Embedding Human Values in the Design of Mixed-Reality Technologies

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Abstract—Current mixed reality (MR) designs predominantly prioritise functionality and usability, often overlooking individual's diverse value needs. To create more meaningful MR experiences, this paper aims to address this gap by exploring how human values can be integrated into MR design. We propose a values-based design process and evaluate it through three design workshops considering a remote collaborative learning scenario. By comparing our approach to an existing MR application for collaborative learning, we demonstrate how embedding human values into MR design can lead to more ethical and human-centred outcomes. Our findings contribute to advancing the design and application of MR technologies to be more aligned with people's diverse needs and values.

Index Terms—Mixed reality, human values, augmented reality, virtual reality, extended reality, value-based design, value-sensitive design, value-centered design, value-driven design, ethics.

1 Introduction

Immersive technologies—including Virtual Reality (VR) and Augmented Reality (AR), or collectively mixed or extended reality (MR or XR)—have been predicted to be the major human-computer interaction modality for the next 50 years [2]. These technologies are shifting information interfaces from 2D displays, such as those found on smartphones, computers, and tablets, to immersive 3D displays—either isolating (VR) or projected on the world around us (MR). This shift has the potential to fundamentally reshape how we perceive and interact with digital spaces. MR, in particular, deepens our engagement with the more complex digital-physical hybrid worlds, extending human sensory capabilities beyond their natural limitations [67].

Despite MR's transformative potential, inhibitors such as the high cost and inconvenience of current headset devices have, thus far, hindered its widespread adoption [20, 36]. These challenges echo the early stages of mobile phone development. Initially expensive and with limited functionality, technological advances have led to them transforming many aspects of daily life [37]. Some researchers forecast MR technologies are moving towards lighter weight, wearable devices and provide frameworks for ubiquitous MR [66]. This may lead to the refiguring and reimagining of social hierarchies (e.g., power dynamics between individuals and organisations), contracts (e.g., legal agreements governing digital ownership and transactions), and regulations (e.g., laws and policies overseeing digital spaces), introducing new institutions [55] such as voting rights in the emerging "metaverse" [46].

The number of ethical concerns surrounding immersive technologies are growing as they become integrated into real-world applications. Examples include digital abuse in the metaverse [42] and how AR games can distort players' perceptions of reality and lead them to adopt conspiratorial thinking without their full awareness or consent [32]. Given that human values reflect our understanding of "*what is important in your life*" and dominate our behaviours, some researchers proposed that "*the goal of HCI is to deliver value*" [15, p. 149]. Emerging MR applications that integrate digital and physical worlds have the potential to be much more transformative and invasive than earlier VR and AR research and development. This has led to recent research beginning to explicitly explore the role of human values in MR for creating more meaningful and human extended realities [36] with consideration of complex topics such as human welfare [12], security and privacy [18].

Despite the recognised importance of embedding human values into MR designs, the methods and approaches remain underexplored. As an emerging technology, MR still faces significant barriers (such as cost and comfort) that need to be addressed before it can be widely adopted and put in the hands (and on the heads) of large segments of the population. Thus, despite the potentially far-reaching impacts of this technology on society, we have yet to see those impacts play out. Yet, as the technology inevitably advances to a point where its capabilities outweigh the barriers to adoption, we are likely to see explosive uptake. This is similar to the slow advance then sudden adoption of smart mobile devices in the 2000s. There is an immediate and compelling opportunity to explore and develop processes that integrate value questions into MR, in time to mitigate negative societal effects and steer development such that the ultimate deployment of MR is a net social positive. However, with few actual deployments of MR technology in the wild, we are limited to a more speculative design approach.

A clear research gap therefore exists in developing a design process that systematically embeds values into MR design and explores its potential impacts before widespread societal deployment takes place. To address this gap, we formulated two fundamental research questions:

- **RQ1:** How can we introduce values into an MR design process?
- **RQ2**: How can we demonstrate the impact of a value-based design (VBD) process on MR design?

This paper aims to contribute to the MR and design communities by addressing these questions through the development and evaluation of a VBD process. Our contributions are twofold: (1) a structured VBD process for embedding ethical and personal values into MR design, and (2) insights and perspectives from three practical workshops evaluating the impact of VBD compared to existing (conventional) MR application design approaches.

2 Background

To introduce the VBD perspective into an MR context, this section first introduces the concept and ethical issues of MR. We then review existing VBD theories and methods.

2.1 Mixed Reality

MR was first introduced by Milgram and Kishino [40] as part of their reality-virtuality (RV) continuum, which describes the integration of real and virtual objects within a single display. According to this continuum, MR includes any experience that exists between 100% real and 100% virtual worlds, such as AR and augmented virtuality (AV). The RV continuum is generally considered to define MR in the Human-Computer Interaction (HCI) community, with a large portion of the literature utilising this framework [58].

MR has a broad range of applications, spanning fields includes education [62], healthcare [61], food [13], architectural [57], tourism [52], and numerous other aspects of daily life. It introduces a more complex interaction paradigm than traditional computing such as PC and mobile

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where interactions are mediated through conventional inputs such as keyboards, mice, and touchscreens [25]. In MR environments, people can simultaneously engage with the physical and digital worlds [72]. This extends the capacity of the limited interactions in AR which usually involves viewing digital overlays [53], and VR, where all interactions are confined to a fully virtual environment [34]. This complexity presents unique ethical challenges for MR adoption such as risks to patient safety in digital surgery [63], sexual harassment in games [41], and intimate surveillance of the worker's body to maintain productivity [12]. The above real-world lessons raise critical questions about the experiences we want to cultivate in an MR world and how they align with individual values and ethical considerations.

2.2 Value-Based Design Processes

Various research fields have developed distinct design processes tailored to achieve their specific goals. These include methodologies like the Double Diamond [5], Design Sprint [6], Agile Method [17], Lean UX Canvas [23], and Design for Six Sigma [39]. While each discipline may have its unique approach, there are commonalities in how these processes unfold and how they structure problem-solving [71]. To better incorporate human values (e.g., empathy, trust, and psychological well-being) in the design process, researchers have proposed approaches such as VBD, Value-Sensitive Design (VSD) [22], Value-Driven Design (VDD) [10], Value-Centred Design (VCD) [16], and Value-Oriented Design (VOD) [49]. While these methodologies are grounded in similar foundational principles, the variation in terminology is often contingent upon the specific disciplinary contexts in which they are applied.

In recent years, there has been growing attention in the HCI field towards integrating values into system design. These values include ethical values, which relate to the question of what is right and wrong; individual values, which prioritise what individuals consider important or unimportant; and cultural values, which capture influences arising from diverse cultural backgrounds. For instance, the IEEE released a standard model that addresses key ethical values such as autonomy, care, fairness, and inclusiveness throughout the design process [1]. Spiekermann and Winkler [60] argued that the IT system should have a mission to play a role in supporting what is good, worthy, beautiful and peaceful in life rather than maximising profit, creating somehow useful and embedding new technical functionality. This perspective has led to the emergence of value-based IT design [9, 59] and value-based engineering [60], which involves the systematic elicitation, conceptualisation, prioritisation, and incorporation of values in the system design process. Furthermore, Doi [19] introduced a value-centred product development process, though it primarily emphasises enhancing usability, (e.g., easy to type even in small spaces). Kheirandish and Rauterberg [31] created a card-based design tool called HuValue, consisting of value wheels, value words, and picture cards to facilitate the incorporation of human values into game design. Collectively, these works illustrate the growing focus on embedding values in system design. However, currently, there is no established design process specifically tailored for MR applications.

Exsiting MR designs predominantly prioritise usability and functionality [71]. Yet, there is a growing recognition of the need for a more ethically grounded design approach that incorporates diverse human values. Integrating values into design processes, offers individuals an opportunity to express their personal philosophies of life, potentially leading to enhanced personal fulfilment, a greater sense of integration, and stronger connections with their broader communities beyond work [68]. Importantly, this ethical reflection should be embedded at every stage of MR design, rather than delayed until ethical issues become apparent (e.g., digital abuse and sexual harassment in MR games).

3 A Value-Based Design Process

To address RQ1, we propose a new VBD process for MR design to incorporate a value perspective into the interaction design process (see Figure 1).

3.1 Design Goals

Current MR interaction design incorporates usability and user experience goals. Usability goals like "efficient to use" align with the value of *universal usability* defined in VSD as making all people successful users of information technology, while "safe to use" reflects the value of *safety* from Schwartz's theory [56].

As the focus on user experience has increased, we seek to tap into the potential of utilising human values to design more meaningful MR experiences. The goals of current interaction design tend to focus more on a range of emotions and felt experiences [71], such as "enjoyable" and "emotionally fulfilling". These are what might be valued in the present phase of development and uptake, but do not take account of the long-term needs of people living in future MR worlds. As values map people's perception of the world, we use them to guide the design to create more meaningful experiences for future MR worlds. Our goals of a user experience that embeds a values perspective are as follows:

- Enabling diverse values to be represented in various MR experiences
- Empowering individuals to choose MR experiences that reflect their values
- Adapting to the changing value needs of individuals over time

3.2 Process Model

We have three phases in the VBD process — *Understand*, *Design*, and *Evaluate* — which align with the traditional design process.

In Phase 1 - *Understand*, designers are invited to analyse the context and conceptualise values. Designers can use the known contextual information (such as context description) to identify relevant groups of people, target audiences, and their characteristics. Using tools such as example value cards, designers can conceptualise values by defining values, value characteristics, and potential value conflicts.

Next, in Phase 2 - *Design*, designers can develop new value-based applications or embed values into existing MR applications. For the development of new value-based applications, this phase requires defining value requirements and envisioning value elements and user stories that reflect those values in the MR application. For existing applications, designers are suggested first to establish a fundamental understanding of its functions and application scenarios. Next, they identify the values that should be emphasised within the context of its application. Finally, designers embed these values into the existing MR application by introducing value elements, such as new functions or features that embody the desired values.

Finally, in Phase 3 - *Evaluate*, designers could verify whether the intended values are incorporated into the MR applications. This ensures that both existing and newly developed MR applications successfully integrate the required values. The final product is a value-embedded application that aligns with the established value requirements.

3.3 Design Activities

The typical phases of the design process are discovering requirements, designing alternatives, prototyping and evaluating [71]. In our work, we use these phases for value-related activities, namely Conceptualise Values, Develop Value Requirements, Value-to-Feature Mapping, Discover Value Gaps, Embed Values in MR Application, and Value-Based Evaluation (see Figure 1). These activities were selected or developed based on insights synthesised from lessons learnt in the VSD or VBD literature. Resources or information may be provided to initiate some of the activities as "input", while the new outcomes or results generated from the activities serve as "output". The outputs of one activity can become inputs for the next.

The ***Analyse the Context*** activity aims to understand the different stakeholders in a specific application context. Who are the direct and/or indirect groups of people involved in this context? What are the characteristics of these groups? In this activity, resources of contextual information are considered inputs, while the identified groups and their characteristics are regarded as outputs. Delineating these different groups and exploring their characteristics, feeds into the ***Conceptualise Value*** activity, where designers are encouraged to reflect on which values are meaningful to the target groups, how these values are defined,

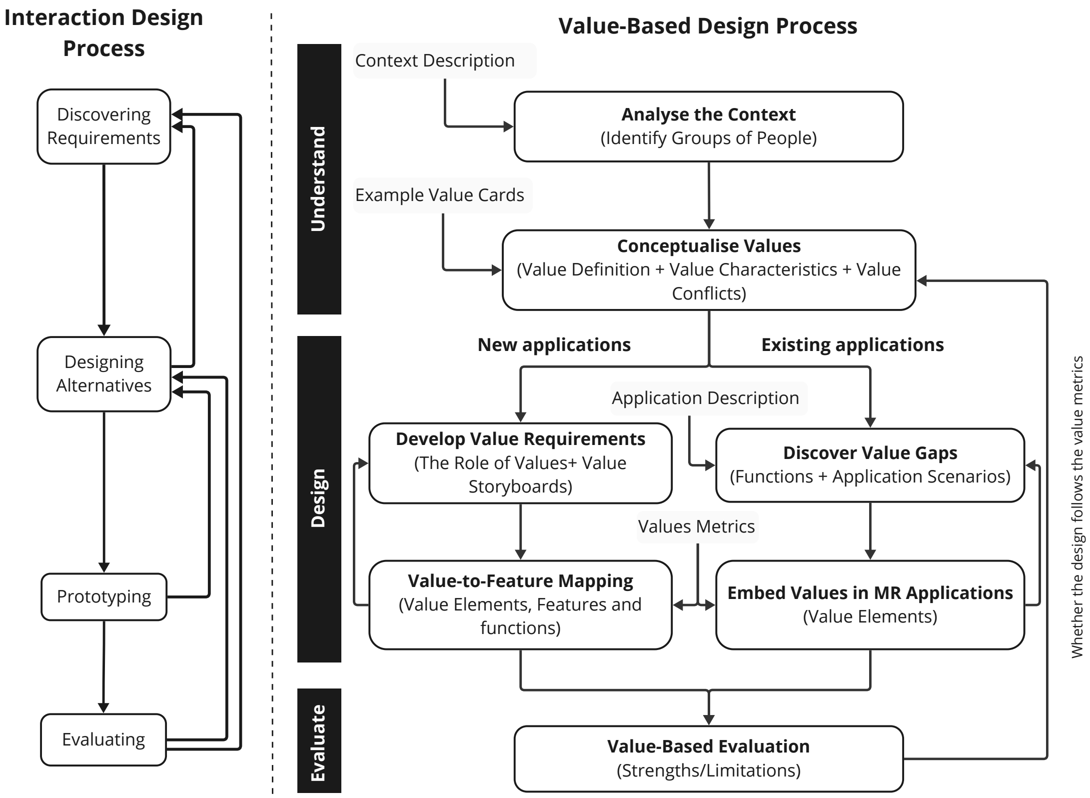

Fig. 1: Comparing the Interaction Design Process (left, [71, p.51]) to Value-Based Design Process (right).

and what their key characteristics are. This is an essential step for embedding values in design. It aims to create a shared understanding of the target values, as "an objective definition is required to operationalise a concept as measurable indicators" [11, p. 3044]. Additionally, designers should consider whether any conflicts exist between values within the same context[1]. By addressing these questions, the activity breaks down a single value into component concepts, allowing the design team to consider how to embed them into MR applications. A series of value metrics including value rankings, definitions, characteristics, and potential conflicts, results from this activity.

For designing new MR applications, ***Develop Value Requirements*** provide a clear and precise way to translate values into the system's value dispositions [1]. We adopted this activity to encourage designers to consider how the target values apply to their MR context. The forms of the value requirements are various, such as formal statements, scenarios, user stories, or use cases. For instance, when embedding values into an MR remote collaborative learning environment, prompts might include: What roles does the target value play in enhancing student engagement, interaction, and communication in a remote collaborative environment? How does the target value contribute to the effectiveness and success of learning performance? Value metrics serve as inputs, with identified value roles as outputs. Next, the ***Value-to-Feature Mapping*** activity enables the envisioning of MR applications guided by value requirements. Designers are encouraged to propose functions, features, or elements to fulfil the roles of the target value. As stated by Spiekermann [59] "If a technology has to be embedded in a specific setting or context, one way to find values is to have participants (or project team members) photograph that setting and imagine the impact that the new technology will have on that setting." In this activity, the roles of values serve as inputs, while the value elements are the outputs.

For existing MR applications, designers are invited to analyse the application to identify missing elements that could represent the target value in the ***Discover Value Gaps*** activity. The application description serves as the input, while the identified functions or application scenarios are outputs. Then, designers could propose new value elements that align with the target value to address the identified gaps in the activity called ***Embed Values in MR Applications***. The identified value metrics are the inputs, while the newly designed value elements are the outputs.

Finally, the ***Value-Based Evaluation*** activity aims to verify whether the intended values are incorporated into the MR system. It examines which parts of the design successfully incorporate the target value (strengths) and identifies areas for improvement (limitations).

4 Evaluation

To evaluate the proposed VBD process in response to RQ2, we conducted a comparative analysis between the design of value-embedded applications developed through our VBD process and an existing MR application designed using conventional methods. As we test our VBD process from ideation, such as a paper prototype rather than a real prototype, comparing documentation from the VBD process and the existing application is key to evaluate the VBD process rather than a user study. The evaluation involved the following steps: (1) selecting an existing MR application with comprehensive documentation, (2) designing MR applications through workshops using the VBD process, and (3) performing a detailed comparison of the application descriptions from both systems to identify key differences.

4.1 Selection Criteria for MR Applications

We selected MR applications in the domains of "education" and "health" as they are the two most frequently mentioned domains to be associated with MR applications [36] and have a significant impact on society. To gather comprehensive documentation, we selected existing MR applications from Ph.D. or Master's theses. These theses often provide detailed theoretical foundations, transparent discussions of iterative design processes, and comprehensive evaluations. This depth provides a holistic understanding of MR applications, which is rarely found in published papers or commercial MR products.

The search was conducted on February 21, 2024, using the ProQuest Dissertations & Theses Global Database. For the education domain, we

[1]An example of a value conflict is privacy versus the provision of private information to a government entity legally authorised to require it [1, p. 33].

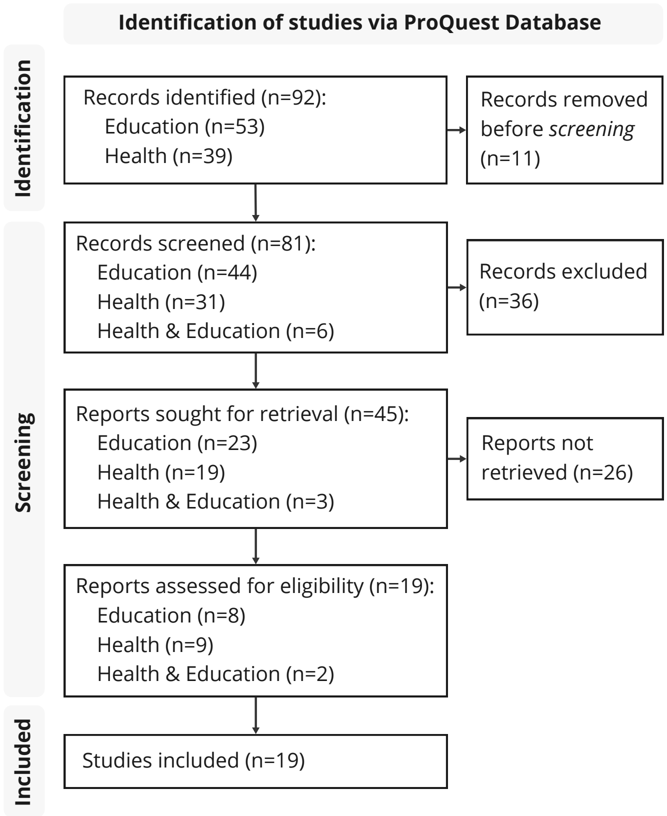

Fig. 2: The thesis selection process for MR applications by using the PRISMA 2020 flow diagram.

used the keywords "educat*", "student", and "mixed reality", which returned 53 results. The keywords "health" and "mixed reality" were used for the health domain, which returned 39 results. We adopted the PRISMA flow diagram [47] to guide the thesis selection process, ensuring transparency and reproducibility throughout the document selection phase (see Figure 2). Prior to the screening, 11 records were excluded as they were either written in languages other than English or identified as duplicates. Among the duplicate records, 6 focused on medical training which covered both the education and health domains. So we categorised these 6 records into a new category labelled "health & education."

During the title and abstract screen, 36 records were excluded for being unrelated to the education and health domain focusing on VR/AR instead of MR, or lacking involvement in MR application design. During the full-text screen, 26 reports were excluded due to insufficient details on MR design (fewer than 30 pages), a focus on VR instead of MR, or lacking involvement in MR application design. Finally, 19 studies met the eligibility criteria and were included in the final selection of MR applications for further analysis (see Table 1).

We conducted an analysis of 19 MR applications and identified key themes within each domain. In the education domain, MR applications were primarily designed for collaborative learning [3,48,64], learning environment simulation [8,38,45,69], and early science education [70]. In the health domain, the applications focused on adaptive MR rehabilitation [7,21,35,65], assistive MR systems [14,28], and MR data visualisation [26,33]. Additionally, MR applications in the medical education theme [24,27,44] cover both domains of health and education. Among these, 4 Ph.D. theses designed adaptive MR rehabilitation systems for stroke patients, while 2 focused on its use in collaborative learning among distance learners. Therefore, the themes of adaptive MR rehabilitation systems and collaborative learning systems provide the most comprehensive and complete documentation of MR system design (e.g., related publications and videos). However, due to the

Table 1: A List of Theses on MR Applications in Education and Health Domains selected from the ProQuest Dissertations and Theses Global Database.

Domains	Author	MR Application Theme	Ref.
Education	Alzahrani	Collaborative Learning	[3]
Education	Peña-Rios	Collaborative Learning	[48]
Education	Vellingiri	Collaborative Learning	[64]
Education	O'Leary	Learning Environment Simulation	[45]
Education	Lui	Learning Environment Simulation	[38]
Education	Barrett	Learning Environment Simulation	[8]
Education	Yannier	Early Science Education	[70]
Education	Yang	Learning Environment Simulation	[69]
Health	Duff	Adaptive MR Rehabilitation	[21]
Health	Baran	Adaptive MR Rehabilitation	[7]
Health	Lehrer	Adaptive MR Rehabilitation	[35]
Health	Venkataraman	Adaptive MR Rehabilitation	[65]
Health	Obeid	Medical Education	[44]
Health	Hilton	Assistive MR Systems	[28]
Health	Chen	Assistive MR Systems	[14]
Health	Kolagunda	MR Data Visualisation	[33]
Health	Gutenko	MR Data Visualisation	[26]
Edu-Health	Granville	Medical Education	[24]
Edu-Health	Hanson	Medical Education	[27]

highly specialised and narrow scope of adaptive MR rehabilitation systems, using it as a reference system would require designing an MR system for stroke patients based on the VBD process. Such design often requires long-term experiments and observations, which is impractical for evaluating the VBD process within a short time frame. Moreover, recruiting experts with a specific background in adaptive stroke rehabilitation presents a significant challenge. Therefore, after careful consideration, we selected the newest MR remote collaborative learning system (MiRTLE+) [3] as the reference system to evaluate the VBD process.

4.2 Overview of the Selected MR application

MiRTLE+ is an MR-based collaborative learning platform. It enables learners to engage in collaborative learning from different geographical locations within an MR learning environment, thereby enhancing their learning performance. The design background (context description) of this application was extracted from the thesis [3] as follows:

> "Collaborative learning allows learners to develop their critical thinking and creativity, and the ability to evaluate individual learning skills and their strengths. Through collaboration, learners work together, share ideas, develop communication skills and learn from one another" [3, p. 46].
>
> "Face-to-face learning is an ideal way to foster collaboration and social interaction among learners. However, students choose to study using distance learning tools due to work, family, and other commitments. Additionally, distance learning requires learners to be more organised and self-controlled" [3, p. 26].

MiRTLE+ consists of seven key components: the MR environment, shared learning activities, authentication and authorisation, voice communication, AR interfaces, immediate group feedback, and recognised expertise level. The MR environment integrates virtual and physical spaces, featuring a virtual classroom with virtual learning boards and a physical classroom equipped with a table, four chairs, markers on the chairs, two iPads, a PC on the table, one pair of AR glasses, and one pair of VR glasses [3, pp. 51-52]. The application used the Uno card game as the shared learning activity. It involves two novice students, unfamiliar with the card game Uno, and two expert students, proficient in the game. Through several rounds of gameplay, the novices gradually learn the game's rules with guidance from the expert students. Prior to engaging in the activity, all four students must register and log into the MiRTLE+ 3D environment, ensuring proper authentication and authorisation for each Uno game [3, p. 64]. Four students interact with the digital card game board during gameplay [3, p. 65], supported by a control panel located on the left side [3, p. 71]. The control panel facilitates various functions, including starting the game, displaying and hiding the game browser, and assessing the players' level of expertise. Communication is facilitated through the voice communication feature, where students can interact by pressing a "press to talk" button, while others can listen and see who is speaking [3, p. 70]. The AR interface supports interaction among students seated in allocated chairs, enabling synchronous avatar actions and real-time event visualisation [3, p. 66]. After each round, the expert students provide feedback to the novices, discussing the errors made during the game. This feedback is supported by immediate group feedback and recognised expertise level, both of which are generated by the MR system.

Furthermore, we analysed the application from a value perspective, addressing the following questions: Were any values considered in its design? Whose values were prioritised? Were values an objective in the system's design? What was the spectrum of values? Were any value conflicts mentioned?

Our analysis revealed that their design did not take values into account, which could be an additional contribution that could be refined in the future. The author introduced collaboration as a functional feature rather than as a core value. The focus on collaboration was primarily to enable geographically dispersed learners to perform a game-based activity designed for informal education settings. Collaboration-related questions, such as "using technology to communicate with others allows me to be more effective in my knowledge transfer [3, p. 183]", were incorporated into the evaluation of experts' teaching experiences through a 4-point Likert scale (strongly agree, agree, disagree, and strongly disagree). Potential value conflicts could arise from *physical well-being*, as noted in the study: "distractions while holding or cybersickness while wearing the interfaces continue to affect some users" [3, p. 155]. Additionally, it is noteworthy that *social anxiety* stemming from collaborative activities was also reported in the study by [48].

4.3 Value-Based Design Workshop

We designed an online workshop[2] to test the proposed VBD process. Compared with the in-person workshop, an online workshop can break geo-isolation and bring experts together synchronously. We presented the design activities based on our VBD process in an online platform *Miro*. We conducted three workshops (W1, W2 and W3) to make sure we collected comprehensive data and each workshop lasted for 2.5 hours.

For each workshop, we recruited an MR expert who possesses in-depth knowledge of the potential capabilities of MR technologies, an education expert with expertise in collaborative learning, a design expert skilled in human-centred design, and a distance learner who chooses to study using remote learning tools due to work, family, and other commitments. A total of 12 participants took part in the workshops (see Table 2). This research was conducted with ethical approval from the Monash University Human Research Ethics Committee (MUHREC). In addition, informed consent was obtained from all participants prior to data collection.

The workshop activities aligned with the design activities in section 3.3. It began with an opening session (10 mins). We provided participants with a general understanding of the workshop. This included an overview of the workshop's motivation (to create more responsible MR technologies by considering human values), an introduction to the Miro (how to use Miro for workshop activities), and a quick exercise for participants to get to know each other.

The core of the workshop was structured into three phases. In Phase 1 (40 mins), participants explored the design context, identified the stakeholders involved, and selected their most meaningful value as a target value. In Phase 2 (50 mins), participants designed an imaginary MR platform, system, or application for remote learning by considering: (1) the roles their target value plays in collaborative remote learning, (2) the functions, features, or elements their system should include to support these roles, and (3) user stories illustrating how their designed MR system integrates the target value. In Phase 3 (40 mins), participants identified the differences between their design and MiRTLE+ and explained how these differences relate to the target value.

[2]Here is a link to the workshop template: https://miro.com/miroverse/value-based-design-workshop/?social=copy-link.

Table 2: Roles and specialised fields of workshop participants from three design workshops W1-W3.

#W	#P	Role	Specialised Field
W1	P1	MR Expert	Remote Collaboration
W1	P2	Design Expert	Interaction Design
W1	P3	Education Expert	Learning Experience Design
W1	P4	Distance Learner	Social Policy
W2	P5	MR Expert	Immersive Visualisation
W2	P6	Design Expert	Interaction Design
W2	P7	Education Expert	Learning Analytics
W2	P8	Distance Learner	Software Engineering
W3	P9	MR Expert	Immersive Visualisation
W3	P10	Design Expert	Human Technology Relations
W3	P11	Education Expert	Curriculum Design
W3	P12	Distance Learner	Information Technology

In the closing session (10 mins), participants engaged in a reflective discussion addressing three key questions: (1) What are the strengths and weaknesses of their design? (2) Which aspects of the workshop activities made it easier or more challenging to embed values into the system? (3) What additional activities would they recommend to facilitate the integration of values?

4.4 Data Analysis

We compared the value-embedded MR applications designed in the workshops with MiRTLE+ to identify key differences and assess whether these differences are value-related. To explain these differences, we reviewed the documentation in the thesis and our VBD process to assess the role of values in shaping these variations. We further reflected on how participant input influenced the design of value-embedded applications. We revisited the conventional design to understand the reasoning behind feature inclusion or exclusion. Based on these analyses, we make recommendations for future improvements to the VBD process to integrate diverse values in future MR designs.

5 Findings

This section presents the findings on the impact of the VBD process on MR features, the influence of value selection on these features, and participants' perspectives on their designs. Representative quotes are included in parentheses to provide detailed insights into the qualitative data.

5.1 Value-Embedded MR Applications

In all three workshops, participants decided to focus on *students* as the primary group, agreeing that facilitating student collaboration is a fundamental aspect of active learning. They identified *educators*, *parents*, *MR technology providers*, *support staff*, *decision-makers* and *learners* other than *students* (such as employees who work from home) as other relevant stakeholder groups.

Participants in W1 and W3 chose *sense of belonging* as their target value, while W2 participants decided to focus on both *trust* and *flexibility*. In W1 and W3, participants agreed that *sense of belonging* is the most meaningful value as it is universally applicable in the collaborative learning context. P3 stated "sense of belonging is something that everybody, regardless of the skills, regardless of the background or regardless of what kind of the [sic] major they are". The MR features for the Sense-of-Belonging-Embedded Application design in W1 are listed in Table 3: col 2; while the Sense-of-Belonging-Embedded Application designed in W3 are listed in Table 3: col 5. In W2, participants argued for both *trust* (trust educators, peers and learning content) and *flexibility* as the most meaningful values, deciding to work with embedding both into their MR application. The Trust-Embedded Application is listed in Table 3: col 3 and the Flexibility-Embedded Application is listed in Table 3: col 4.

To better describe how value-embedded applications integrated target values, participants described their design in value storyboards. For example, P3 fictionalised an IT student Aster, the protagonist of the story, to use the Sense-of-Belonging-Embedded application in a Virtual Classroom (see Table 3: col 2, row 1):

> "Aster joins a table with their friends for the class. In between activities they chit-chat with friends without bringing the attention of or distracting other students. Aster raises their hand and a yellow flag appears next to their avatar so their teacher knows they need help. When working on an activity, Aster can bring up relevant apps onto the table where they can work together with their peers."

P3 noted that when Aster interacted with their friends in the Virtual Classroom, the Spatial Audio feature enabled clear communication among them, as the volume increased when individuals were closer together (see Table 3: col 2, row 7). This functionality contributes to a sense of belonging within small groups. As an education expert, P3 observed that in physical classrooms, students often exhibit reluctance to raise their hands in front of their peers. Therefore, the feature that allows "Aster to raise their hand, with a yellow flag appearing next to their avatar," provides a more discreet means for students to signal their engagement, allowing them to feel a sense of belonging in the learning community without drawing undue attention. P3 remarked that "the student may not have to feel as visible because they know that only the teacher can see that flag". These value narratives illustrate how participants convey values not only through the design of MR features but also within real-world application scenarios.

5.2 Impact of Value-Based Design on MR Features

While both the value-embedded applications developed in the workshops and MiRTLE+ aim to facilitate remote collaborative learning, the former explicitly emphasis on holistic aspects of students' learning experiences, rather than just task-based usability. For example, in W2 the value-embedded applications provided Social Bubbles and Gather Town to increase students' *sense of belonging* (see Table 3: col 2, row 4). MiRTLE+ does not give students the space to make social connections, which limits their ability to foster a sense of inclusion, community, and connectedness. In the value-embedded application, students can hang out and interact outside the classroom, providing them a sense that they belong to this collaborative learning community.

Value-embedded applications enhance awareness of others and human-to-human interaction. Participants felt that the collaboration on MiRTLE+ is limited to the Game Board and Control Panel. Instead, participants suggested that students should be "able to start a conversation by 'walking' to the group/people" rather than checking to see who is there through the Control Panel ("the system should allow me to see who are there to talk by turning my head around in the environment instead of scrolling through the panel"). While participants agreed that "voice communication is a good choice", starting a conversation by holding the Press-to-Talk Button increase the sense of distance which decline *sense of belonging* ("[there is] no need to press any buttons to speak"). Moreover, the Human-to-Human Interaction design allows students to be aware of their peers during collaborative activities ("working on an activity you would expect to see other people working on the same artefact"), rather than sitting in assigned chairs as in MiRTLE+ with the Game Board interaction.

The value-embedded MR applications also focused on enabling the expressions of emotions. Participants felt that there was no eye or facial expressions communication in MiRTLE+, so it was hard to feel the emotions of others through Unified Avatars ("it is difficult to know if the person is listening to me in this way"). However, in value-embedded applications, students can communicate not only knowledge but also emotions, which may make them feel highly connected ("they can interact with others means they can share [the] same feeling and connected with others"). In addition, participants suggested nonverbal communication such as hand gestures, visual cues, and avatar emojis to increase *sense of belonging*.

Value-embedded applications offer diverse personalised support, such as Personalised Environments and Personalised Avatars. Participants expressed that the virtual classroom in MiRTLE+ resembled a "detention room" without being able to modify the MR environment. P1 remarked, "I would like to be able to move my chair or furniture to any locations [sic] I wanted", reflecting a desire for greater control over the virtual space. In contrast, the value-embedded applications provide students with personalised environments, contributing to a sense of comfort and belonging within the learning space ("students are able to change the theme, lighting or other objects in the environment that does not affect the other's interface so that they feel more belonged to the collaborative learning space"). Moreover, participants highlighted concerns regarding the avatars in MiRTLE+, describing them as "a bit too uncanny valley". In contrast, participants emphasised the importance of allowing students to design their own avatars, promoting greater *flexibility* and a stronger *sense of belonging*. Additionally, the integration of more Realistic Human Projections was suggested to enhance *trust* in the collaborative interactions. This enhanced personalisation was perceived as instrumental in promoting a more engaging and individualised learning experience.

All of the above differences between MiRTLE+ and value-embedded applications demonstrate a shift of design focus from performing tasks to supporting, reflecting and embedding values.

5.3 Impact of Value Selection on MR Features

The focus on different values in the workshops resulted in both contrasting and similar features within participants' value-embedded applications (see Table 3). While some of the differences and similarities stemmed from participants' perceptions of what was important in the VBD process, most of the differences were driven by explicit values.

Contrasting features primarily emerged between *trust* and *flexibility*, or *trust* and *sense of belonging*. Participants emphasised that realistic representations of students, teachers, and the classroom were critical for fostering *trust* within the MR environment ("they need to be as realistic as possible to increase trust"), such as Realistic Human Projections and Realistic Learning Space. Conversely, to promote *flexibility* and *sense of belonging*, participants proposed digital representations, such as Personalised Avatars, Virtual Assistants and Virtual Learning Spaces, which they believed would allow students to customise their collaborative learning experience and thus enhance their sense of community. One example is that participants from W2 designed Virtual Assistants to increase *flexibility* and *sense of belonging* as they could assist students with their collaboration ("get a virtual assistant who recap[s] what you did last time and point to what's next"), while for increasing the *trust* of the learning activities, they believed that Human Feedback should be provided ("gen Zs dont [sic] want feedback from AI but from real teachers"). Another example is that participants released the ability to use Virtual Learning Space for embedding *flexibility* and *sense of belonging* in various scenarios, while participants from W2 emphasised the Realistic Learning Space to maintain *trust* as they were closer to the reality.

However, there are also similar features, especially between *sense of belonging* and *flexibility*. Personalised Learning and Self-Paced Learning also emphasise *sense of belonging* and *flexibility*. Both value-embedded applications create the Virtual Assistant to increase *flexibility* ("re-direct the student to where they left off") and *sense of belonging*. Physical Sensation was created to increase *trust* and *sense of belonging*.

5.4 Participant Perspectives on Their Design

Participants provided valuable insights into the effectiveness of their value-embedded MR applications. While they recognised that several aspects of their designs successfully aligned with the target values, they also identified areas requiring further refinement to fully address the values.

Table 3: A comparison of features elicited from VBD workshops W1–W3 with the original MiRTLE+ application design.

MiRTLE+	Sense-of-Belonging (W1)	Trust (W2)	Flexibility (W2)	Sense-of-Belonging (W3)
Virtual Classroom	Virtual Classroom	Realistic Learning Space	Virtual Learning Space	Virtual Learning Space
-	Personalised Environment	-	-	-
Physical Classroom	-	-	-	-
-	Social Bubbles & Gather Town	-	-	-
-	-	-	-	MR "Portfolio Wall"
Unified Avatars	Personalised Avatars	Realistic Human Projections	Personalised Profile	Personalised Avatars
Press-to-Talk Button	Spatial Audio	-	-	Spatial Audio
-	Facial Expressions	-	-	-
-	-	-	-	Hidden Triggers
Shared Learning Activities	Interactive Learning	Standardised Learning	Personalised Learning	Non-Competitive Learning
Control Panel	Human-to-Human Interaction	-	-	Visual Speaker Cues
Game Board	Digital Objects Interaction	-	-	Digital Objects Interaction
-	Physical Sensation	Physical Sensation	-	-
Immediate Group Feedback	Individual Feedback	Human Feedback	-	-
-	Virtual Assistant	-	Virtual Assistant	-
Recognised Expertise Level	-	-	-	-
AR Interfaces	Cross Platform Supports	-	-	-
Authentication	-	-	-	Biometric System
-	Built-in Accessibility	-	-	-

Note: Social Bubbles refer to immersive virtual environments where individuals or small groups can interact and communicate, fostering a sense of belonging. The symbol "-" indicates instances where no equivalent or relevant feature was elicited or designed in comparison to other value-embedded applications.

5.4.1 Sense-of-Belonging-Embedded MR Application

Two sense-of-belonging-embedded MR applications were praised for fostering empathy, supportive community, and positive collaboration among students. P9 and P2 described the applications as effectively creating an environment where users could "understand and share the feelings of another" and "openly express your thoughts/ideas". These features were particularly effective in facilitating collaborative activities, such as being able to "annotate on each other's work" and "receive and give feedback". This enhances the connection among students and a sense of community that works together. In addition, the applications supported interactions among different group sizes, creating a fluent spectrum of *sense of belonging*, such as P10 said "switching between class wide and small group/private conversations". P3 emphasised the practical value of the application in educational contexts, stating, "I would actually find it useful for classroom contexts, it could allow suitable supervision and collaboration/social connection".

To further enhance *sense of belonging*, participants from W3 suggested incorporating non-verbal cues such as facial expressions, emojis and cheerful design elements to express collaborative moments. As P12 and P10 described the application should support "showing facial expressions" and "controlling the avatar's facial expressions". Interestingly, the missing feature of Facial Expressions was included in the MR application from W1. Similarly, P10 recognised the importance of cross-platform support to maintain a seamless user experience across different devices and systems, which was a feature incorporated in the application designed in W1. Moreover, participants from W3 advocated for consistent identity representation, including avatar, icon, video, screen name, and profile colour. P12 emphasised the need for user consent when sharing collaborative space such as "ask permission when inviting other people to join your virtual space". However, they acknowledged potential value conflicts in the design process and stressed the need for deeper understanding and management of such conflicts ("understanding of potential conflicts with other values"). These long-standing issues can be further addressed through the application of the VBD process.

In addition to the limitations related to the embedded values, participants identified several challenges in their designs that were not directly associated with value conflicts but instead arose from technical constraints. These challenges included concerns about the connectivity requirements necessary for the application to function effectively, as well as the need to improve digital literacy among students. Addressing these issues was considered essential for enhancing the overall student experience, particularly in the context of MR remote collaboration.

5.4.2 Trust-Embedded MR Application

Participants expressed confidence that their trust-embedded MR application promoted transparency, validation, and standardisation of learning content, which contributed to a more trustworthy learning experience. As P6 and P8 noted, the application was designed to "be transparent about things that are being taught" and to provide "reassurance that [I] get the right, validated, and similar content that my peers are getting". Additionally, participants highlighted the meaningfulness of the Realistic Human Projection feature in fostering trust, as it conveyed the presence of real individuals in the virtual space rather than artificial agents. P5 remarked that "[a] more realistic representation of the collaborators" enhanced trust between users and peers within the system.

Despite these strengths, participants identified areas for further improvement, particularly in enhancing the safety of the learning environment. Suggestions included implementing alternative login methods as opposed to traditional password-based systems ("people can log in with their unique gestures/facial expressions instead of a specific password"). Furthermore, participants emphasised the importance of encrypting conversations between students and virtual assistants to ensure data security ("the proposed virtual assistance should ensure the encrypting the conversations having with the students"). Participants argued that these improvements would further enhance the application's ability to foster *trust* among students.

5.4.3 Flexibility-Embedded MR Application

For the flexibility-embedded MR application, participants believed that their design effectively personalised the learning experience by accommodating individual preferences. As P7 noted, the application allows for "personalising the content and experience based on the user preference and their behaviour". This flexibility was further emphasised by P5 and P6, who agreed that the application overcomes traditional constraints of physical location and time, enabling students to "attend a session anytime and anywhere".

However, participants also identified challenges related to data collection and privacy. Specifically, P7 raised concerns about striking a balance between personalising the students' experience and ensuring data privacy ("[we need to] find the balance between to collect [sic] the user behaviour data without going into the surveillance data"). P5 also suggested that the application should not be restricted to a fully virtual environment, emphasising that the physical learning space should be included to accommodate various preferences ("maybe we should not eliminate the option for people to attend physical classes").

6 Discussion

This research serves to bridge the MR community and the value-based design community. The motivation behind this study is to shift the design focus for MR applications from a usability-driven perspective to a value-driven perspective. In this section, we reflect on our findings, research methods, and limitations, and we provide recommendations for future work.

6.1 Reflect on Research Methods

Our proposed VBD process and associated evaluation methods address RQ1&2, responding to current MR design approaches lacking consideration for delivering on human values, which should be a key goal in HCI [15]. First, there is a lack of methodologies specifically aimed at integrating values into MR applications. In section 3 we address RQ1 through the proposal of a new VBD process to introduce values into an MR design. The evaluation in section 4 and findings in section 5 answer RQ2, which demonstrates the impact of the VBD on the explicit incorporation of values. Our research found the primary distinction between value-embedded applications and the existing application lies in the fact that, while both facilitate remote collaborative learning, value-embedded applications place additional emphasis on students' life-ability learning experience rather than task-based usability, such as the Social Bubbles feature for enhancing a sense of belonging. Furthermore, the selection of different values significantly influences the development of both contrasting and similar features within value-embedded applications. Thus, the VBD process helps develop the ability to consider values in MR and provides practical insights for the development of future MR regulations to address value-based issues. However, this proposed process is not intended as a definitive solution. Rather, it serves as an illustrative example to initiate discussions within the MR community about integrating values into MR design and fostering the development of value-based approaches in this field.

6.2 Reflect on VBD Process

Our VBD process should be viewed not as a one-time initiative, but as an ongoing consideration throughout all stages of design. This perspective is critical, as values are not static; they continually evolve over time and may vary with the involvement of different groups [56] in the MR environment. If we metaphorically consider all the values identified in MR design as a "human-value cloud[3]", this cloud will inherently shift as MR scenarios change, the affected groups evolve, and the temporal context of use transforms. It also emphasises that human values are not fixed or isolated, but influence each other and change over time. For example, the value of *privacy* may interact with *accessibility* and require trade-offs or compromises in certain design decisions. This dynamic nature requires ongoing consideration throughout the design lifecycle, rather than treating them as static requirements. Thus, the VBD process must be adaptive and responsive to these ongoing changes.

Moreover, the role of designers in MR application design should extend beyond that of MR technical specialists alone. Currently, decision-making in MR design projects heavily relies on system experts and sometimes end-users through the design process. Yet, our VBD process fosters collaboration among MR experts, design experts, end-users, and domain experts, such as educational experts, to design applications that prioritise human values. Each of these roles is vital in MR design, contributing diverse perspectives that enrich the conceptualisation, integration, and reflective evaluation of values. As suggested in the field of value-based engineering, the inclusion of roles such as value leads [1] and value experts [60] is essential in the system design process. Their involvement in MR design can facilitate a more meaningful and respectful approach, given their expertise in ethics, values, and technology.

6.3 MR Collaborative Learning Design

Focusing specifically on the context of MR collaborative learning, current MR designs predominantly emphasise technical issues, such as enhancing immersion, accuracy, and consistency [43]. While these works may not explicitly address values, several value-embedded MR features identified in the workshops can be effectively realised using existing MR techniques. For instance, the feature of Visual Speaker Cues can be implemented through awareness cues [50, 51], which facilitate quicker identification of a collaborator's gaze direction. Additionally, gesture expressions for the feature of Human-to-Human Interaction can be achieved using augmented 3D hands [30] and hand gesture sharing [4]. These value-embedded features can also be implemented using AR/VR concepts [29, 54], referring to a concise, pattern-based approach that enables modular, and user-friendly design within learning environments. This indicates that MR designers need not develop entirely new value-embedded features; instead, they can leverage existing MR technologies in a value-driven manner. Such an approach has the potential to significantly contribute to the MR community by fostering more respectful and value-oriented designs.

6.4 Limitations

We acknowledge several limitations in our research. First, the current VBD process primarily focuses on developing features that embed human values and telling value stories in MR experiences that show how value is embodied when users engage with MR applications. Other potential approaches for incorporating values, such as whether we can incorporate behaviours that embody specific users' values into the MR experience, as well as the values embedding at the level of social applications rather than at the level of MR development, remain underexplored in this research. Second, to observe the integration of values, we focused on embedding a single value. However, in real-world MR application contexts, the situation is often complex, necessitating consideration of how multiple values can coexist, interact, and either constrain or reinforce one another. Third, the VBD process has not yet been tested in the context of real-world application development, where value-embedded features are fully implemented. As a result, its impact on value integration in actual MR systems is not yet fully understood. The MiRTLE+ shows a collaborative card game activity within a remote learning environment. While this example provides a testbed, it raises questions about its real-world applicability to other learning activities. Exploring diverse collaborative learning contexts or scenarios could offer a more robust evaluation. Fourth, the generalisability of the VBD process across multiple MR application domains has not been established. Our research tested the process within MR remote collaboration and the relevance of specific values in designing MR experiences may vary across different usage scenarios. For example, the concept of *sense of belonging* in a social interaction scenario may be more complex and multifaceted than *sense of belonging* in an MR meditation context. Thus, further analysis on a case-by-case basis is needed to assess the broader applicability of the VBD process.

6.5 Recommendations for Future Work

As noted in the limitations, future research for value specialists within the design community could focus on several key areas. First, it is important to explore which value-related design methodologies are appropriate for the design of MR and to examine how different approaches influence embedding values in MR design. For example, conducting comparative studies that directly investigate the differences between the value-related design methodologies for MR and non-MR applications. Our study revealed that participants were more inclined to understand and embed values in MR design through Value Storyboard; however, transitioning from values to functional design in MR poses significant challenges, making it difficult to conceptualise necessary functionalities. Therefore, investigating additional value-based activities that could assist design teams in integrating these values is essential. Second, researchers should address how to incorporate multiple values

[3]We define the human-value cloud as a dynamic and fluid collection of human values. The "cloud" metaphor emphasises the interconnected, dynamic, and nonlinear nature of these values, which are not static but instead adapt based on the application context, groups of people, and temporal factors. Importantly, the term "cloud" does not imply a physical or 3D representation; rather, it is intended to highlight the fluid and adaptive nature of these values.

in complex real-world MR applications and consider how to manage conflicting values among different groups within the MR environment. Third, there is a need to investigate how to embed the values of indirect groups of people into MR experiences, rather than solely direct users. For example, when a student is engaged in a remote collaboration at home, how might a parent's presence in the MR space affect their privacy? Finally, the current VBD process for MR applications requires further refinement to ensure its suitability across multiple MR application domains. This highlights the urgent need for additional insights from value specialists to enhance this framework.

For MR specialists in the HCI community, future work could focus on several key areas. First, beyond focusing mostly on functionality and usability needs, MR experts can utilise the VBD process to explore the values of the target users or direct/indirect stakeholders consider important, and add value requirements to design requirements. Second, with transparency and accountability emerging as key requirements for ethical MR design, the appropriate documentation of VBD processes for scrutiny and compliance by third parties will need to be explored. Third, evaluating the VBD process across diverse MR application scenarios will help determine its adaptability and efficacy.

For the broader community, including policymakers, industry stakeholders, and international organizations, efforts should focus on raising awareness of value considerations in the design and deployment of large-scale MR platforms, establishing regulations or design principles that prioritize value integration, fostering best practices for value-driven design, and assessing the social implications of MR design to ensure that technology serves the broader community effectively and equitably.

7 Conclusion

This research aimed to investigate methodologies for introducing human values into MR designs. To achieve this, we introduced the first VBD process tailored specifically for MR, building on established interaction design practices. Our VBD process integrates value-centred perspectives into key design activities, such as value conceptualisation and value storyboard. Additionally, we developed a practical workshop template to facilitate the use of the VBD process in designing value-embedded MR applications. To evaluate the effectiveness of the proposed VBD process, we conducted three practical workshops in which participants designed MR three value-embedded applications around specific values. These applications were subsequently compared to an existing MR application to assess the utility of the VBD approach.

Our findings demonstrate that the VBD process enables participants to design MR applications that prioritise specific values, such as creating a more supportive and inclusive learning environment to foster a sense of belonging or developing a transparent and standardised MR learning experience to enhance trust. Furthermore, the selection of different values resulted in both contrasting and convergent features within participants' designs, highlighting the significant influence that a value-based perspective can have on MR design.

This research establishes a foundational practice for embedding values into MR applications and addresses the need for value-based design approaches in MR development. These findings offer important contributions to the ethical and human-centred design of MR systems, fostering more socially responsible solutions.

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