical feasibility at the interior scale though systematic application to academic workspaces remains underexplored.

The distinction between biomimicry and biophilic design matters for practice. Biophilic design, per Kellert et al. (2008) and Browning et al.'s (2014) fourteen patterns, addresses psychological and sensory responses to natural stimuli, whereas biomimicry addresses functional performance by emulating how natural systems solve problems such as thermoregulation and structural adaptation. The two overlap in practice: a living wall is simultaneously biophilic, offering sensory contact with nature, and biomimetic, contributing to evapotranspiration cooling. This study argues that academic workspace design requires both dimensions, though the process and ecosystem levels of biomimetic application, currently underrepresented in workspace practice, are particularly well suited to its functional complexity.

Methodology

This study adopted a qualitative, interpretive research design appropriate to its focus on the situated, subjective experiences of academic staff with their office environments. Qualitative approaches are suited to investigations that seek depth of understanding over breadth, and to contexts where phenomena of interest are embedded in lived practice and institutional culture (Creswell 2013; Mason 2002). An interpretivist epistemological stance was adopted, acknowledging that participants' accounts of their workspaces are

shaped by disciplinary norms, professional identities, and personal experiences of the built environment factors that are analytically significant rather than sources of bias to be controlled.

Interview Design and Conduct

Data were collected through semi-structured interviews, a format that enables systematic coverage of predetermined topics while preserving flexibility to probe emergent lines of inquiry (Gray 2014). The interview guide addressed five thematic areas: (1) spatial configuration and privacy; (2) environmental quality, including lighting, ventilation, and acoustics; (3) the integration of natural elements and biomimetic features; (4) flexibility and personalisation of the workspace; and (5) sustainability and institutional responsibility in design decisions. The full interview guide is included as Appendix A.

Interviews were conducted in 2025, either face-to-face in office or meeting room settings at participants' institutions, or via Microsoft Teams, according to participant preference. All sessions were audio-recorded with informed written consent and subsequently transcribed verbatim by the lead researcher.

Participant Recruitment and Sample

Thirty academic staff members were recruited across six departments, Design, Business, Arts and Humanities, Engineering, Law, and Psychology from multiple UK universities. Purposive sampling was used to achieve disciplinary diversity; initial contacts were established by direct email, and a small number of additional participants were recruited through professional referrals. Five participants per department provided sufficient within-department depth while enabling structured cross-departmental comparison.

Table 1 summarises participants by title, expertise area, and recruitment method.

A sample of thirty is consistent with established thematic saturation benchmarks in qualitative interview research (Guest, Bunce, and Johnson 2006; Braun and Clarke 2021). Saturation was assessed iteratively: analytical memos documented when new interviews ceased to generate substantively new codes. Ethical approval for the study was granted by Brunel University of London ethics committee (Ref. 4631-A-Mar/2025-53976-1). Participation was voluntary, participants provided informed written consent, and all data were anonymised using alphanumeric codes (AS1–AS30). Recordings and transcripts were stored securely in compliance with institutional data protection requirements.

Reflexive Thematic Analysis

Interview transcripts were analysed using reflexive thematic analysis (Braun and Clarke 2006, 2019), a method that treats themes as actively constructed by the researcher through systematic engagement with data, rather than as pre-existing entities to be discovered. Analysis proceeded through six stages: familiarisation with data through repeated reading and note-taking; generation of initial codes across the full dataset; construction of candidate themes; review and refinement of themes against the coded data and the dataset as a whole; definition and naming of themes; and write-up (Braun and Clarke 2006). Figure 1 presents the analysis process schematically.

Initial coding generated codes relating to spatial conditions, environmental factors, institutional structures, and individual coping strategies. Codes were iteratively clustered and refined into five

overarching themes (see Figure 2 for a sample theme identification diagram). The final five themes were selected because they represented the broadest and most conceptually distinct patterns across the dataset, each encompassing several related codes while remaining sufficiently distinct from one another. Together, they captured the principal spatial and environmental challenges described consistently across participants and provided the analytical foundation for the subsequent interpretation and development of the Biomimetic Design Translation Framework. Reflexive memos were maintained throughout analysis to record interpretive decisions and interrogate potential researcher assumptions. These trustworthiness strategies, such as multiple-coder checking, an audit trail, and a reflexive memo, are aligned with established criteria for rigour in qualitative research (Lincoln and Guba 1985; Liamputtong 2011). Table 2 provides a sample coding example illustrating the pathway from raw data to theme.

Following the completion of thematic analysis, the five themes were used as the empirical foundation for developing the Biomimetic Design Translation Framework presented in the Discussion section. The framework development process involved three steps. First, each empirically derived theme was translated into a corresponding user need or design challenge, drawing directly on the coded data and participants' own articulations of their workspace problems. Second, relevant biomimetic design precedents were identified from the existing literature, selecting strategies with documented evidence of addressing the specific functional problems — acoustic attenuation, thermal regulation, daylight distribution, adaptive zoning — identified within each theme. This selection was guided by Pedersen Zari's (2018) three-level taxonomy (form, process, ecosystem), and

prioritised process- and ecosystem-level strategies on the basis that these address functional complexity more substantively than form-level referencing alone. Third, each pairing of user need and biomimetic strategy was evaluated for conceptual coherence and cross-referenced against the interview data to ensure that the strategy was responsive to the specific conditions participants described. The resulting framework is an interpretive instrument grounded in empirical evidence and biomimetic theory, not validated by an expert panel or post-occupancy evaluation, and presented as a staging document for subsequent applied research rather than a prescriptive design guide.

Table 1. Academic staff interviewed (n = 30).

ID	Title	Expertise Area	Recruitment
Design Department			
AS 1	**Professor**	**Engineering, product design**	**Direct email**
AS 2	**Reader**	**Design strategy, management**	**Direct email**
AS 3	**Professor**	**Design, branding**	**Direct email**
AS 4	**Senior Lecturer**	**Engineering, sustainability**	**Direct email**
AS 5	**Senior Lecturer**	**Product design**	**Direct email**
Business Department			
AS 6	**Senior Lecturer**	**Management**	**Referral (AS 11)**

AS 7	**Honorary Senior Lecturer**	**Finance strategy**	**Direct email**
AS 8	**Senior Lecturer**	**Marketing**	**Direct email**
AS 9	**Senior Lecturer**	**Strategic management**	**Direct email**
AS 10	**Senior Lecturer**	**Business communications**	**Direct email**
Arts & Humanities Department			
AS 11	**Reader**	**Education**	**Direct email**
AS 12	**Senior Lecturer**	**Creative computing**	**Direct email**
AS 13	**Research Development Advisor**	**Education**	**Referral (AS 11)**
AS 14	**Senior Lecturer**	**Education, leadership**	**Referral (AS 6)**
AS 15	**Teaching Fellow**	**Social sciences**	**Referral (AS 13)**
Engineering Department			
AS 16	**Senior Lecturer**	**Space science instrumentation**	**Direct email**
AS 17	**Reader**	**Sustainable construction**	**Direct email**
AS 18	**Lecturer**	**Additive manufacturing**	**Direct email**
AS 19	**Professor**	**Geotechnical engineering**	**Direct email**
AS 20	**Reader**	**Civil engineering**	**Referral (AS 19)**
Law Department			

AS 21	**Senior Lecturer**	**Commercial law**	**Direct email**
AS 22	**Lecturer**	**Private law**	**Direct email**
AS 23	**Assistant Professor**	**Corporate law**	**Referral (AS 21)**
AS 24	**Teaching Fellow**	**Intellectual property law**	**Direct email**
AS 25	**Lecturer**	**Commercial law**	**Direct email**
Psychology Department			
AS 26	**Senior Lecturer**	**Psychology, cultural identity**	**Direct email**
AS 27	**Senior Lecturer**	**Psychology**	**Direct email**
AS 28	**Assistant Professor**	**Relationships**	**Direct email**
AS 29	**Reader**	**Child health**	**Direct email**
AS 30	**Lecturer**	**Health, behaviour**	**Referral (AS 27)**

Table 2. Sample coding excerpt illustrating pathway from data to theme.

Data Extract (representative)	Initial Code	Subtheme	Theme
'I can hear everything through these walls — it completely destroys concentrated work' [AS16]	**Noise intrusion from adjacent spaces**	**Inadequate sound insulation**	**Lack of acoustic privacy**

'There is no way to open a window … by mid-afternoon my concentration falls off a cliff' [AS4]	Sealed building / no ventilation control	Poor air quality, thermal autonomy	Environmental discomfort
'I'm doing five different types of work in a day, but the space doesn't support any of them' [AS11]	Fixed layout incompatible with work variety	Spatial rigidity, functional undifferentiation	Spatial inflexibility
'We're not allowed to move the furniture without filling in a form' [AS21]	Institutional restriction on workspace adaptation	Limited agency, lack of ownership	Limited personal control
'After a few hours with no windows, no plants, nothing — it feels suffocating' [AS26]	Sterile environment, absence of nature cues	Ecological disconnection, sensory depletion	Absence of natural elements

Findings

The thematic analysis identified five cross-cutting themes that recurred across all six disciplinary groups. While disciplinary emphases varied, these five themes constituted a consistent pattern of concern across the dataset. Each theme is presented below with representative participant quotations. Quotations are selected to illustrate thematic patterns across departments and are identified by participant code and department; they are representative of broader patterns within each theme rather than exceptional cases.

Participants occupied a range of office configurations. Approximately half described working in nominally private single or shared offices

(occupied by two to four staff), while the remainder worked in open-plan or semi-open arrangements, including shared departmental suites and hot-desking environments. Several participants occupied hybrid spaces — rooms formally designated as private offices but separated from adjacent areas by thin partition walls or shared doors offering limited acoustic separation. This variety of setting types is relevant to interpretation: while acoustic privacy and lack of control emerged as cross-cutting concerns, their precise character varied with the degree of enclosure. Where office type is especially salient to a theme, it is noted in the analysis below.

Theme 1: Lack of Acoustic Privacy

Acoustic privacy emerged as the most pervasive barrier to productivity. Participants across all departments described disruption from neighbouring conversations, corridor traffic, and digital meetings conducted in proximity to focused work. Even academics occupying nominally private offices reported that inadequate sound insulation permitted intrusive noise from adjacent rooms.

> ***'The problem is that I can hear everything through these walls — phone calls, meetings, even individual conversations. It completely destroys any attempt at concentrated work. [AS16, Engineering]'***

The challenge was particularly acute for activities requiring confidentiality such as student advising, marking, peer review, which are central to academic professional practice. Multiple participants described displacing productive work to libraries and cafés as a direct response to unmanageable office acoustics, a pattern consistent with Kim and de Dear's (2013) finding that the privacy costs of open-plan

offices frequently outweigh their collaborative benefits, and with Bernstein and Turban's (2018) evidence that open workspaces may paradoxically reduce genuine interaction.

> ***'I've given up trying to have private conversations in my office. I take my laptop to a coffee shop when I need to actually think. [AS8, Business]'***

Theme 2: Environmental Discomfort and Sensory Stress

Environmental discomfort, encompassing lighting quality, thermal regulation, air quality, and ventilation was raised across all departments. Central concerns included over-reliance on artificial lighting, inability to access fresh air in sealed buildings, and the unresponsiveness of centralised HVAC systems to individual and seasonal variation.

> ***'The air in here is genuinely stagnant for most of the day. There's no way to open a window, the ventilation system makes a constant noise, and by mid-afternoon my concentration just falls off a cliff. [AS4, Design]'***

Limited access to natural daylight was framed consistently as a physiological and psychological concern. This aligns with established evidence linking daylight exposure to circadian regulation, mood, and cognitive performance (Heerwagen 2000; Allen et al. 2016). Psychology faculty were particularly articulate about the cognitive implications of artificial lighting, while several Engineering and Design participants described deliberately positioning workstations to maximise window access, a behavioural adaptation that underscores both the perceived importance of daylight and the inadequacy of current spatial provision.

Theme 3: Spatial Inflexibility and Physical Strain

Spatial inflexibility emerged as a structural barrier to the diverse, rapidly shifting character of academic work. Participants described existing layouts as fixed and functionally undifferentiated, unable to support transitions between solitary research, collaborative work, student advising, and administrative tasks within a single working day.

> ***'My office is set up for one thing — sitting at a desk in front of a screen. But in reality, I'm doing five completely different types of work in a day, and the space just doesn't support any of the others. [AS11, Arts and Humanities]'***

Ergonomic inadequacy compounded spatial inflexibility. Participants described furniture as outdated and insufficiently adjustable. Arts and Humanities academics reported that ergonomic equipment required formal medical justification placing the burden of provision on individuals rather than reflecting an institutional baseline. A shared aspiration across departments was for modular or reconfigurable arrangements: moveable seating, acoustically separable zones, and small-group breakout areas that would support multiple work modes without requiring staff to leave the building. This desire maps closely onto the activity-based working principles documented by Appel-Meulenbroek et al. (2011), suggesting that participants had intuited ABW logic from lived experience rather than from design knowledge.

Theme 4: Limited Personal Control and Customisation

A persistent thread across interviews was the desire for greater autonomy over workplace conditions. Participants described minimal ability to adjust lighting, temperature, or acoustic environments, and

faced institutional restrictions on personalising offices through plants, artwork, or furniture rearrangement.

> ***'We're not even allowed to move the furniture without filling in a form. It feels infantilising — as if we can't be trusted to know what we need to work effectively. [AS21, Law]'***

This limited agency carried both practical and symbolic weight. Practically, it forced informal workarounds personal fans, headphones, remote working, which are disruptive or sub-optimal. Symbolically, it communicated institutional indifference to staff well-being. Elsbach and Pratt (2007) document that workspace personalisation, what they term 'workspace marking' functions as a mechanism for asserting professional identity and managing cognitive boundaries. Institutional restrictions on this marking may therefore carry costs beyond physical comfort, undermining the sense of ownership and professional recognition that sustains motivated academic engagement.

Theme 5: Absence of Natural and Restorative Elements

Participants across all departments associated natural elements, plants, natural materials, outdoor views, and organic textures with psychological restoration, reduced stress, and enhanced creativity. Their absence was linked to perceptions of environmental sterility and cognitive depletion. This finding is consistent with stress recovery theory (Ulrich 1983) and attention restoration theory (Kaplan and Kaplan 1989), both of which predict that contact with natural environments supports recovery from cognitively demanding work.

> ***'Even just looking outside at trees makes a difference to how I feel. When I'm in a room with no windows, no plants, nothing — after a few hours it just feels oppressive. [AS26, Psychology]'***

Crucially, participants drew a consistent distinction between authentic and cosmetic nature integration. Graphic wallpaper, artificial plants, and nature-themed imagery were dismissed as inadequate, a finding with direct implications for design practice. The operative mechanism is not visual representation per se but functional or experiential contact with genuine ecological qualities: living organisms, dynamic daylight, natural material variation, and outdoor connection. This distinction reinforces the argument that process- and ecosystem-level biomimetic strategies, rather than form-level nature referencing, are required to deliver the environmental qualities participants found credible and restorative (Pedersen Zari 2018).

The absence of informal or restorative zones within academic buildings was a closely related concern. Without designated areas for reflective breaks, creative conversation, or cognitive recovery, staff displaced these activities externally, to cafés and green spaces, reinforcing uninterrupted work cultures that are incompatible with sustained intellectual performance.

Cross-Departmental Comparison

Table 3 provides a structured cross-departmental comparison of thematic emphasis. While all five themes recurred across disciplines, their relative salience varied in ways that reflect disciplinary work cultures and workspace types. Engineering academics placed highest

emphasis on acoustic privacy and environmental control, consistent with the sustained, solitary concentration that research-intensive scientific work demands. Psychology faculty foregrounded environmental discomfort and the absence of natural elements, reflecting their professional engagement with the links between environment and mental health. Design academics emphasised aesthetic quality and creative stimulation. Business faculty prioritised confidentiality and task efficiency. Arts and Humanities academics focused on sensory authenticity and emotional comfort. Law faculty expressed the strongest frustration with limited personal control, unsurprising given the confidential nature of much legal academic work and the associated demand for private, controllable space. These disciplinary variations do not undermine the cross-cutting nature of the five themes; rather, they indicate that the same structural failures manifest differently depending on the work demands of each discipline.

Table 3. Cross-departmental thematic salience.

Theme	Design	Business	Arts & Hum.	Engineering	Law	Psych
Acoustic privacy	High	High	High	Very high	High	High
Environmental discomfort	High	High	High	High	Moderate	Very h
Spatial inflexibility	High	High	High	High	High	High
Limited personal control	High	High	Moderate	Moderate	Very high	High

Absence of natural / restorative elements	**High**	**Moderate**	**High**	**Moderate**	**Moderate**	**Very h**
Disciplinary emphasis	**Creative stimulation, aesthetic quality**	**Confidentiality, task efficiency**	**Sensory authenticity, emotional comfort**	**Focus, thermal control, autonomy**	**Personal agency, private space**	**Psycho regula multi- senson design**
Note: Salience ratings reflect the frequency and intensity of theme expression within each departmental g assessed through coded transcript data. 'High' indicates the theme appeared in most interviews wi department and was articulated with consistent concern. 'Very high' indicates the theme was the most pr cross-cutting concern within that departmental group, appearing in all interviews and frequently foregrou participants as the primary barrier to well-being or productivity. 'Moderate' indicates the theme was pres less frequently or less emphatically expressed. Ratings are interpretive summaries derived from coded tr data and cross-checked by a second coder; they are not quantitative frequency counts.						

Discussion

Biomimetic Design Translation Framework

The five empirical themes provide the evidential basis for the Biomimetic Design Translation Framework presented in Table 4, the paper's primary contribution: a diagnostic instrument mapping user-identified needs to nature-inspired design strategies, organised by

Pedersen Zari's (2018) three levels of biomimetic application (form, process, ecosystem).

Collectively, these five empirical themes demonstrate that the quality of academic workspaces is determined primarily not by individual preferences or behaviours but by institutional decisions regarding space allocation, environmental provision, and workplace management, supporting the interpretation of workspace design as a matter of institutional responsibility and equity.

The framework functions as a conceptual staging instrument rather than a prescriptive design guide: a structured, contestable starting point that makes explicit which biomimetic strategies are plausibly suited to which user needs, and at which level of the Pedersen Zari hierarchy each operates. This distinguishes evidence-based design implication from speculative prescription (Heerwagen 2000); questions of implementation, feasibility, cost, and contextual fit are left to subsequent applied research.

Strategies operating at the process and ecosystem levels are prioritised because they address the functional complexity of academic work — thermoregulation, acoustic performance, spatial adaptability, user control — more substantively than form-level nature referencing, which addresses sensory experience but not function. Participatory design processes appear at the ecosystem level because staff desired co-production of their workspaces, connecting to the established co-design literature (Sanders and Stappers 2008).

Table 4. Biomimetic Design Translation Framework: empirically grounded mapping of user needs to nature-inspired design strategies.

User Need / Challenge	Biomimicry Level (Pedersen Zari 2018)	Biomimetic Design Strategy	Intended Impact and Supporting Evidence
Acoustic disruption and lack of privacy	Form / Process	Honeycomb-inspired partition structures; dense natural-fibre acoustic panels; acoustic moss walls [illustrative, not exhaustive]	Attenuates auditory distraction; supports confidential work and sustained cognitive focus
Spatial inflexibility and fixed layouts	Ecosystem	Modular zones inspired by branching network growth patterns (coral, mycelium); reconfigurable microhabitat clusters (Pedersen Zari 2018)	Enables diverse work modes; increases user autonomy; reduces spatial fragmentation
Poor ventilation and thermal discomfort	Process	Passive ventilation modelled on termite mound convection (Turner and Soar 2008); evapotranspiration cooling via planted walls	Improves air quality; reduces reliance on mechanical systems; enhances thermal comfort
Inadequate natural daylight	Form / Process	Canopy-inspired ceiling diffusion panels; light-shelf systems drawing	Supports circadian regulation

		on leaf canopy geometry (Pawlyn 2011)	(Heerwagen 2000); reduces eye strain; improves mood and energy
Limited user control over environment	Ecosystem	Responsive climate zones modelled on self-regulating ecosystems; user-controlled adaptive shading (Pedersen Zari 2018)	Empowers users; accommodates individual variation; reduces stress from environmental helplessness (Elsbach and Pratt 2007)
Absence of natural and restorative elements	Form / Ecosystem	Living green walls; water features; fractal-patterned surfaces; natural material palettes — wood, stone, clay (Kellert et al. 2008; Browning et al. 2014)	Reduces physiological stress (Ulrich 1983); replenishes directed attention (Kaplan and Kaplan 1989); enhances creativity
Non-ergonomic and inflexible furniture	Form	Ergonomic forms derived from skeletal and exoskeletal biomechanics; adjustable structures	Reduces physical discomfort; supports extended working periods;

		modelled on adaptive plant morphology	**improves posture and musculoskeletal health**
Absence of informal and restorative zones	**Ecosystem**	**Spatial zoning modelled on ecological microhabitats (Pedersen Zari 2018); nested areas differentiated by activity type — focus, collaboration, recovery**	**Facilitates cognitive recovery; supports informal interaction; reduces attentional fatigue**
Visual monotony and sensory depletion	**Form**	**Natural material textures; colour palettes derived from natural ecosystem chromatics; dynamic lighting simulating diurnal variation**	**Enhances sensory engagement; creates psychological comfort; counters cognitive fatigue**
Poor adaptability to seasonal change	**Process**	**Climate-responsive shading modelled on hygroscopic plant mechanisms (pinecone, Banksia seedpod); phase-change thermal materials (Vincent et al. 2006)**	**Maintains indoor comfort year-round; reduces energy demand; responds dynamically to external conditions**
Limited staff involvement in design decisions	**Ecosystem**	**Participatory co-design processes conceptualised through**	**Improves spatial relevance; strengthens user**

		ecological mutualism — iterative, mutually adaptive engagement between occupants and design professionals (Sanders and Stappers 2008)	**ownership; translates institutional commitment to staff well-being into design practice**

Note: Biomimetic strategies listed in each row are illustrative examples drawn from the existing literature, not exhaustive inventories of all possible approaches. Precedents were selected based on: (a) documented relevance to the functional need identified in that row (e.g. acoustic attenuation, thermal regulation); (b) explicit grounding in biological principles rather than mere aesthetic reference; and (c) alignment with Pedersen Zari's (2018) taxonomy, with preference given to process- and ecosystem-level strategies where available. Each strategy listed in the Biomimetic Precedent column is primarily biomimetic in character — that is, it operates by emulating a natural function or system — though some strategies (e.g. living green walls, daylighting systems) may simultaneously deliver biophilic benefits through sensory contact with natural stimuli; these overlaps are intentional and reflect the complementary relationship between the two approaches.

Discussion

The convergence of concerns across six disciplines and multiple institutional settings is analytically significant. It suggests that the spatial and environmental challenges documented here are not artefacts of individual preference or departmental characteristics but reflect systemic misalignments between institutional design logic and the functional requirements of academic labour. This finding has implications beyond workspace design: it points to a broader institutional pattern in which standardisation of space, of environmental systems (lighting, heating, ventilation), and of service provision (what is supplied and at what level) is pursued at the expense of responsiveness to the diverse, knowledge-intensive work that universities are designed to support. Understood through a

responsible design lens, this is not solely a design-performance problem but an equity problem: the staff most exposed to substandard acoustic, thermal, and spatial conditions are frequently those with the least institutional power to change them, including early career, part-time, and non-permanent staff sharing peripheral or provisional office space, so standardised provision functions as a matter of institutional fairness as much as efficiency.

The study's findings both confirm and extend existing literature, while also introducing productive tensions into it. The open-plan challenge is well established (Kim and de Dear 2013; Bernstein and Turban 2018), but the present study extends it into a context where the costs of acoustic disruption are professionally and ethically specific, thereby affecting not only individual productivity but the quality and confidentiality of student-facing interactions. Academic staff are not merely knowledge workers; they are also educators, advisors, and examiners whose professional responsibilities require spatial conditions that generic office design models do not routinely provide.

The finding that participants rejected superficial nature simulation while responding positively to authentic ecological integration importantly advances the biophilia literature. Wilson's (1984) biophilia hypothesis and the Kaplan and Kaplan (1989) attention restoration theory predict benefits from nature contact, but they do not specify the degree of ecological authenticity — that is, the extent to which a nature-derived element functions according to genuine ecological principles rather than merely resembling nature in appearance — above which these benefits are reliably activated. This study suggests that this threshold is not trivial: form-level nature referencing (artificial plants, nature imagery) may fail to deliver the restorative benefits associated with genuine ecological engagement.

This has practical implications for how biophilic design is implemented and evaluated and provides an empirical argument for process and ecosystem-level biomimetic strategies over decorative nature referencing.

The theme of limited personal control surfaces a dimension of the workspace problem that remains undertheorized in the design literature. Elsbach and Pratt (2007) establish the significance of workspace marking for professional identity, but the institutional mechanisms that restrict this marking, facilities management protocols, estates procurement structures, and standardised fit-out policies, have not been examined empirically in academic settings. This study provides evidence that these mechanisms are experienced not merely as inconveniences but as institutional signals of indifference. Read through a responsible design lens, the capacity to exercise control over one's immediate working environment is not incidental to well-being but constitutive of dignity at work, and its uneven distribution across staff groups is itself a matter of institutional equity. If participatory design processes (Sanders and Stappers 2008) are to deliver the sense of psychological ownership, the felt sense that one has agency over and investment in a space — that the literature predicts will support well-being and motivated engagement- they must address not only the design brief but the institutional culture that governs ongoing workspace use.

A rigorous assessment of the Biomimetic Design Translation Framework requires acknowledging its limitations. The mapping from empirical need to biomimetic strategy necessarily involves interpretive judgement: the claim that termite mound ventilation logic applies to academic offices, for example, is plausible but not proven. The framework does not establish causal pathways; it proposes

design hypotheses grounded in user evidence and biomimetic precedent. Evaluation of these hypotheses requires post-occupancy studies in which biomimetically redesigned spaces are assessed against the needs identified in this study. Additionally, the framework does not account for the political economy of institutional design decisions: heritage building constraints, capital budget cycles, estates procurement frameworks, and sustainability commitments (such as BREEAM certification) all shape what is achievable, and future work should examine how biomimetic strategies can be pursued within these constraints rather than assumed to be unconstrained choices.

Several limitations of the study must be acknowledged directly. First, the sample is drawn exclusively from UK universities; findings may not transfer to academic workspace cultures in other national contexts, which vary significantly in building stock, institutional cultures, and space standards. Second, the study relies entirely on self-reported data. Participants' accounts of their workspaces reflect perceived experience rather than objectively measured environmental conditions; acoustic levels, thermal performance, and daylight access were not independently measured. Third, participant distribution across departments was structured for disciplinary diversity but not stratified by gender, career stage, institutional type, or building age, variables that may influence workspace experience and that future studies should systematically examine. Fourth, the reflexive thematic analysis, while conducted with multiple-coder checking and an audit trail, reflects interpretive choices that other researchers might make differently; the framework presented in Table 4 is one defensible mapping, not a uniquely correct one.

Conclusion

This study makes three contributions. Empirically, it provides a detailed, cross-disciplinary account of the spatial and environmental challenges experienced by academic staff in UK university offices, grounded in thirty qualitative interviews and organised through rigorous thematic analysis. Conceptually, it advances the distinction between biomimetic design operating at the levels of natural process and ecosystem emulation and surface-level biophilic treatment, arguing that the functional complexity of academic work requires the former. Practically, it proposes the Biomimetic Design Translation Framework, mapping empirically identified user needs onto nature-inspired design strategies as an evidential foundation for subsequent design development.

The findings confirm that the challenges facing academic workspaces are structural: they reflect persistent misalignments between institutional design logic and the demands of academic labour that neither incremental refurbishment nor surface-level greening will resolve. Framed as a matter of responsible design, these are not only questions of comfort and performance but of who within the institution is afforded dignified, restorative working conditions and who is not, making their resolution a question of institutional equity as much as design quality. Addressing them requires both better design and different design processes ones that treat academic staff as co-producers of spatial knowledge rather than passive occupants of standardised environments.

Future research should proceed in three directions. First, post-occupancy evaluation of spaces redesigned according to biomimetic principles measuring acoustic performance, thermal comfort, daylight

access, and self-reported well-being would provide the outcome evidence currently absent from the literature. Second, the framework should be tested and refined through participatory design workshops with academic staff and estates professionals, examining its practical applicability within real institutional constraints. Third, the study should be extended to non-UK contexts and to under-represented staff demographics early career researchers, professional services staff, and those with disability-related workspace requirements to examine the generalisability and equity implications of biomimetic, responsible workspace design.

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The Role of Computer-Based Knowledge Acquisition in Industry-Oriented Collaboration for Responsible Design

Dr Mohammed Elsouril

Abstract

Designing in response to industry-led briefs is a knowledge-intensive learning process that requires students to engage with complex real-world challenges. Brunel Design School frequently collaborates with organisations, businesses, and SMEs worldwide to develop creative briefs that form an integral part of students' learning experiences. The value of this approach lies not only in the generation of innovative design concepts but also in students' ability to accurately interpret industrial requirements and translate them into solutions that effectively address user needs.

This paper examines the implications of a spatial design brief developed through collaboration between three organisations, a globally recognised audio equipment brand, a UK-based high-street retailer and a design agency with the university. The objective was to design an accurate representation of a non-assisted retail sales experience within a 3m × 3m installation footprint.

The brief included more than 200 pages of technical, and visual requirements, supported by over 12x three-dimensional computer-based models to assist students in developing their design solutions.

The project was undertaken by 58 second-year students for their Design Practice module, who are generally enrolled in Industrial Design BA, Design BSc, and Product Design Engineering BSc programmes. Findings demonstrate the effectiveness of 3D computer models in supporting design knowledge acquisition throughout the project, which involved four industry collaboration workshops, ten seminar sessions, and the production of final artefacts through 3D printing, presentation and fabrication-based work over an eight-week period with guidance given around navigating the world of generative AI without compromising critical knowledge building.

The results highlight the importance of computer-based models in industry-led collaborative projects, enabling students to develop authentic, high-quality, and award-winning design solutions through real world design reference points. Furthermore, the study demonstrates how such collaborations can strengthen industry-academia engagement while inspiring and preparing future generations of designers to be more responsible.

Keywords

Knowledge-based Design, Computer Aided Design, Systems Thinking, Experiential Learning

Introduction: The role of collaborative design for multi-disciplinary skill attainment and professional practice

It is well known that academia and industry need to foster and grow collaborative project-based learning together to create a future

prosperous education sector as well as prepare the workforce to transition into real-life experience.

UNESCO now calls for provisions in education that are more holistic, that can envision change and foster transformation through multi-disciplinary collaborations which can be formed outside of formal governance structures as mentioned by Pritchard et al.(2023). More involvement of external organisations is needed to achieve these outcomes, engage the students, staff and communities and better embrace responsible change. This approach, supported by experiential learning pedagogy offers a transformative model of practice, that is able to indicate what real-world learning could do to develop the students' understanding and provide education for a more responsible future.

At Brunel Design School, students on a second year core module were directed to directly get involved with three major UK based companies to address a retail design challenge as part of their module. Its purpose was to fulfil not only the strategic goals of the organisations involved and the university, but also to focus on the experiences shared in the activities involved that develop and grow the skillset of the students and enhance their preparations to face the external world. The school believes that these opportunities can allow them to build up their real life design content for their portfolios going forward.

Underlying this mechanism is the Kolb's cycle where experience, reflection, conceptualisation and experimentation take place within the overall delivery of experiential learning education.

In medical disciplines (Biotech)for example, ELC (experiential learning cycle theory) had been used to cultivate new talent by

facilitating high quality experiences and enable systemic innovation (Zong et al, 2026).Within this context, responsible design education extends beyond the production of functional artefacts and encourages future designers to consider the broader consequences of their decisions.

The challenge briefed the students within the Retail environment not only focuses on the technical innovation behind managing a 3m x 3m spatial design project, but also by considering diverse communities with different abilities, cultural backgrounds and expectations to reflect the wider profiles of shoppers. Preparing students to interpret industry requirements through human-centred, ethical and inclusive perspectives becomes an important aspect of contemporary design practice that delves beyond pure technical requirements. Our approach particularly explores how industry collaboration and computer-based design knowledge acquisition can support students in developing more responsible approaches to designing physical and experiential environments for diversifying scenarios of use and assuming a wider range of abilities from the target audience that defaults to our minds.

In effect, both Kolb's (Kolb, 1984) and the role of computer-based knowledge acquisition (Kugler et al. 2023), enable students to further reach into responsible design arenas, by providing (as educational environments) access to authentic industry data models, and assets, as well as multidisciplinary teaching, mentoring and continuous industry feedback cycles that are more aligned with a truly reflective cycle of the product's development lifecycle. The student's embodiment of their experiences through the design of their final physical and digital prototypes have resulted in professional-quality outcomes and recognition.

Industry-Academia Transformational Processes

The collaborating companies were asked to discuss their early thoughts of the design challenge they want to set. Our team then translated it into first, a formal academic pro forma document that contain the challenge in bite-sized structure, simple enough to be read from a single A4sheet but implicitly containing a potential raft of multi-disciplinary areas and specialisations that the students could get inspired, and encouraged to further develop their interests into subsequent disciplines as seen in figure 1 below.

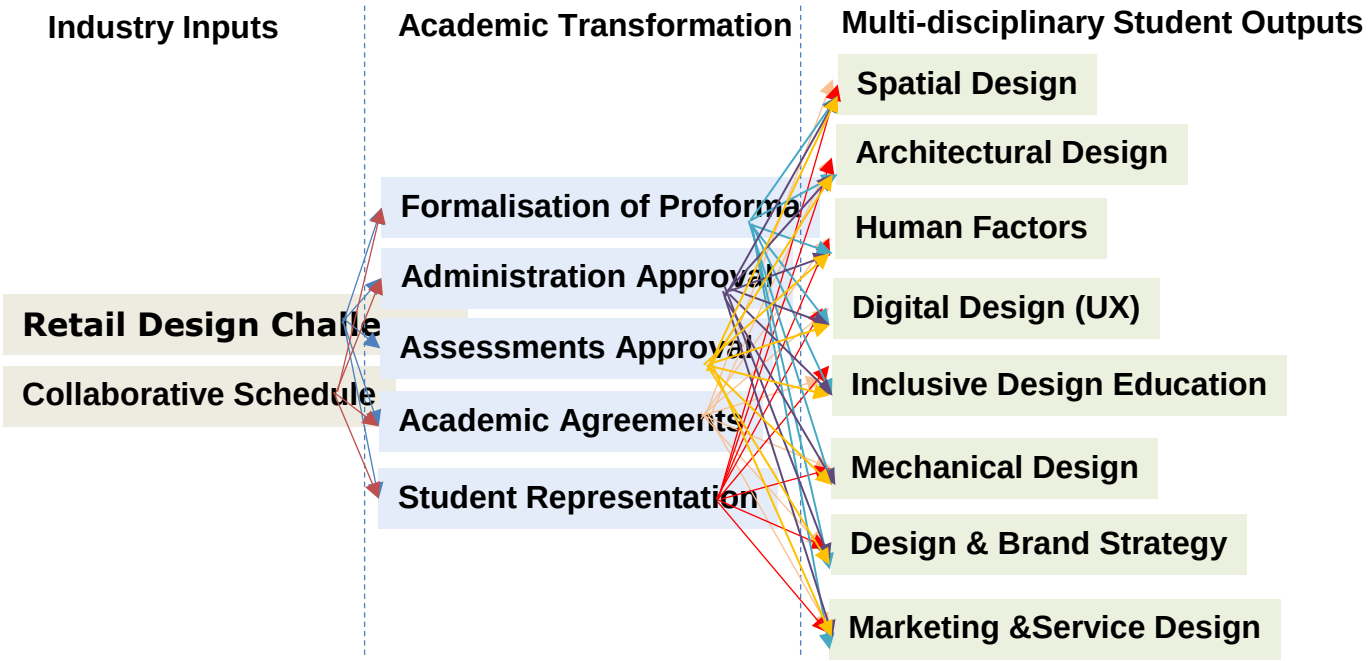


Figure 1 Above. Transformation of Industry inputs through academic collaboration to multi-disciplinary areas for students to develop their skill set.

On the left of the diagram, a timeline with our collaborators (collaborative schedule) is input into our discussions, alongside the challenge. Following on from that, the formalisation of the proforma,

along with approvals from admin, assessment units, and academics and students involved was sought. Carefully designed, eight disciplinary opportunities, defined by certain keywords to enable students to further enquire.

Design, being a universal language is not afraid to deal with new areas of knowledge acquisition (Almeqdad et al, 2023) especially when dealing with diverse learning styles. Having started off with a brief to design a retail space for a audio equipment company to promote their products, the brief itself had undergone a transformative process of elaborating on each keyword within the brief into a whole potential for students to delve into during their experience by creating critiques within these topics within their weekly seminars and workshop sessions.

The common requirement of designing a 3 meter by 3 meter enclosure now translates into a series of enquiry based structures for students to follow through. These structures are used as scaffolds in the practice based learning environment evolving around the classroom seminars and discursive workshop sessions. They can be shown, evolved and further elaborated by following through the questioning prompts used below as conversation starters, and let critical thinking do the rest:

What does it take to fill a space of key brand messaging points?, How can an interesting, exciting and 'loud' space for the brand be created? How the pathways for customers to walk within that space -be created safely, yet capture their attention and enhance their senses?. This kind of questioning allowed students not only to think about the space and furniture, and hardware fixings within it, but also to convey

aesthetic value and visual presence. Using certain examples of brand messeging from around the world also reinfornced these enquiries.

The words‘ safety, attention, senses’ – provided a gate away to explore how design can be used in translating those singular key words into a more richer, wider context delivered through discursive and practice based ideation sessions. Not only allowing students to place careful attention on how the space is used, but how will it also be prevented from misuse, by placing strong emphasis on safe spaces, and injury prevention measures in the way things are placed within the environment.

Other prompts used – How can designing table tops, stands, décor, can be achieved in accordance to the human body size typical within the selected shoppers’ profiles? Can students obtain anthropometric data of human heights to design for reach? What is the minimum distance between to objects within a space to safely move in between and not cause disruption to the flow? How about reaching out into the table tops and trying out the audio equipment? What if a person on wheelchair needs to navigate the space?. This kind of questioning, not only allowed students to step away from the hard technical requirements of the space, but think about how it will be used from human centred perspective. Placing themselves in the shoes of the buyers, shoppers, by passers, and curios shoppers, are there things that can be done to make their experience appeasing, pleasant and intuitive.

From a marketing and brand perspective – other ideas emerged amongst the discussions; How can the characteristics of a population close to the retail store to target be identified? Is it possible to transform linguistic messaging and communications into a better,

more highly visual, impactful symbol of meaning, How is it possible to reduce words and promote other communicative techniques that are more globally understood through design language? Does iconography, associative cultural cues and semiotics have a role in this ? This really allows the student to think about certain shapes, curvatures, points in space and placement of design features in a more meaningful and cohesive manner. Something that strikes the emotional chords of the potential buyers and represented organisations alike within a free for all environment.

Across the eight weeks of delivery, each of these disciplinary areas were prepared for content, probing these questions and passing them out between the cohort, industry collaborators and academics involved – to inspire, question, and very importantly, try to open new areas in the students minds for them to find their motivations and potentially specialise within, upon them raising their independent enquiry.

With this ethos, these questions encouraged the students to move beyond purely visual or commercial considerations and consider more responsible design principles, including accessibility, inclusion and the equitable participation with a more diverse user background in mind within retail environments. Equitable business performance, equitable user needs and how they can be met, equitable decision making across all disciplines typically involved in a spacial design objective.

Predefined Models vs. Abstract Modelling

Computer Based Design Models supplied to them, contained predefined constraints, geometric features, sizing information, colour

material finish, as well as methods of manufacture and assembly; fixtures, fittings, centre of mass, etc) based on 12 audio equipment systems. The CAD itself usually constructed by sequentially adding parametric sketches and applying CAD operations (Rukhovich et al, 2025) were accessible by the students, to understand structure, order, and hierarchy of the audio equipment's physical features. Stored in the SharePoint cloud, students were given access to these product thanks to the industrial collaborators. One of the companies that design this equipment was more than happy for the students to extract key geometric information and accommodate their retail space to promote the sales of these products. That is a key purpose of this challenge. Alluring customers, educating potential buyers, and providing informative points of sales within the space and positioning them appropriately, and effectively is inhibit within the challenge of this brief.

These predesigned assets contained geometric data points for students to access and imprint into their ideas throughout their design process. This method of collective transformative learning, enable students to create new knowledge and practices within an existing system. Coined recently as Expansive Learning studies have shown its benefits and relevance in industry-orentied learning particularly useful within the systems thinking paradigm (Novoa Munoz & Parulekar Prasad Hari, 2025).

On the otherhand, students were given the freedom to navigate and synthesise an open 200 page guideline documents from the collaborators, containing rather less tangible bits of knowledge. Elements that are implicit, that need synthesis and interpretation. Information, related to graphical layouts, tone of voice, brand imagery, visual balance, proportionality, marketing assets, cognition

guidelines and essentially everything related to human appeal, and touchpoints representing meaning. Principles that students could use to guide their conceptual ideas of any sensory touch points they want to create. Understanding brand, layering, and visual management. Much of these interpreted as abstraction points create a less controllable challenge for students. The challenge is to try and make sense of these.

The categorisation shown below, explains how the students were encouraged to explore computer-based model information evolving around tangible CAD assets, and other elements within the resources provided containing abstract knowledge – where extraction, in interpretation is needed by the students and their individual personal background and sensitivities and awareness.

Structured	*Abstract*
CAD Geometry	**Brand Values**
Dimensions	**Emotional Triggers**
Assembly	**Experience Touchpoints**
Materials	**Perception Enhancements**
Manufacture	**Marketing& Promo**
Constraints	**Semiotics, Tone, Storytelling**

Table 1 Above showing structured, predefined models supplied early in the project, vs, abstract, ongoing modelling based on information supplied and student's interpretations.

On the left, structured knowledge accessible through simple analysis of 12 audio equipment models provided. On the right, abstract knowledge requiring students to identify, collate and synthesis personalised versions of what they can interpret - explicit, tacit, geometric, symbolic, experiential and commercial knowledge

purposely under defined for students to free roam and make their own remarks upon.

For example, CAD geometry details are fixed well quantifiable and explicit requirements and specifications that students can simply refer to and reuse. Whereas 'experience touchpoints' for example, are fairly subjective to the perception of the student what they prioritise within the environment. Information in this regards had to be researched, analysed, somewhat made sensible, and decisions about it to be made and justifiable. Likewise, dimensions, assembly, material specs, manufacture specs and hard constraints are there to be used or reused, whereas Brand Values, Emotional Triggers, Perception Support, Tone, Story telling and so on, need to be researched, determined, development, elaborated, and decided on, before having to be justified and made for rationalisation for it to be brought into the attention of the audience or in this case, the organisations involved.

Our Approach to Shared Practices and facilitation of Student-Industry Engagement

Our approach presents a practice-based case study undertaken within a second-year undergraduate product design module at Brunel Design School. Over a period of eight-weeks, several types of activities were facilitated and enabled involving collaboration between Brunel University London and three UK industry partners each bringing in their own perspectives, perceptions, and insights into this brief.

The student cohort represented a diverse multidisciplinary learning environment, comprising students from Industrial Design, User Experience Design and Engineering Design programmes. Each

discipline contributed different forms of knowledge, methods and perspectives, allowing the design challenge to be approached from multiple viewpoints on top of the academic and industrial inputs. This sophisticated relationship between the stakeholders paved way to be more comfortable dealing with systems thinking, same challenge, different viewpoints. Seeing the different students learning journeys was more exciting this way.

This diversity reflected professional design practice, where responsible solutions increasingly require collaboration between individuals with different expertise, experiences and ways of understanding user needs. Concise commercial requirements were systematically expanded into multidisciplinary educational opportunities. Individual statements within each brief were decomposed into interconnected knowledge domains including industrial design, ergonomics, human factors, marketing, branding, responsible design, ethicality, manufacturing, spatial planning, digital interaction and user experience design.

The approach allows everyone involved, including the lecturers, administrators and so on, to treat knowledge without isolation. Forming truly intertwined mental models within a very simple at first design challenge. The negotiations of the wordings, terms, and hypothetical ideas thrown back and forth between the stateholders involved including the students meant that everyone was encouraged to push their thinking beyond disciplinary boundaries and to begin appreciating the variety of the knowledge sources, and diverse communication styles affiliated within certain areas of the discussions. In order to acquire practical knowledge, students had to

make sense of ideas, discussions, and remarks coming their way, all the time.

In addition, the module adopted an experiential learning approach, combining lectures, workshops, design reviews, independent research, iterative prototyping and regular feedback from both academic staff and industry representatives. Students progressively developed concepts through sketching, digital modelling, physical prototyping and presentational activities, allowing continual reflection and refinement throughout the design process. The academic's role faithfully shifted into the facilitator role, optimised to allow and promote students to navigate a more open ended unfamiliar space and prepare to be active within problem based learning experiences.As a result of the practices facilitated above, the students are believed to have acquired knowledge from several different sources to create a more accurate, holistic understanding of the industry brief requirements.

Figure 2 below visually represents this phenomenon. The students' awareness grows, based on the design decisions they have made, and being able to assign the source to the consequencesbeyond aesthetic and commercial success is factored in. Through engagement with the industry constraints, customer experience requirements and accessibility considerations, students were encouraged to recognise the relationship between design choices and user inclusion. This shift from designing objects towards designing experiences represents an important transition towards responsible design practice that is more holistic, and wholesome. Designers should not be afraid to step outside their areas of expertise and attain new skills.

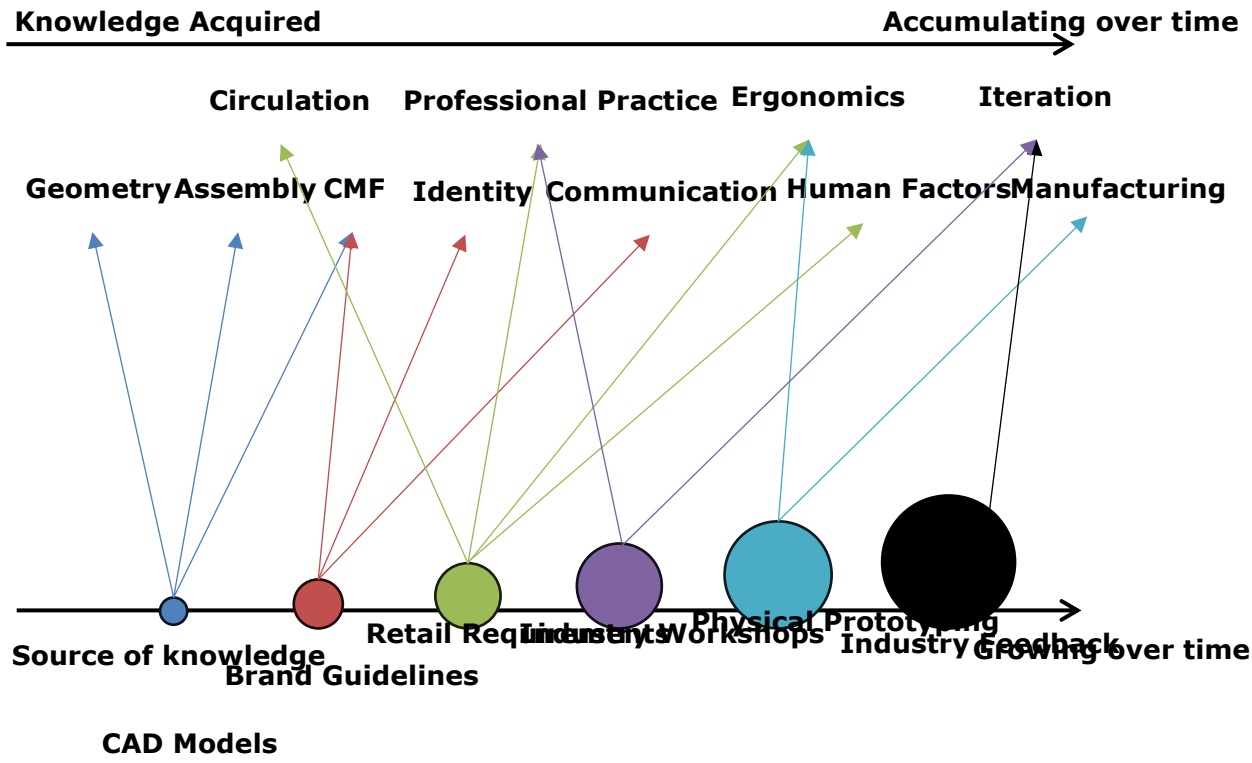


Figure 2 Above showing knowledge acquisition through computer-based design assets obtained from several different sources pointed out to the students as their experience grows over time.

Designers should follow a linear approach in accumulating the knowledge over a period, but also to consider an iterative, cyclic approach, where they may have to go back and update their knowledge to their latest thinking.

Outcomes

At the end of the module, when work was submitted, the difference of this approach harnessed significant results. First, several students were selected to exhibit their work to representatives from the United States educational visit. This was during a university showcase event

where the student's work was identified as 'remarkable'. The opportunity provided students with an opportunity to communicate and justify their design decisions to external audiences 'on the spot' and essentially were the mechanism to enhancing Brunel University's international profile amongst the visitors. Such exhibitions also create opportunities for wider collaboration in the future, demonstrating the value of industry-academic partnerships in supporting institutional reputation, future recruitment activities and external engagement towards are recognisable responsibilities towards a growth strategy.

The module also resulted in external recognition through national design competitions. One project was awarded the regional winner prizeentry, competing against 8 other universities in the UK also tackling a retail design challenge. The project was followed up with an invite to participation in a professional pitching event in Central London where concepts were presented to industry representatives and wider communities of practice from the prestigious world of retail. The experience allowed the student behind the project to further develop professional communication and presentational skill set in addition to engrossing into a more confident entrepreneurial spirit within a commercial environment that is beyond the university setting. As a result of their successful work, a prize award and certificate were also awarded.

In addition to the award itself, some students actively shared the project across professional social media platforms, creating narratives around the design process deployed - through posts, tagging collaborating organisations and engaging with wider design communities the student, university network and academic contacts circle was grown. Enhance the visibility of both individual work and

collaborative university-industry initiatives as alternative to traditional methods for CV job hunting can provide a shortcut to reaching active employers.

The experiential nature of the project also contributed to graduate employability. One student successfully secured a industrial internship with a design organisation located approximately one hour away from Brunel University London. A placement role for 12month was also offered. The work that was produced for this module helped develop the content for their portfolio in which during the recruitment process was viewed. More broadly, the remaining students incorporated the project into their own graduate portfolios, curriculum vitae and employment applications, using the experience to demonstrate their capability in responding to real life industry briefs, working with computer-based design assets (technically competent and managerial operations) and communicating multidisciplinary design thinking to prospective employers.

Altogether, these outcomes demonstrate that industry-oriented collaboration supported by computer-based design resources can extend learning beyond the classroom, providing students with opportunities for external recognition, professional networking, employment and portfolio development.

Equally, the collaborations strengthened relationships between academia and industry, enhancing opportunities for future partnerships while contributing positively to the university's reputation and producing graduates capable of responding confidently to real-world design challenges.

It is also important to note that the case presented in this paper demonstrates how generative AI focused mostly on its use for supporting the human thinking. The core driver behind the project, developing of the solutions, and the knowledge attainment was driven by students. Successful outcomes can be achieved through critical thinking, navigation around the complex requirements of the brief, and at the same timeuse of AI tools can be more useful within enquiry-based learning, questioning and act as more of a clarification seeking tool to support reaching a meaningful and sensible output.

Conclusions

This paper has presented an approach for transforming industry-led design challenges into multidisciplinary experiential learning opportunities within undergraduate design education. By expanding concise commercial briefs into interconnected disciplinary themes, students were encouraged to independently explore technical, human-centred and commercial dimensions of design. The integration of authentic industrial collaboration, iterative prototyping and experiential pedagogy enabled students to develop specialist knowledge and broader professional competencies that they can then take with them to harness success and gain even more recognition within the creative industry.

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Letter from the Chairman's Desk

By Sunil Bhatia PhD

I wrote an editorial some years ago about how light guides our movements and actions. In that article, I explained how the intensity of light influences our bodies and helps us respond to our surroundings.

Scorching sunlight tans our skin as the body responds to prolonged exposure to ultraviolet radiation. Similarly, the eyes adapt to changes in light intensity by adjusting the size of the pupils, regulating the amount of light entering them and helping the retina transmit visual information to the brain. When the intensity of light exceeds our ability to adapt, we may experience temporary visual impairment or even temporary blindness.

Darkness presents a different challenge. When we cannot see, we instinctively extend our hands and move them in different directions to explore the space around us. Through touch, we gather information about nearby objects and transmit it to the brain, which uses these signals to guide our actions. When visual information is unavailable, the brain relies more heavily on other senses to assess the surroundings and help us move safely.

This is comparable to the experience of a blind person who must navigate an unfamiliar environment without relying on sight. Such a person may move cautiously, using a cane, touch, hearing, and other

available information to determine the safest direction. The absence of visual information does not eliminate the brain's ability to guide movement; rather, it increases our dependence on other sensory channels.

The same principle becomes particularly important when driving. When a vehicle approaches at high speed from the opposite direction, its glaring headlights can temporarily impair the other driver's vision, increasing the risk of an accident. One design response is to plant bushes or other suitable vegetation along highway dividers. These can help screen the glare of oncoming headlights and, depending on their density and placement, reduce some traffic noise.

Light can also be deliberately employed to influence human behaviour. In certain law-enforcement situations, powerful lights or multiple reflectors may be directed towards a suspect to impair their vision temporarily and make it difficult for them to assess their surroundings. Such methods raise important questions about safety, proportionality, and the ethical use of technology. Intense light can also be used as a weapon in warfare, where dazzling an opponent may temporarily interfere with their ability to see and respond.

Light has even been used as an instrument of psychological torture. For example, exposing a person to intense light continuously, particularly in dark room, can disrupt sleep and cause severe psychological distress. Sleep is essential for the brain's normal functioning, including memory processing and the regulation of emotions. When adequate rest is denied, a person's ability to think clearly and cope with stress can deteriorate. Such practices demonstrate how the manipulation of the environment can affect the

human mind, but they also raise serious ethical and human-rights concerns.

The plant kingdom, too, depends on light, although not all plants require direct sunlight. Light influences photosynthesis, growth, flowering, and numerous other biological processes. Greenhouses are designed to regulate environmental conditions, including temperature, humidity, and light exposure, to promote healthy and efficient plant growth.

Animals are also influenced by light. Humans have long understood that artificial lighting can alter animal behaviour and have exploited this knowledge for commercial purposes. For instance, poultry farmers sometimes use carefully managed lighting programmes to influence laying patterns in hens. This illustrates how an understanding of biological responses to light can be translated into practical applications, although such practices must also take animal welfare into account.

I have also come across reports of scientific research exploring how light can influence particular brain circuits and potentially assist in understanding or treating certain neurological disorders. If such developments continue to advance, they may offer valuable opportunities for humanity. However, they must be approached with caution. Technologies capable of influencing brain activity should be developed and used responsibly, with safeguards against exploitation, misuse, and the pursuit of selfish or antisocial objectives.

Light is not the only factor that guides our actions. Touch also plays a fundamental role in communication, protection, and human relationships.

Consider an infant touching its mother's breast during feeding. This contact is part of a complex interaction involving the infant's feeding reflexes, the mother's physiological responses, and the hormonal mechanisms that support milk production. Similarly, a touch between two people in love may communicate affection, intimacy, reassurance, or emotional connection. The meaning of touch depends on its location, intensity, context, and the relationship between the people involved.

Touch can also provide emotional support during illness. When a patient in hospital is comforted by someone holding their hand, the gesture may communicate care, concern, and solidarity. Such reassurance can reduce feelings of isolation and anxiety and may contribute positively to the patient's experience of recovery.

Even routine household activities demonstrate how touch guides our actions. When I wash soiled utensils, my hands move across their surfaces under running water until I am satisfied that they are clean. My fingers and palms continually explore the surface, helping me detect residual dirt or grease. Once the utensil feels clean, I put it aside and begin washing another. Touch thus provides feedback that enables the brain to coordinate movement and assess the result of an action.

Surgery presents another interesting example. A patient's muscles may tense in response to anxiety, pain, or other stimuli before anaesthesia takes full effect. Such responses can complicate medical procedures, which is why appropriate anaesthesia and muscle relaxation, when medically indicated, are important. Here, the body's respon ses to sensory information and perceived danger must be carefully managed to enable the surgeon to work safely.

Light also presents a challenge in the operating theatre. The hands and instruments of a surgeon can cast shadows over the area being operated on, obstructing visibility. To address this problem, designers developed surgical lighting systems that use multiple light sources positioned at different angles. When one source is obstructed, light from the others can illuminate the area and reduce the shadow. This is an excellent example of design using the physical properties of light to overcome a practical problem.

Human responses to touch can vary dramatically according to the nature of the object involved. A person who sees someone approaching with a weapon may instinctively retreat to avoid injury. The anticipated consequences of contact trigger a protective response even before physical contact occurs.

Yet other tools are designed to make contact with the body without causing injury. Razors, for example, are intended to cut unwanted hair while minimising damage to the surrounding skin. Hair itself is composed largely of keratin and does not contain the nerve endings responsible for sensing pain. Consequently, cutting the exposed hair shaft does not normally cause pain. Plucking a hair, however, can hurt because the force acts on the hair follicle and surrounding tissues, which contain sensory nerve endings.

A similar distinction applies to nail care. Cutting the free edge of a nail is generally painless because that portion consists of dead, keratinised cells. Pulling or tearing a nail, particularly near its attachment to the skin, can damage living tissue and cause considerable pain.

Our ancestors may not have understood these processes in modern scientific terms, but through experience they learned to distinguish

between actions that achieved a practical objective and those that caused unnecessary suffering. Contemporary designers continue to refine razors, nail clippers, and other personal-care tools to remove unwanted growth efficiently while minimising injury.

These examples reveal a broader principle: successful design requires an understanding of the relationship between an object's physical properties and the human body's responses to it. The designer's challenge is not merely to make a tool perform its function, but to ensure that it does so safely and comfortably.

I would also urge the research community to explore the sense of smell more extensively. Smell contributes to the recognition of familiar people, the perception of the environment, emotional associations, and aspects of social bonding. Olfactory cues may play a role in the interactions between infants and their mothers, including the recognition of familiar maternal odours. Yet much remains to be understood about the ways smell influences human relationships and behaviour. This is an important field of research that may offer further benefits to humanity.

The principles discussed above are not entirely new. Human beings have been learning to use the properties of light, heat, touch, and other natural forces for thousands of years.

The mastery of fire was one of the most consequential achievements in human history. Fire provided warmth, protection, cooking, and illumination. It also presented dangers that demanded careful handling. Early humans had to learn how to ignite, maintain, transport, and control it.

Consider the development of the fire torch. Tinder catches fire readily but burns quickly, whereas a suitably chosen piece of wood can sustain a flame for a longer period once it has ignited. Combining materials with different burning properties would have helped people develop more effective methods of maintaining fire.

A burning branch could provide illumination while allowing a person to move through darkness. But carrying it required an understanding of the relationship between the flame, the direction of the wind, and the position of the hand. If the branch were held carelessly, the wind could blow the flame towards the person carrying it, causing burns. Experience would therefore encourage people to hold the torch at a suitable distance and orientation.

This was design through observation and adaptation. A simple object acquired a useful form because its users learned to accommodate the physical behaviour of fire. The same principle continues to inform the design of tools, machines, protective equipment, and weapons.

Fire also became an instrument of warfare, used to threaten, destroy, and attack opponents. The ability to control it gave humans considerable power over their environment. However, I would hesitate to conclude that mastery of fire alone made humans superior to all other living beings. Rather, the ability to learn from experience, develop techniques, and transmit knowledge across generations helped humanity transform its relationship with nature. Other animals and plants also possess remarkable adaptations, but humans developed distinctive ways of controlling and applying natural forces.

Light has also played a crucial role in the development of modern science. Scientists have used it to investigate matter, reveal

structures invisible to the naked eye, and understand physical processes that would otherwise remain inaccessible.

Ernest Rutherford and other physicists helped transform our understanding of atomic structure through experiments involving the scattering of particles. Although Rutherford's landmark experiments were not simply applications of light, the broader development of atomic physics depended on the study of radiation and the interaction of matter with different forms of energy. X-rays, in particular, became an important medical tool because they can penetrate soft tissues and reveal internal structures, assisting physicians in diagnosis.

The photoelectric effect provides another striking example of the relationship between light and matter. It occurs when light of sufficient frequency strikes a material and causes electrons to be emitted from its surface. In 1905, Albert Einstein explained this phenomenon by proposing that light transfers energy in discrete packets, now called photons. His explanation helped establish the quantum nature of light and earned him the 1921 Nobel Prize in Physics.

The influence of light is also evident in evolutionary adaptations. Different animals have developed different eye structures suited to their environments and ways of life. For example, the horizontally elongated pupils found in many grazing animals can help them maintain a broad view of their surroundings and detect approaching predators. In contrast, vertical slit pupils occur in a number of ambush predators and can assist with particular aspects of judging distance and managing light. These are not universal rules, since eye shape and visual function vary considerably among species.

Human vision has evolved to meet the needs of our own ecological and behavioural circumstances. Such differences remind us that the design of a sensory organ is closely connected to the challenges an organism faces in its environment.

The psychological influence of light has practical implications for architecture and public-space design. A poorly illuminated passage, stairwell, or parking area may make people feel vulnerable, particularly when visibility is limited and they cannot easily assess their surroundings. Good lighting can improve visibility, help users navigate, and contribute to a sense of security.

Designers must therefore recognise that lighting is not merely a decorative feature. It influences how people perceive a place, whether they feel comfortable entering it, and how safely they can move through it. Conversely, deliberately inadequate lighting can discourage people from using a space. Such hostile design choices may exclude vulnerable users instead of addressing the underlying problems of safety and accessibility.

Darkness, however, should not automatically be equated with danger. Natural darkness is essential to many ecological processes, and excessive artificial lighting can disrupt the behaviour of nocturnal animals. The real challenge for designers is to balance human needs for visibility and safety with the environmental value of darkness.

Many animals seek concealment when threatened, using shadows, vegetation, or other features of the environment to avoid detection. Open, brightly illuminated areas may make concealment more difficult. These contrasting responses show how the perception and use of light depend on the particular needs of a living organism.

Light can also cause harm at the cellular level. Historical examples include the occupational disease known as *phossy jaw*, which affected workers exposed to white phosphorus in certain match factories during the nineteenth and early twentieth centuries. The condition was not ordinary bone cancer but a devastating form of phosphorus-related necrosis affecting the jawbone. Workers could develop painful abscesses, severe facial disfigurement, and life-threatening complications. The disease resulted from exposure to a hazardous chemical substance, not simply from the effects of light. The visible glow sometimes associated with phosphorus-related materials should not be confused with the underlying mechanism of the disease.

Campaigns for improved working conditions and the restriction or prohibition of dangerous white phosphorus in match production helped bring attention to this occupational tragedy. Annie Besant was among the social reformers associated with campaigns for workers' rights and better labour conditions. The broader history of industrial reform reminds us that scientific knowledge must be accompanied by social responsibility.

The Mystery of Darkness and the Origins of Life has some connections. Light has contributed enormously to human progress, but darkness continues to provoke philosophical questions. In my observation, darkness has a mysterious character, particularly when we consider the formation and development of life.

Why do so many important biological processes occur beyond the reach of direct light?

Human reproduction begins with the union of a sperm and an egg, followed by a complex sequence of cellular divisions and developmental changes within the mother's body. The developing

embryo grows in an environment protected from direct light. Seeds, too, often germinate beneath the soil, where darkness may provide suitable conditions for particular stages of growth. Some seeds require exposure to light for germination, while others germinate more successfully in darkness. Nature does not follow a single universal rule.

Nevertheless, these examples invite us to consider how life develops through processes that remain hidden from ordinary observation. We see the plant above the ground, but much of its growth depends on roots, soil, moisture, and biological activity that take place out of sight. Similarly, the visible human body conceals numerous processes essential to life.

Science uses light and other methods of observation to investigate these hidden processes, identify causes, and understand effects. Yet every discovery also raises further questions. What remains unknown is not necessarily beyond scientific explanation; it may simply require better instruments, new methods, or a more comprehensive understanding.

One particularly interesting question concerns the brain. Why is the human brain enclosed within the protective structure of the skull and not directly exposed to light? The answer lies primarily in the need to protect this delicate organ from physical injury and maintain a stable internal environment. The brain processes information received through sensory pathways, including visual signals transmitted from the retina. It does not need direct illumination to perform its ordinary functions.

The absence of direct light does not mean that darkness itself gives the brain mysterious powers. Rather, it reminds us that the body has

evolved specialised structures for different functions. The eyes receive light; the retina converts it into electrical signals; and the brain interprets those signals alongside information from other senses. These systems operate together without requiring the brain itself to be illuminated.

Could evolution have produced a brain that directly responds to light? Certain organisms possess light-sensitive structures outside conventional eyes, and biological systems vary widely. But in humans, the established organisation of the visual system demonstrates how specialised structures can perform distinct functions while working in coordination.

There is an old saying that plants are, in some respects, inverted versions of humans: much of a plant's supporting and nutrient-absorbing structure lies beneath the ground, while its leaves and stems extend above it. The comparison is metaphorical rather than anatomical, but it captures an important observation: the parts of living things that remain hidden may be just as essential as those we see.

My central argument is that light, darkness, touch, smell, and other sensory influences shape the relationship between living beings and their surroundings. They guide movement, influence behaviour, help us avoid danger, and offer designers opportunities to improve the tools and environments we create.

Understanding these influences requires both scientific investigation and philosophical reflection. Science helps us explain the mechanisms at work; design enables us to apply that knowledge; and ethical judgement determines whether our applications serve humanity or cause harm.

Light has helped us see the world more clearly, but darkness reminds us that much of life unfolds beyond immediate perception. Perhaps the most valuable lesson is not that one is superior to the other, but that both must be understood if we are to comprehend the complexity of life and our place within it

It is a great honor for us that Brunel University is celebrating 60 years and Prof Gabriella Spinelli Gabriella and Prof Arthi Manohar of Design Department has accepted our invitation of Guest Editor for publishing special issue with us.

We are happy to be part of their celebration and they contributed truly an international publication.

Enjoy reading.

With Regards,

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Forthcoming Issues

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Sustainable Design, Participatory Design, Social Design, Responsive Built Environment, System Thinking, Design Thinking Applications

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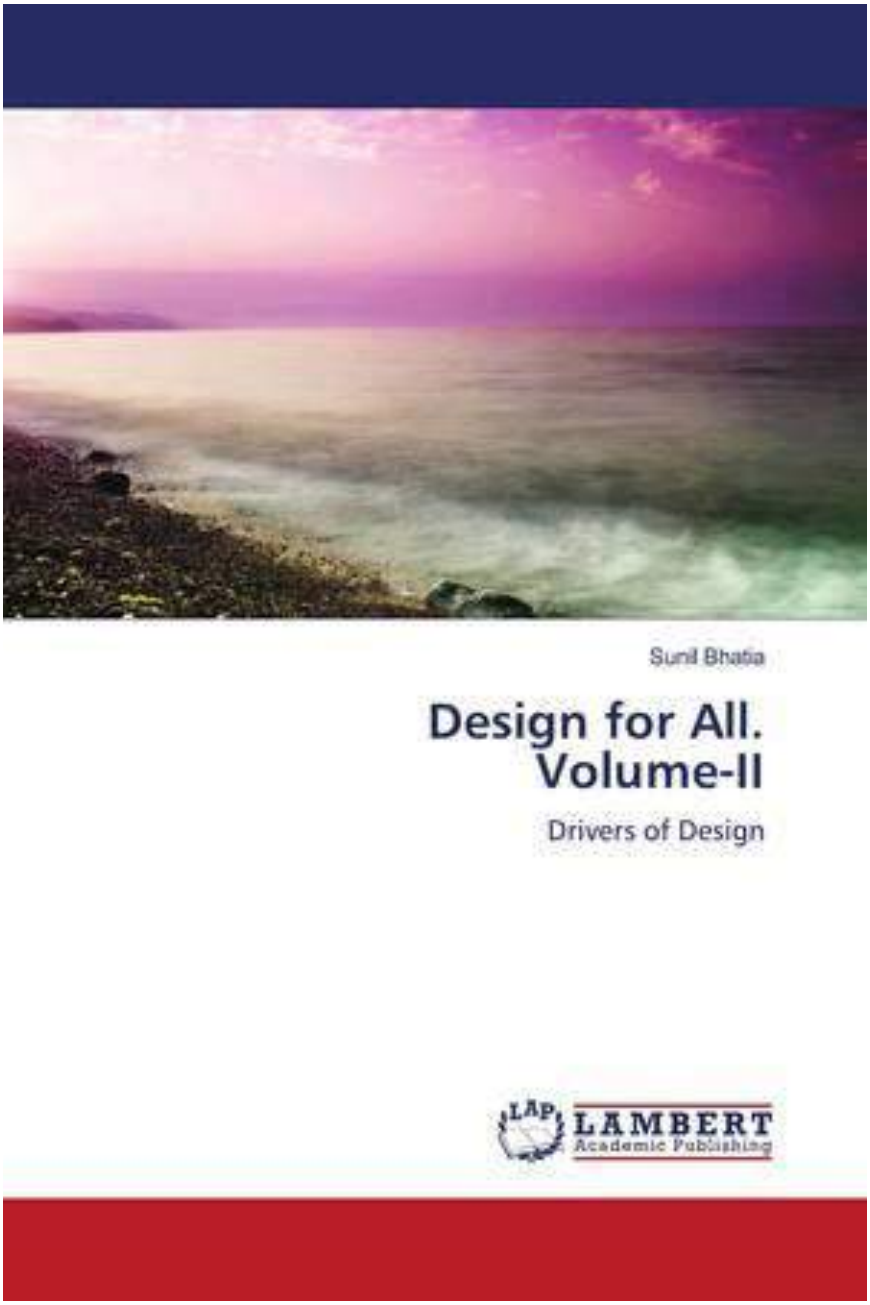
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SDG 12 (Responsible Consumption and Production) through her role at the Department of Design

SDG 11 (Sustainable Cities and Communities) through her role at the School of Interdisciplinary Studies and Sustainability.

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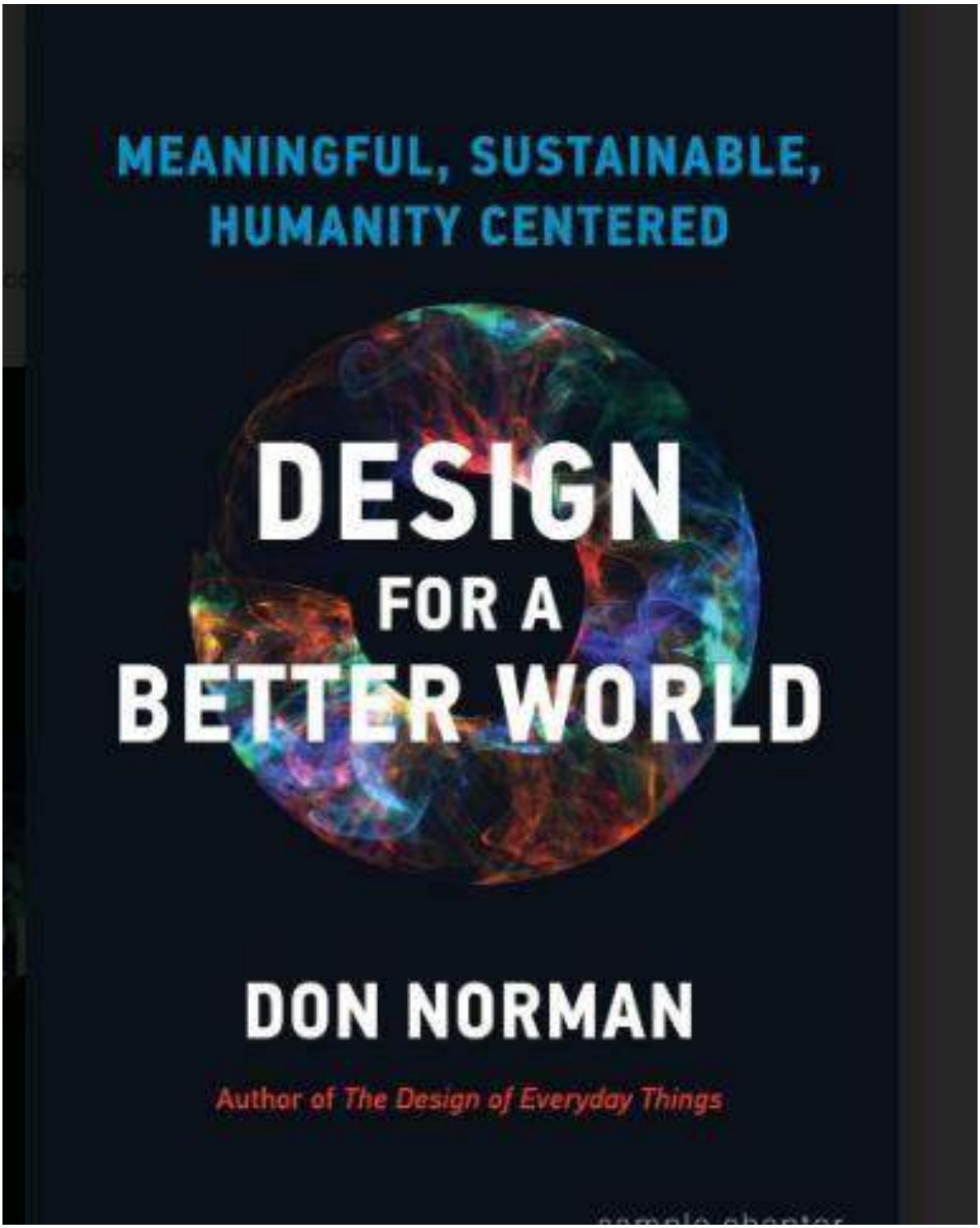


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News

1. A Comprehensive Scientific Report and Call for International Cooperation in Education from Kindergarten Through University

Muayad Al-Samaraee

A Call for International Cooperation

We invite the global education community—from kindergarten through university—to cooperate in developing, testing, and governing this framework. Specifically, we call for an international union that includes teachers, researchers, policymakers, industry, families, and students. We call for pilot programs in multiple countries and contexts. We call for open standards for blocks, data, artificial intelligence, and safety. We call for teacher training and open educational resources. We call for independent review of all structural, seismic, climatic, lunar, artificial intelligence, and security claims. We call for inclusion as a foundational design principle, not an afterthought. We call for open publication of results, including negative results. We call for equitable access so that no learner is excluded because of cost, disability, language, or geography. The goal is not to replace existing STEM education. The goal is to add a coherent, inclusive, and scalable pathway from the first block to the lungs of the planet.

Introduction: The New Landmarks

The child who acquires all this knowledge will not fear the impossible. She will reject the worship of the impossible. She will see it as a larger version of what she can already do—and a responsibility to do it safely, justly, and with care. She will hesitate, but not because she lacks courage. She will hesitate because she has learned that building is a promise to the people who will live inside the result. If society as a whole becomes capable, the Great Pyramid and the Great Wall of China will cease to be terrifying miracles. They will become historical engineering projects—impressive, cautionary, and no longer beyond the limits of human understanding. The new landmarks may not be pyramids at all. They may be houses that do not fall, shelters that protect, and a world that ordinary people can build together.

The Ionian Pyramid may become one expression of this maturity—if it is tested, reviewed, approved, and shared. The 28-letter language may become one way to teach it. The savant syndrome innovation may become one way to involve everyone. Patents may protect the design. But independent verification, engineering review, and ethical oversight alone can prove safety and performance. This is not legal advice. All performance claims require independent verification before implementation. But with safety, testing, education, and support, confidence can turn into skill, and a skill shared by a family, a neighborhood, and a city is how ordinary people build extraordinary things. The built world is not a closed door. It is something learners can understand, question, and improve. And the language of dialogue is not a substitute for the human being, but a bridge to him.

Abstract

This report proposes a comprehensive framework for STEM education that integrates hands-on building, a formal pattern language, artificial

intelligence, inclusive communication, and problem-solving through grand challenges. The framework is built around the SAMANSIC dual-scale building platform, protected by US utility patents on corner blocks and interlocking cross blocks, and the 7-4-28 pattern language. The central hypothesis is that when learners engage with the same geometry of blocks at toy scale and at real construction scale, they acquire transferable knowledge in structural engineering, mathematics, spatial reasoning, process sequencing, and social communication. Artificial intelligence can read block arrangements as data, translate them into natural language, and support learners with diverse communicative needs. This report presents the theoretical foundations, the block system, the 7-4-28 language, a systematic progression from early childhood to university, and a proposed grand challenge—the Ionian Pyramid—as a testable case study. It then sets out a research agenda, ethical safeguards, and a call for global cooperation among teachers, researchers, policymakers, industry, families, and students. The report explicitly states that many claims are projections, that the 28-letter language is a design specification and not an established scientific fact, and that all performance, safety, seismic, lunar, and climate claims require independent verification, engineering review, and regulatory approval. The goal is not to replace existing STEM education, but to add a coherent, inclusive, and scalable pathway from play to planetary responsibility.

Introduction: The Need for Coherent STEM Knowledge

Education systems around the world face a persistent challenge: students often learn mathematics, science, and engineering as separate subjects, disconnected from the built world they live in. They memorize formulas but do not understand load paths. They study climate change but do not know how to model, test, or intervene. They

use digital tools but do not see how physical arrangements become data. Meanwhile, many learners—those who cannot speak, see, or hear, those with autism or Down syndrome, and others who need different pathways—remain on the margins of STEM participation. This report responds to that challenge by proposing a dual-scale, language-based STEM education framework that begins with a child holding a plastic block and extends to university research, planetary engineering, and inclusive dialogue.

The framework is not a single curriculum. It is an architecture for cooperation. It invites kindergarten teachers, primary and secondary teachers, university faculty, researchers, policymakers, industry partners, families, and students to build a shared educational ecosystem. The report is written as a scientific call for cooperation. It presents the framework, the existing evidence base, the missing evidence, and the research needed to verify or refute claims. It does not provide legal advice. Nor does it claim that any proposed technology is proven. Rather, it asks the global education community to test, refine, and govern the framework together.

Theoretical and Pedagogical Foundations

The framework rests on established traditions in education and cognitive science. Constructivism, associated with Seymour Papert, holds that learners build knowledge best when they make public, shareable products. Embodied cognition holds that physical manipulation supports abstract thinking. Universal Design for Learning calls for multiple means of representation, expression, and engagement. Semiotics and pattern languages, following Christopher Alexander, show that complex systems can be described through lawful combinations of recurring elements. Artificial intelligence,

when used as a patient mediator rather than an authority, can expand dialogue and personalization. The innovation proposed here is not the invention of these principles. It is their integration around a single physical platform.

The very shape of the block a child holds can be cast in concrete. The same connection rules that form a toy wall can form a real wall. The same pattern language that describes a sentence can describe a structural joint. The same artificial intelligence that translates a block arrangement into speech can also translate it into simulation data. This integration is the core educational hypothesis: transfer across scales, domains, and modes of expression. If the hypothesis is correct, then a child who learns the language of building can later understand, question, and improve the built world. And if the hypothesis is wrong or incomplete, the research agenda set out below will reveal where and why.

The SAMANSIC Dual-Scale Building Platform

The SAMANSIC platform is protected by two US utility patents. US 12,703,973 B2 covers the corner block and the broader interlocking building block system. US 12,709,890 B2 covers the cross block and the broader system. Both patents are titled "Interlocking Construction Blocks" and name Daniel Anthony Leonard Boot and Muayad S. Dawood Al-Samarrai as inventors, with Samaraee & Daniel Innovation Specialists Incorporated as assignee. Both patents describe real interlocking concrete building blocks for walls and foundations, not merely toy shapes. This legal protection is important because it distinguishes the platform from conceptual blocks that may carry design patents, trademarks, or expired toy patents.

The claimed system includes a standard block, a hollow or reinforced block, an end block, an extended end block, a corner block, a double block, and a cross block. The standard block is the basic modular unit. It has an outer wall, a head, lobed convex connection parts, concave receiving parts, protruding edges that act as bearings, and a central vertical opening or groove. The head contains a hole extending from top to bottom for concrete, reinforcement, or utilities. The block is nominally 399 mm long and 200 mm high, with widths ranging from 150 mm to 399 mm. The hollow or reinforced block adds a partition wall and an additional hollow cavity for insulation, reinforcement material, concrete, rebar, wires, conduits, pipes, sensors, or optical fibers. The extended end block doubles the length of the outer wall and creates a groove between the lobed connection and the connection between the end wall and the head piece. The corner block is a unitary 90-degree corner with a W-shaped channel and a connecting piece. The double block joins two standard blocks along their outer faces. The cross block allows walls to continue in three different directions, making T-junctions and intersecting wall configurations possible.

The structural features are engineered for real building behavior. The blocks interlock without mortar using curved lobes, sockets, a central groove, and protruding edges. Radiused corners and edges, preferably 6 mm to 12 mm, reduce stress and chipping. Chamfered edges, preferably 2 to 4 degrees and optimally 3 degrees, leave a gap of about 2 mm for mechanical fasteners, cladding, insulation, and thermal expansion. The hollow cavities can carry rebar, concrete, insulation, wires, conduits, pipes, sensors, and optical fibers. The double block adds width and resists bending, buckling, and shear. The corner block creates a 90-degree angle in a single unit. The cross

block enables three-directional extension. These are real building functions, and they are also teachable engineering concepts.

The 7-4-28 Pattern Language

The 7-4-28 language contains seven basic forms: Entity, Relation, Process, Sequence, Container, Limit, and Modifier. Each form has four colored ports: red for mathematics and quantity, blue for space and shape, green for time and sound, and yellow for social meaning. Seven forms multiplied by four colors gives twenty-eight letters. Each letter represents a lawful connection between two blocks. The letters are EA, EB, EC, ED; RA, RB, RC, RD; PA, PB, PC, PD; SA, SB, SC, SD; CA, CB, CC, CD; LA, LB, LC, LD; and MA, MB, MC, MD. The red port, A, becomes a numerical variable. The blue port, B, becomes a spatial coordinate. The green port, C, becomes a time series or process variable. The yellow port, D, becomes a social classification or meaning variable. In this way, every physical arrangement of interlocking blocks can be read as a structured expression.

The interlocking blocks map directly onto the seven forms. The standard block is Entity. The double block and cross block are Relation. Dry assembly is Process. The extended end block is Sequence. The hollow and reinforced block is Container. The end block is Limit. The corner block is Modifier. The patent geometry defines the lawful connections. The lobed convex part enters the concave receiving part. The bearing or protruding edge enters the central vertical opening. Two bearings of two adjacent blocks end-to-end can be captured in a single groove. The W-shaped channel of the corner block accepts the bearings on either side. The cross block accepts two bearings in the central groove and a third in the side groove. The

extended end block accepts a bearing in its end groove. These are the lawful connection types, and they constitute the grammar.

The 7-4-28 language also links physical blocks to data and artificial intelligence. Each letter becomes a transformation specification from physical to digital. Artificial intelligence can read the arrangement, generate partial arrangements, ask the learner to verify them, and translate the result into text or speech. It is essential to state clearly that the 28-letter language is a design specification, not an established scientific fact, and is not covered by any patent. It must be tested for reliability, validity, and educational effectiveness. The patents protect the block design. But they do not prove that the language improves learning, communication, or structural understanding. That proof must come from independent research.

Artificial Intelligence and the Language of Dialogue

The proposed artificial intelligence is not a cold machine. It is a translator and a patient teacher. It does not judge, diagnose, or treat. It reads the arrangement and translates it into a spoken or written sentence. It asks a simple verification question, remembers preferences, suggests partial arrangements, and asks the learner to complete them. It shares progress with the family or specialist only with consent. In this way, dialogue becomes an enjoyable educational game and a respectful human relationship. The artificial intelligence is designed to support the learner, not to replace the teacher, the family, or the community. It is a bridge, not an authority.

The framework is also a language of dialogue for people who face communicative challenges. For those who cannot speak, the blocks become a tangible alternative to speech. For those who cannot see, the raised shapes, ports, and tactile marks become a language like

Braille read by the fingers. The geometry itself becomes a readable surface. For those who cannot hear, colors, shapes, and arrangement form a complete visual dialogue. Meaning is seen rather than heard. For those who neither speak nor hear, the blocks provide a complete language that they build, see, and touch, and that artificial intelligence translates into text. For people with autism, the language is literal without metaphor. Its rules are fixed without surprises. And a routine provides safety without forcing eye contact or speech. For people with Down syndrome, the pace is slow, sentences are short, repetition is present, steps are small, blocks are tangible, colors are clear, and the artificial intelligence is patient and never tires. For any other challenge, the system remains flexible. Block size, color, and texture can be customized. Handles or rough surfaces can be added. Symbols can be enlarged. The system has room for everyone, because no single tool fits everyone. The savant syndrome innovation is implicitly linked to the interlocking block platform, but it is not directly claimed in the patents. It requires independent educational research.

Curriculum Progression: From Kindergarten to University

In early childhood, children become familiar with the seven shapes and four colors through free play. They build towers, walls, corners, and simple barriers. They learn that blocks connect in lawful ways. They learn to name shapes and colors. They learn that a wall needs a foundation and that corners are weak points. The goal is not to teach engineering vocabulary. The goal is to build intuition through the hand. The child learns that scale is a variable, not a wall. The small block and the large block can follow the same logic.

In primary school, children learn the letters as shape-color pairs. They match letters and build simple words. They learn counting, fractions, symmetry, patterns, balance, and problem-solving. They build models of walls, corners, and joints. They test which arrangements are stable. They begin using artificial intelligence to translate arrangements into sentences. They learn that a sentence in the language is a lawful arrangement of blocks, just as a wall is a lawful arrangement of structural units. They learn that errors are not failure but information. They learn to review, test, and explain.

In secondary school, students build complete sentences and learn the rules of agreement. They study load paths, compression, tension, shear, reinforcement, tolerance, fit, foundations, walls, seismic design, and material integration. They learn why a real wall needs reinforcement, why corners are weak points, and why real buildings need steel and concrete. They use simulation tools and begin independent projects. They study patents and learn that patents protect design, not safety. They learn that the 28-letter language is a design specification and not an established scientific fact. They learn that seismic design is untested and that many claims are projections. The responsible learner absorbs this and says: "We can try this, but first we test, simulate, review, approve, and involve the people affected."

At university, the language becomes a research tool for data analysis, model building, and communication with artificial intelligence. Students study structural engineering, seismic design, foundation engineering, materials science, robotics, and extraterrestrial construction. They work on grand challenges such as the Ionian Pyramid, affordable housing, heritage restoration, and lunar habitats. They also study ethics, regulation, and social impact. They learn that

the built world is not a closed door. It is something learners can understand, question, and improve. They learn that the legacy of Mimar Sinan adds historical continuity, showing that mortarless interlocking, seismic damping, material selection, and foundation isolation are timeless principles now organized in SAMANSIC STEM. The past is not a museum. It is a laboratory.

Grand Challenge Case Study: The Ionian Pyramid

The SAMANSIC alliance proposes the Ionian Pyramid: a structure that generates negative ions through natural electromagnetic concentration and accelerates the decomposition of greenhouse gases at rates far faster than natural processes. It is envisioned as the planet's artificial lungs. Omega architecture is said to reduce total infrastructure requirements, costs, and construction timelines by 90%, while doubling the efficiency of each pyramid by a factor of 9 to 29. A self-financing mechanism is proposed: a closed cycle that converts oceanic plastic waste into educational toys, placing no financial burden on governments. Global deployment would follow atmospheric circulation patterns and strategic locations, beginning in Sudan and Egypt, and extending across Mexico, China, Indonesia, the United States, and Europe. The SAMANSIC block platform is protected by US patents such as US 12,703,973 B2.

In a scientific report, these claims must be treated (the Ionian Pyramid concept would require engineering verification and regulatory approval). The best STEM education does not ask the child to believe this. It asks him to test it. Model ion generation. Simulate atmospheric transport. Calculate the energy budget. Audit the cost claims. Examine the patent scope. Ask who benefits, who is affected, and what could go wrong. Do not worship the pyramid. Improve it, or

replace it with something better. The educational value does not depend on the validity of the Ionian Pyramid claim. It depends on using it as a testable grand challenge. The 2004 Geopolaration survey, verified by the Jordanian Natural Resources Authority, provides a documented baseline capability for lunar and extraterrestrial claims, but those applications require independent testing case by case. The legacy of Mimar Sinan adds historical continuity, showing that mortarless interlocking, seismic damping, material selection, and foundation isolation are timeless principles now organized in SAMANSIC STEM.

Implementation and Cooperation Framework

The framework requires cooperation among many stakeholders. Teachers from kindergarten through university must adopt, adapt, and evaluate the framework. Researchers in education, psychology, engineering, artificial intelligence, and materials science must design and conduct verification studies. Policymakers must integrate the framework into national STEM strategies, standards, and funding. Industry must manufacture the blocks, develop artificial intelligence tools, and support teacher training. Families must participate in dialogue and home learning. Students must participate in co-design, testing, and improvement. No single group can build this alone.

We call for multi-site pilot studies in diverse contexts: urban and rural, high-income and low-income, inclusive classrooms, after-school programs, and university laboratories. Experiments should use mixed methods: quantitative assessments of spatial reasoning, mathematics, and engineering knowledge; qualitative studies of engagement, inclusion, and dialogue; and longitudinal tracking of STEM participation. For scale, the framework needs open standards

for block geometry, connection types, data formats, artificial intelligence translation protocols, and safety. Patents protect the design. Open educational resources can protect the learning. Teachers need training in constructivist pedagogy, structural concepts, artificial intelligence mediation, inclusive communication, and ethical safeguards. Training should be designed in cooperation with teachers and continuously evaluated.

Evaluation and Research Agenda

The framework generates several testable hypotheses. The first is that dual-scale manipulation improves transfer of structural concepts. The second is that the 7-4-28 language improves symbolic thinking and communication. The third is that artificial intelligence-mediated dialogue increases participation of learners with communicative challenges. The fourth is that grand challenge projects increase motivation and persistence. The fifth is that inclusive design increases STEM participation across diverse populations. These hypotheses must be tested with rigorous methods. Measures should include spatial reasoning tests, engineering concept inventories, mathematics achievement, language and communication measures, engagement and motivation scales, inclusion and participation indicators, teacher self-efficacy, and long-term STEM pipeline data.

Patents protect design, not safety. The 28-letter language is a design specification. Seismic design is untested. Many claims are projections. All performance claims require independent verification, engineering review, and regulatory approval before implementation. This is not legal advice. The research agenda should include independent structural testing, seismic simulation, materials testing, artificial intelligence bias auditing, educational effectiveness trials, and ethical

review. Negative results should be published. The goal is not to defend the framework but to discover what is true, what is useful, and what must be changed.

Conclusion: A Bridge to the Human Being

The child or the human being (at every stage of life), once he acquires this knowledge, will not fear the impossible. He will reject the idea of the impossible. He will see it as a larger version of what he can already do—and a responsibility to do it safely, justly, and with care. You will hesitate, but not because you lack courage. You will hesitate because you have learned that building is a promise to the people who will live inside the result. If society as a whole becomes capable, the Great Pyramid and the Great Wall of China will cease to be miracles. They will become historical engineering projects—impressive, no longer beyond the limits of human understanding, and a world that ordinary people can build together.

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(Courtesy: Ammon)

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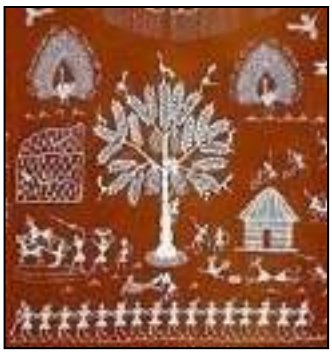
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