

Fiziksel Olanın Ötesinde Endüstriyel Tasarım: Unreal Motoru Kullanılarak Yürütülen Sanal Ürün Geliştirme Uygulamaları Üzerine Otoetnografik Bir İnceleme

Hüseyin Özkal ÖZSOY^{1*}

¹Mimar Sinan Güzel Sanatlar Üniversitesi, Mimarlık Fakültesi, Endüstriyel Tasarım Bölümü, 34672, İstanbul

¹<https://orcid.org/0000-0001-5531-3539>

*Sorumlu yazar: ozkal.ozsoy@msgsu.edu.tr

Araştırma Makalesi

Makale Tarihi:

Geliş tarihi: 19.06.2025

Kabul tarihi: 27.09.2025

Online Yayınlanma: 16.03.2026

Anahtar Kelimeler:

Endüstriyel tasarım
Sanal ürün geliştirme
Unreal Motoru
Oto etnografi
Dijital prototipleme

ÖZ

Bu araştırma, fiziksel olarak hiç üretilmeyen sanal ürünlerin, gerçek zamanlı bir 3B ortamda nasıl kavramsallaştırılabileceğini, yinelemeli biçimde geliştirilebileceğini ve değerlendirilebileceğini otoetnografik bir metodoloji aracılığıyla incelemektedir. Unreal Engine'in yüksek doğruluklu görselleştirme, yapay zekâ destekli davranış simülasyonu ve etkileşimli prototipleme olanaklarından yararlanılarak, yalnızca sayısal bağlamlarda (örneğin oyunlar, simülasyonlar ve bilgisayar üretimi medya) kullanılmak üzere tasarlanan ADA isimli Akıllı Sosyal Yoldaş Ürününün geliştirilme süreci belgelendirilmiştir. Dört haftalık süreç boyunca, 1. hafta başlangıç değerleri ile karşılaştırıldığında önemli iyileşmeler gözlemlenmiştir: Davranışsal Karmaşıklık Skoru %180 artmış, Anlatsal Tutarlılık %70 gelişmiş, farklı duygusal ifade sayısı ise %175 oranında artmıştır. Anlatsal entegrasyon metriklerinde de büyüme kaydedilmiştir; örneğin Anlatı Tutarlılık İndeksi %104, Bağlamsal Anlamsal Uyum ise %72 artış göstermiştir. Otoetnografik öz-değerlendirme ölçümleri, bilişsel yükte %45 azalma, akış halinde çalışma deneyiminde %129 artış ve epistemik güven düzeyinde %85 yükseliş göstermiş, bu da tasarım sürecindeki teknik ve deneysel ilerlemeyi ortaya koymuştur. Bu bulgular, fiziksel prototipleme olmaksızın da anlamlı, anlatı açısından zengin ve duygusal derinliğe sahip tasarım niteliklerinin sistematik olarak elde edilebileceğini göstermektedir. Çalışma, sanal ürün tasarımının yalnızca geliştirme maliyetlerini düşürmek ve yaratıcı özgürlüğü artırmakla kalmayıp, aynı zamanda "kullanışlılık" kavramını da anlatsal bütünlük, sembolik anlam ve duygusal etkileşim bağlamında yeniden tanımladığını ortaya koymaktadır. Bu sonuçlar, gerçek zamanlı 3B ortamların endüstriyel tasarım eğitimi ve pratiğinin geleceğinde üstleneceği rolü vurgulamaktadır.

Industrial Design Beyond the Physical: An Autoethnographic Investigation into Virtual Product Development Practices Using Unreal Engine

Research Article

Article History:

Received: 19.06.2025

Accepted: 27.09.2025

Published online: 16.03.2026

Keywords:

Industrial design
Virtual product development
Unreal Engine
Autoethnography
Digital prototyping

ABSTRACT

This research investigates how virtual products, which are never physically manufactured, can be conceptualized, iteratively refined, and evaluated within a real-time 3D environment using an autoethnographic methodology. Leveraging Unreal Engine's capabilities for high-fidelity visualization, AI-driven behavior simulation, and interactive prototyping, the study documents the design and development of ADA, an Intelligent Social Companion Product intended exclusively for digital contexts such as games, simulations, and computer-generated media. Across a four-week process, findings demonstrated substantial improvements when compared to Week 1 baseline values: the Behavioral Complexity Score increased by 180%, Narrative Coherence improved by 70%, and the number of distinct emotional

expressions expanded by 175%. Narrative integration metrics likewise showed growth, including a 104% increase in Narrative Consistency Index and a 72% rise in Contextual Semantic Fit. Autoethnographic self-report measures indicated a 45% reduction in cognitive load, a 129% increase in flow state, and an 85% rise in epistemic confidence, underscoring both the technical and experiential progression of the design process. These results reveal how expressive, narrative-rich, and affective qualities can be systematically achieved in the absence of physical prototyping. The study concludes that virtual-only product design not only reduces development costs and expands creative freedom but also redefines “usefulness” in terms of narrative integration, symbolic resonance, and emotional engagement. These insights highlight the emerging role of real-time 3D environments in shaping the future of industrial design practice and education.

To Cite: Özsoy HÖ. Industrial Design Beyond the Physical: An Autoethnographic Investigation into Virtual Product Development Practices Using Unreal Engine. *Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi* 2026; 9(2): 656-684.

1. Introduction

The boundaries of industrial design practice are rapidly evolving in response to the growing integration of immersive, real-time visualization technologies (L. Guo and Wang, 2021). Traditionally, industrial design has focused on the creation of physical products, with methodologies rooted in sketching, model-making, prototyping, and user testing (Page, 2000; Buchanan, 2009; Self, 2012). However, with the proliferation of powerful digital engines such as Unreal Engine (Sanders 2016), there is a notable shift toward the conceptualization and development of virtual products (Algharabat et al., 2017), which are not intended for physical realization, but instead exist and function solely within digital environments such as video games, simulations, video clips or other interactive computer-generated media (Yadav and Pavlou, 2020).

This shift is not merely technological but epistemological (Kuhn and Weinstock, 2002); it demands a reconsideration of how we define a "product", what constitutes "use", and how designers evaluate form, function, and interaction when tangibility (Djajadiningrat et al., 2004) is no longer present. As industrial design increasingly intersects with disciplines such as digital art, game design, and virtual simulation (Bernardo and Duarte, 2021, 2023; Zhang et al., 2024), the emergence of non-physical yet fully interactive and experiential products represents a critical area of inquiry (Desmet and Hekkert, 2007; Ferrar, 2009). These virtual products are no less complex than their physical counterparts; they require careful attention to ergonomics, user experience, system behavior, and visual expression (Bordegoni and Ferrise, 2013). However, they also present new opportunities: freed from the constraints of manufacturing, material costs, and physics, designers can experiment with novel forms and interactions that may be infeasible or impossible in the real world (Lee et al., 2001).

Among the most compelling cases for virtual-only product design is the development of Intelligent Social Companion Products, which blend characteristics of smart devices, socially assistive robots, and digital avatars (Chaturvedi et al., 2023). These are envisioned as interactive, emotionally expressive entities designed to accompany users in digital spaces, games, narrative experiences, or simulations, supporting entertainment, education, or companionship (Breazeal, 2000; Pfadenhauer, 2015). Their use

is not limited by physicality; their realism, affective behavior, and utility derive entirely from visual scripting (Davis et al., 2011), artificial intelligence (AI) logic (Nilsson, 1991; McCarthy, 2022), and the experiential quality of interaction rendered within their realm, which can also be a real-time engine such as Unreal Engine (Lee, 2023).

This study aims to explore the implications of designing a product that operates within Unreal Engine, not as a game asset in the traditional sense, but as a virtual industrial product, a designed object with intentional form, interaction, and functionality, situated entirely in a digital environment. Through an autoethnographic investigation (Cooper and Lilyea, 2022), the author assumes the dual role of designer and researcher, developing an Intelligent Social Companion Product (Clavel et al., 2013) while systematically reflecting on the tools, processes, and outcomes encountered. This method facilitates an in-depth examination of the cognitive processes and design procedures involved in virtual product development (Bao et al., 2002), unencumbered by the limitations of physical fabrication.

Unlike previous research that focused on Unreal Engine for physical product visualization or prototyping (Müller et al., 2016; Kloiber et al., 2020; Ghinea et al., 2021; David et al., 2022), this study diverges by emphasizing virtual products as end-products, not as steps toward physical realization, but as legitimate design outcomes. It interrogates the notion of product utility in digital environments and examines how industrial design principles must adapt when the product will never be held, touched, or physically operated. The Unreal Engine environment serves not only as a design and testing platform, but also as the final habitat for the product.

Therefore, the research raises fundamental questions: *What constitutes success or failure in virtual product design? How is usability evaluated in a digital-only context? What role does behavior simulation play in product identity? And how can industrial designers meaningfully contribute to these emerging domains, traditionally dominated by digital artists or software developers?* These questions are addressed through both qualitative reflections and quantitative data collected during the design process.

The primary aim of the study is to investigate how an intelligent, non-physical product can be systematically developed, iteratively refined, and evaluated entirely within a real-time 3D environment, using an autoethnographic methodology. This focus distinguishes the work from prior research that emphasizes physical prototyping or surface-level visualization. By operationalizing custom evaluation metrics—behavioral complexity, narrative coherence, and emotional expressiveness—alongside autoethnographic reflection, the study demonstrates how industrial design methods can be extended into purely virtual ecosystems.

In doing so, the research makes an original contribution to industrial design knowledge by (1) defining methodological pathways for virtual-only product development, (2) proposing novel criteria for evaluating non-physical products, and (3) reframing “usefulness” through narrative and affective dimensions rather than ergonomics or manufacturability. These theoretical and practical contributions highlight the expanding terrain of 21st-century design practice.

2. Background Information and Literature Review

As industrial design continues to evolve in tandem with advancing digital technologies (Loy et al., 2015), the boundaries between physical and virtual products are becoming increasingly blurred (Roberts et al., 2020). To provide context for the study, this section reviews key developments in industrial design's digital transformation, the growing relevance of real-time engines like Unreal Engine, and the emergence of intelligent companion products in both physical and virtual environments. Additionally, it introduces the autoethnographic research approach used in this work and highlights the current gaps in the literature regarding the design of purely virtual products.

2.1. The Evolution of Industrial Design in the Digital Age

The field of industrial design has historically focused on the conception and realization of tangible products that fulfill functional, aesthetic, and user-oriented goals (Gatzky, 2020). Traditional workflows have relied heavily on physical prototyping, ergonomic testing, and material-driven iterations (Page, 2000). However, in the last two decades, the proliferation of digital tools has radically transformed the industrial design landscape (Zhao and Cai, 2023). Computer-Aided Design (CAD), rapid prototyping, and Virtual Reality (VR) have enabled designers to visualize, simulate, and refine products before producing physical prototypes (Jezernik and Hren, 2003; Özsoy, 2019). These technologies have largely served to support and enhance physical product development rather than replace it (Tan and Li, 2024). Recent developments, however, suggest a new paradigm is emerging: the design of products that are never intended for physical realization. This trend is evident in areas such as digital fashion (Colby, 2024; Collins and Thompson, 2024), speculative design (Dunne and Raby, 2024), and virtual architecture (Ghaziany, 2022), where designed artifacts are experienced and interacted with solely within digital platforms. In industrial design, this marks a significant departure from material-centric practices, raising questions about the role of function, interactivity, and usability when physical affordances are not involved (Sentana-Gadea et al., 2025). In parallel, the increasing integration of artificial intelligence into design workflows (Elal and Özsoy, 2024) is poised to influence virtual product development practices, shaping how designers conceptualize, iterate, and evaluate digital artifacts within environments such as Unreal Engine.

2.2. Unreal Engine and Virtual Product Design

Unreal Engine, developed by Epic Games, has become a dominant platform in real-time 3D content creation, particularly within the gaming and cinematic industries (Lee, 2023). Its visual scripting interface (Blueprints), high-fidelity rendering capabilities, and support for artificial intelligence have made it increasingly attractive to designers outside its original gaming context (Sanders, 2016). Recent academic studies and industry reports have highlighted its potential for product visualization, prototyping, and interactive simulation (Özsoy, 2025; Xiao, 2025).

While much of the research on Unreal Engine in design education and practice has focused on using the engine as a visualization tool for physical products (Pizzolante et al., 2024; Zhong et al., 2024), there is

limited academic attention given to the engine as a platform for the final deployment of virtual products themselves. This study attempts to address that gap by treating Unreal Engine not merely as a simulation or visualization medium, but as a full-fledged ecosystem for designing and delivering end-user digital experiences with industrial design rigor.

2.3. Intelligent Social Companion Products in Digital Contexts

The concept of Intelligent Social Companion Products intersects with several fields, including socially assistive robotics (Naseer et al., 2025), human-computer interaction (Ding et al., 2024), and affective computing (Pervez et al., 2024). These products are characterized by their ability to interpret, simulate, or respond to social cues, typically to provide emotional support, entertainment, or companionship. In physical embodiments, examples span from robotic pets such as Sony's Aibo to therapeutic robots like Paro, as shown in Figure 1 (Ompico et al., 2021).



Figure 1. Sony Aibo (AIBO 2025) and Paro (The Therapeutic Robot 2025)

In digital domains, similar behaviors can be simulated through AI-driven avatars, virtual assistants, and game characters (Qu et al., 2025). However, these entities are often created by developers or animators with limited adherence to industrial design practices (Mortimer et al., 2024). There remains a rich opportunity to explore how designers, trained in product semantics, interaction logic, and user-centered principles, can contribute to the development of intelligent virtual-only products that may exhibit "lifelike" behavior or emotional intelligence, yet exist solely within a simulated world.

2.4. Autoethnography and Design Research

Autoethnography has increasingly gained recognition in design research as a means of bridging practice and reflection, particularly in contexts where the researcher simultaneously assumes the role of designer (Bochner and Ellis 2016; Adams et al., 2017). This methodology allows deep introspection and systematic documentation of design thinking, challenges, and learning processes (Xue et al., 2025), which is particularly suitable for emerging topics where standardized methods are not yet established. Autoethnography, which positions the researcher as both observer and participant, is a suitable method for exploratory, design-led inquiries where experiential insights significantly contribute to knowledge production (Ellis et al., 2011).

In the context of virtual product design, autoethnography enables designers to capture the tacit, experiential knowledge involved in working within a real-time visualization platform such as Unreal Engine (Xue et al., 2023). Through iterative reflection, log-keeping, and analysis, this method facilitates a structured understanding of how tools, decisions, and constraints shape the resulting product, even when the product is entirely virtual.

2.5. Gaps and Opportunities in Existing Literature

Despite the increasing importance of virtual environments in contemporary design practice (Jahandideh, 2024), a substantial gap persists in the literature regarding how industrial designers conceptualize and develop non-physical products as final design outcomes rather than as intermediate steps in traditional workflows. Most existing literature treats the digital realm primarily as a transitional stage for prototyping or visualization (Akpan and Offodile, 2024; Wang et al., 2024), rather than as a legitimate and final context for product use. Moreover, although virtual companions, as shown in Figure 2, have been extensively explored by game and interaction designers (Guo et al., 2024; Pretty et al., 2024; Xie et al., 2024), contributions from industrial design, especially those focusing on form-giving, affordance design, and user-centered empathy, remain notably underrepresented.

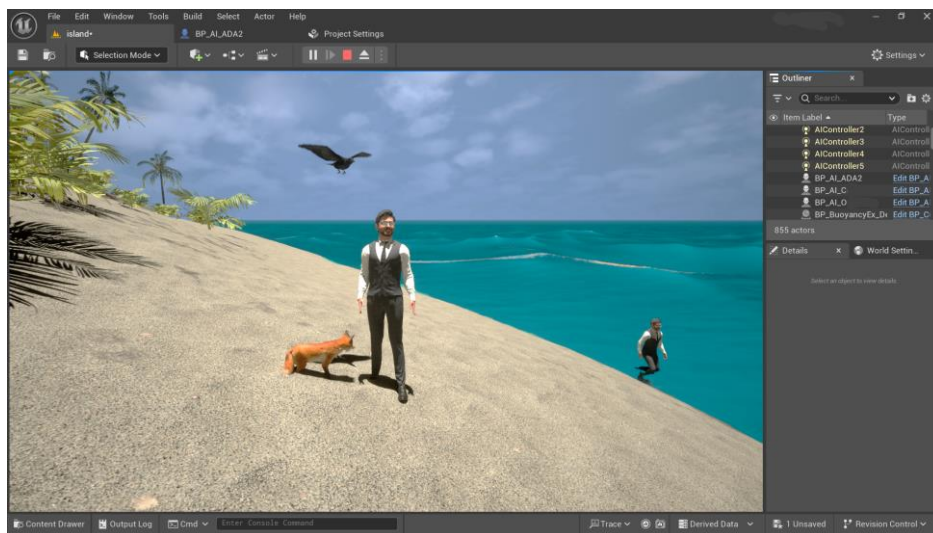


Figure 2. The player character is in the middle, accompanied by his virtual companions, the crow and the fox, who follow him at all times. On the right is an AI version of the player character wandering randomly (An environment exploration game designed and programmed by the Author.)

This study responds to these gaps by

- Proposing a framework for designing virtual-only intelligent products with industrial design principles,
- Exploring how Unreal Engine supports such a process,
- Reflecting on the implications for the future of industrial design education and practice.

The focus on a product that blends robotic, intelligent, and companion characteristics, yet is never intended for physical production, offers a new lens through which to examine what it means to “design” in a post-material context.

3. Methodology and Case Study

The study adapts the autoethnographic methodology (Adams et al., 2017; Cooper and Lilyea, 2022) mentioned in the previous sections to investigate the processes, challenges, and opportunities associated with designing a virtual product that exists exclusively within a real-time 3D environment. The product developed for this case study combines the affordances of socially assistive robotics (Matarić and Scassellati, 2016), virtual pets (Rault, 2015), and smart devices (Silverio-Fernández et al., 2018), yet it exists solely in a virtual realm. The approach enables a reflexive and critical investigation into the design process, not merely as an act of artifact creation, but as a research method.

3.1. Research Aim and Design Framework

The primary research objective is to explore and demonstrate how Unreal Engine facilitates the development of fully virtual, socially interactive intelligent products and assess the cognitive and creative value of designing for non-physical deployment. The research follows a structured design process, adapted from traditional product development models (Ulrich and Eppinger, 2011), but modified to accommodate the affordances of real-time virtual prototyping. The framework of this process consists of:

- Contextual Research and Benchmarking
- Conceptual Design and User Scenario Creation
- Asset Modeling and Rigging
- Blueprint Scripting for Behavior Simulation
- Interface Mockups and Feedback Simulation
- Narrative Integration and Deployment Testing

Each step was documented through design journals, annotated screenshots, screen recordings, and reflective memos, resulting in a robust corpus of qualitative data that captures both the procedural and experiential dimensions of the study.

3.2. Researcher Biography

The designer-researcher conducting this study possesses a hybrid background in electronics engineering and industrial design, which directly informs the aims, methods, and interpretations of the work. His academic background comprises separate MSc degrees in Electronics Engineering and Industrial Design, followed by a PhD in Industrial Design. He currently holds an associate professor position in industrial design. He has teaching responsibilities in areas such as advanced CAD, simulation-oriented CAD, electromechanics, intelligent product design, and software management, while also serving as a

technical consultant in university projects. This trajectory reflects long-standing expertise in parametric modeling, digital simulation, and electro-mechanical integration. Professionally, the researcher has held roles as an industrial designer and design engineer across sectors, including defense, solar energy, lighting, telematics/IoT, and instrumentation, with responsibilities that cover enclosure and human-machine interface planning, PCB design, and embedded firmware development. These experiences contribute to advanced proficiency in CAD modeling, embedded prototyping, and interaction design, while also underpinning current competence with real-time visualization and interaction prototyping using game engines such as Unreal Engine 5. This professional and academic profile constitutes both an asset (technical depth for building high-fidelity virtual prototypes) and a positional lens, as it may lead to an emphasis on manufacturability, system behavior, and interaction logic when interpreting results.

3.3. Tools and Platforms

3D models used in this research were created in SolidWorks, as shown in Figure 3.

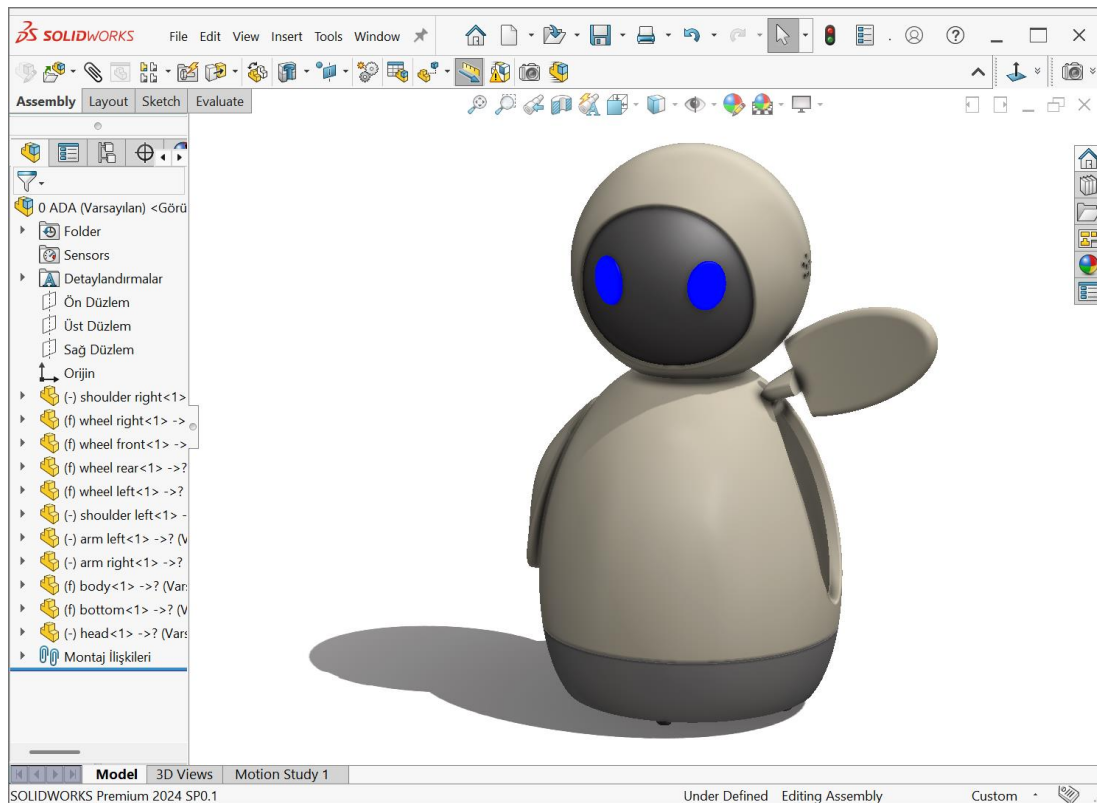


Figure 3. ADA (Autonomous Digital Assistant) 3D model in SolidWorks (Author's work)

Other tasks, such as virtual world generation and coding, were conducted using Unreal Engine 5, primarily utilizing its Blueprints visual scripting system, Niagara particle system, and Control Rig for animation prototyping, as shown in Figure 4. No physical materials or prototyping tools were used, as the entire workflow was restricted to virtual design environments.

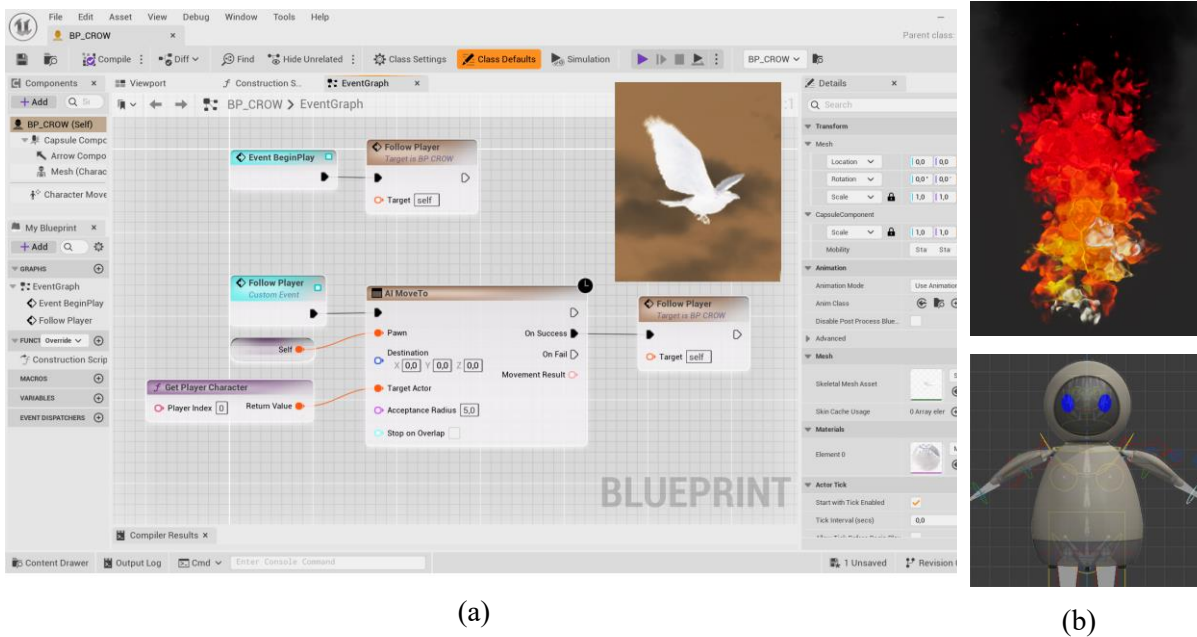


Figure 4. *a:* AI-controlled Crow and its Blueprint command blocks.
b: Fire generated with Niagara Particle System, and Control Rig for animation
 (The author's game project).

3.4. Timeline of the Study

The development of ADA was conducted between March 4, 2024, and March 31, 2024, over a period of four weeks. In total, the process comprised approximately 98 hours of active work, distributed across 20 sessions. The workflow was structured into distinct phases: (1) Conceptualization and Initial Modeling (March 4–8; 5 sessions, 22 hours), (2) Detailed 3D Modeling and Virtual Integration using SolidWorks and Unreal Engine (March 9–15; 6 sessions, 30 hours), (3) Animation and Gesture-Response Module Development (March 16–22; 5 sessions, 26 hours), and (4) AI Behavior Design, Testing, and Iterative Refinement (March 23–31; 4 sessions, 20 hours). Each phase built upon the outcomes of the previous one, ensuring a cumulative progression toward the final virtual prototype. This timeline clarifies both the temporal allocation and methodological rigor underlying the autoethnographic case study.

3.5. Autoethnographic Documentation

To ensure methodological rigor and traceability, the study employed a set of structured qualitative research protocols (Creswell and Poth 2018), which included documentation such as shown in Figure 5:

- **Reflective Memos** – Written after each session to capture insights, frustrations, and cognitive breakthroughs.
- **Thematic Coding** – Applied retroactively to the memos to identify recurring motifs such as iteration patterns, interaction dilemmas, and immersion affordances.
- **Process Timelines** – Logged time spent in each design phase to quantify workload and complexity distribution.

- **Virtual Interaction Logs** – Evaluations of in-engine testing scenarios, including how the virtual product responds to user inputs and environmental stimuli.

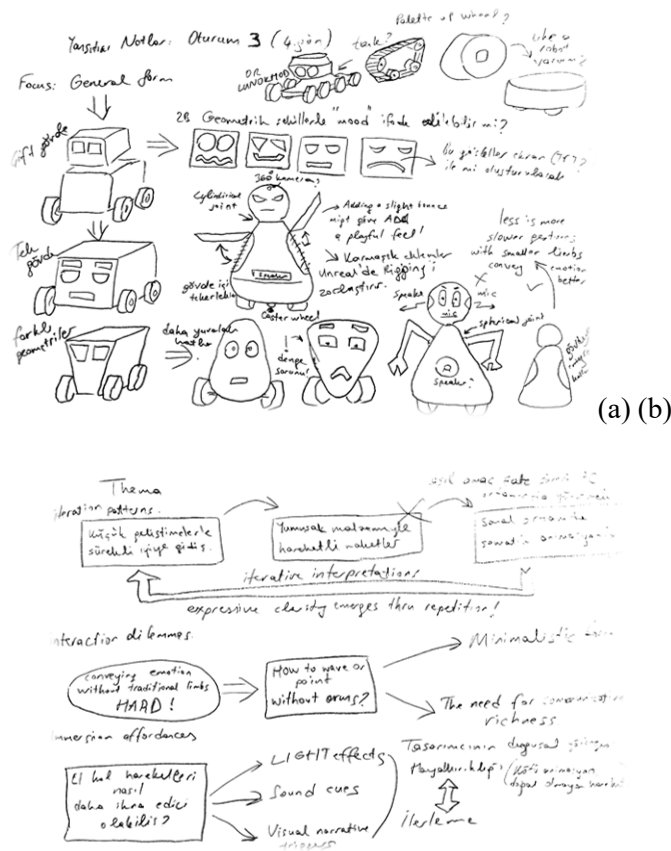


Figure 5. Sample reflective memo page with timeline (a) and thematic schema for interaction design (b).

3.6. Development of Evaluation Metrics

To complement qualitative documentation, three custom evaluation metrics were developed to capture the evolving expressive and narrative qualities of the virtual product. Each metric was designed to reflect the specific affordances of Unreal Engine’s state-driven architecture and the speculative, non-physical context of the study.

3.6.1. Behavioral Complexity Score

This metric was derived from weekly interaction logs within Unreal Engine, with behaviors defined as distinct state transitions ADA could execute in response to contextual triggers. Each new state or conditional pathway was logged and weighted according to its ability to expand the agent’s interactional repertoire. The score was normalized on a 5-point scale to allow comparability across development weeks.

3.6.2. Narrative Coherence Score

Narrative alignment was operationalized through structured self-evaluation during weekly scenario deployments. Using reflective memos, each iteration was assessed against a 5-point rubric that emphasized consistency between ADA's behavior and the narrative objectives of the scenario (e.g., maintaining believability, sustaining story logic, supporting thematic symbolism).

3.6.3. Emotional Expressiveness Index

This index measured the number of distinct emotional states ADA could display in contextually appropriate ways. Expressive states were defined as discrete combinations of animation, gestures, and timing cues, evaluated through both interaction testing and design journal reflections. Each addition was logged when the system demonstrated clear affective distinctiveness (e.g., surprise vs. concern, joy vs. calm).

Together, these three metrics provided a structured means of tracking iterative development in dimensions that are central to virtual-only product design: behavioral richness, narrative alignment, and affective depth. While author-developed and not externally validated, they offered a systematic framework to complement autoethnographic insights and thematic analysis.

3.7. Case Study Summary

The case study is done within the design process of an Intelligent Social Companion Product, named ADA. Designed to operate within a speculative narrative scenario, ADA is capable of responding to user prompts, simulating emotional states, and assisting in virtual environments. Core interactions are derived by investigating various other commercial digital assistants, as shown in Figure 6. They include gaze tracking, gesture response, context-sensitive dialogue, and adaptive emotional feedback, some of which are simulated using Unreal Engine's Blueprint system. As the model was not intended for end-user deployment, it served as a research probe to evaluate design feasibility, behavior richness, and emotional believability in virtual-only products.

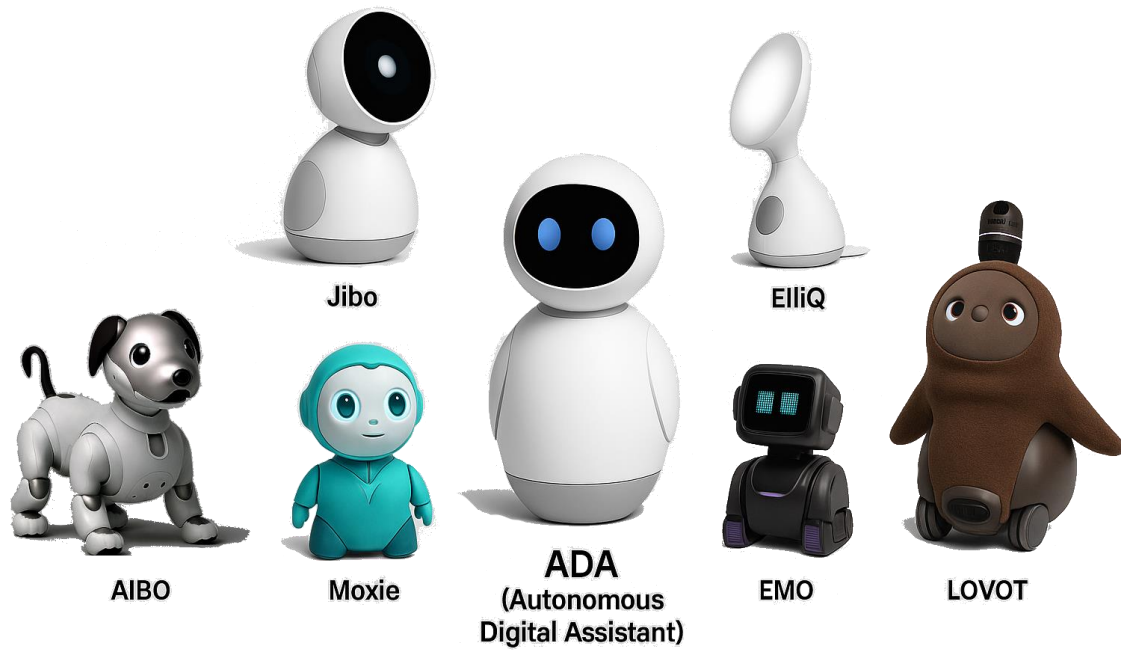


Figure 6. ADA and other commercial intelligent social companion products.

By the end of the study, ADA functioned as a modular and behavior-rich character suitable for integration, as shown in Figure 7, into diverse Unreal Engine contexts, including interactive storytelling, games, and virtual training modules. The design process was analyzed for its efficacy, creative freedom, and implications for the broader practice of industrial design in post-physical contexts.



Figure 7. Various moods of Ada in an Unreal Engine environment (Author’s 3D models and code)

3.8. Validity and Limitations

The study demonstrated the potential of virtual-only product design; however, several challenges arose during the research process. These difficulties not only influenced the project's direction but also emphasized the limitations of current tools and methods, summarized as follows.

Learning Curve with Unreal Engine: Although Unreal Engine offered high-fidelity visualization and a flexible state-driven architecture, its technical depth posed a steep learning curve. The initial phases of the study demanded considerable time investment to develop proficiency in Blueprint scripting and to implement basic interaction logic. This slowed early iterations and contributed to elevated cognitive load in the first two weeks.

Managing Cognitive–Emotional Strain: The autoethnographic approach required continuous self-observation and reflection, which at times led to heightened self-awareness that disrupted the design “flow.” Balancing the dual roles of designer and researcher occasionally introduced tension, particularly in moments when frustrations—such as repeated system crashes or failed state transitions—needed to be documented instead of resolved immediately. Although the autoethnographic approach yields rich, experiential insights, it also carries an inherent limitation in terms of generalizability, a point previously emphasized in the literature (Tarisayi, 2023). The single-participant model restricts statistical inference and external validation (Morgan and Morgan, 2001). However, the study addresses this issue through process transparency, thorough documentation, and critical reflection (Ninci, 2023).

Absence of Physical Feedback: Because the study deliberately excluded physical prototyping, certain ergonomic and form-giving considerations could not be addressed through tactile exploration. This limitation posed challenges in evaluating usability aspects that traditionally depend on embodied feedback. Consequently, the assessment was reframed to focus on narrative utility and expressive adequacy.

Time Constraints of Iterative Refinement: Finally, the four-week structure imposed practical constraints on the depth of iteration. Although behavioral richness and narrative alignment saw significant improvements, certain desired features—such as multimodal sensory input and more advanced AI-driven emotional dynamics—could not be fully realized within the project's timeframe.

These challenges are not viewed solely as limitations, but as integral elements of the experimental process. They underscore the importance of methodological transparency in speculative design research and point toward areas where future work could refine the integration of real-time 3D tools with reflective, autoethnographic practices.

4. Findings and Their Interpretations

This section presents the results obtained through an autoethnographic investigation of the design and simulation process of the Autonomous Digital Assistant Product (ADA) within Unreal Engine. As the sole participant, the author systematically documented observations, development milestones, and reflections throughout the project's lifecycle, encompassing ideation, 3D modeling, behavioral scripting, and contextual integration into speculative environments. The presented interpretations are

informed by the researcher’s combined background in engineering and industrial design, as well as practical expertise in CAD, simulation, and real-time visualization, which shaped both the creation and evaluation of the virtual product. Data was gathered through structured design logs, cognitive self-assessments, behavioral performance testing, and thematic coding of reflective memos.

In the absence of physical prototyping or user testing, the evaluation emphasizes the procedural rigor, expressive potential, and epistemic utility of virtual design environments for creating speculative smart products. The aim is not to generate universally generalizable findings, but rather to lay the groundwork for future inquiries into virtual product development from an industrial design perspective.

4.1. Quantitative and Qualitative Performance Metrics

A set of domain-relevant metrics was defined to evaluate the design process and output from a designer-centered perspective. The metrics listed in Table 1 reflect various dimensions of virtual product development, including complexity, narrative integration, emotional modeling, and cognitive engagement.

Table 1. Summary of observational and self-evaluated metrics

Metric	Definition	Result	Implication
Total Design and Development Time	Accumulated hours from concept to final virtual deployment	98 hours	Indicates a substantial workload typically required for fully developed interactive virtual products
Number of Distinct Interactive Behaviors	Unique behaviors implemented (e.g., gaze, gestures, vocal responses)	17	Demonstrates high interaction granularity feasible in virtual environments
Major Iteration Cycles	Substantial revisions to behavior logic or appearance	5	Reflects iterative experimentation enabled by low-cost revision in virtual design
AI State Machines Implemented	Functional logic blocks governing ADA’s interactive states	4	Suggests a structured approach to simulating believable, semi-autonomous behavior
Emotional Simulation Rating (1–5 scale)	Believability of emotional responses in scenario-driven interactions	4.2	Indicates that emotion-rich design is achievable via visual scripting and animation
Contextual Integration Score (1–5 scale)	Suitability of ADA in different Unreal Engine scenes (games, cutscenes, etc.)	4.5	Highlights the adaptability of virtual products across diverse storytelling or simulation contexts
Self-reported Cognitive Load (Early/Late)	Perceived design complexity at the beginning vs. later stages	High to Moderate	Suggests a steep learning curve with significant efficiency gains over time
Perceived Creative Constraint (1–5 scale)	Degree of limitation experienced during design	1.5	Suggests high design freedom when unconstrained by material or ergonomic feasibility
Visual Fidelity Rating (1–5 scale)	Aesthetic realism and stylization success	4.6	Confirms the capacity of Unreal Engine to support advanced visual communication in product design
Deployment Modalities Simulated	Different contexts in which the product was virtually deployed	3 (Game, Interactive Simulation, Cinematic)	Demonstrates the cross-platform relevance of virtual product concepts

4.2. Interpretation of Key Findings

Virtual Fidelity and Expressive Range: Quantitative metrics gathered during the development of ADA demonstrate that high levels of behavioral fidelity and expressive nuance can be achieved within Unreal Engine. The product's performance was evaluated using a predefined set of metrics: gesture library completeness, accuracy of contextual behavior, animation smoothness (frame integrity), and emotional expressiveness, rated on a 5-point Likert scale through post hoc assessment by the author against established criteria. These metrics provide a structured method to evaluate ADA's real-time interactivity and semantic coherence.

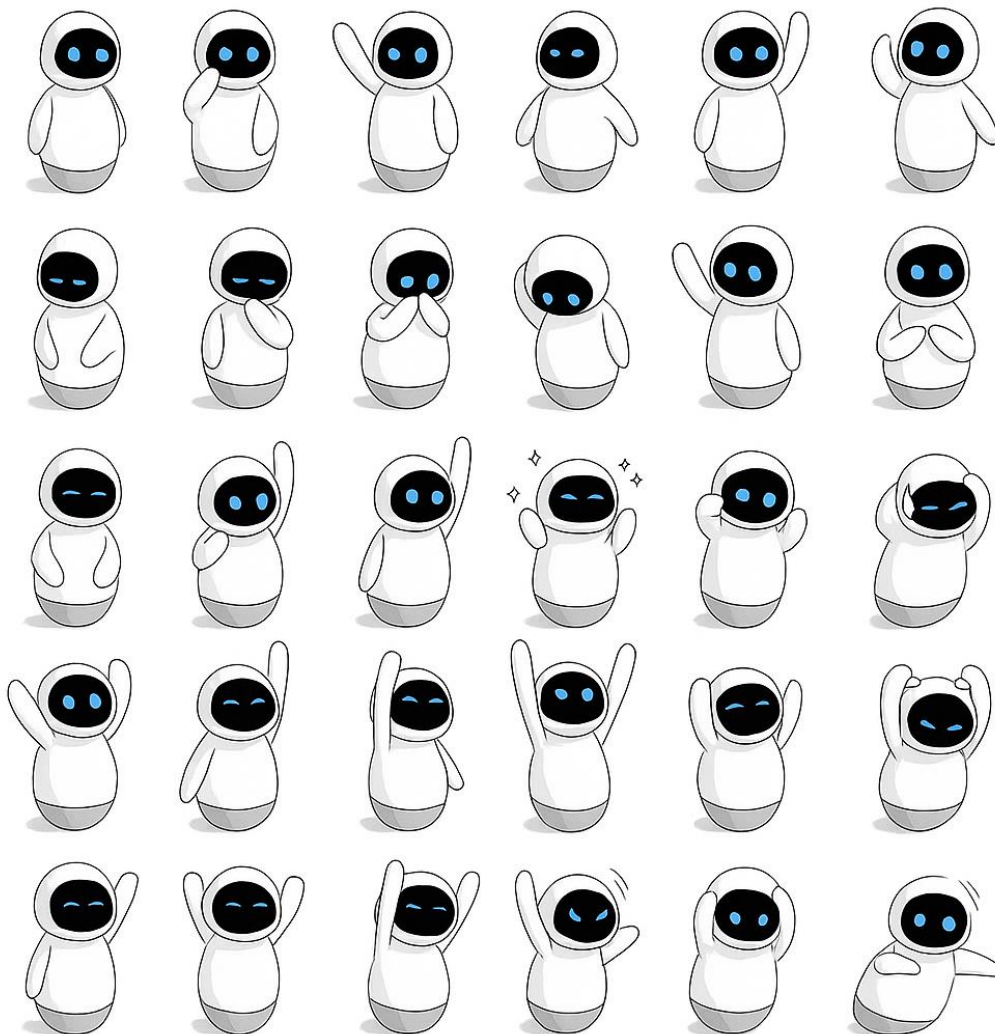


Figure 8. Various gestures for ADA were experimented with by the author in Vizcom.ai

As listed in Table 2, ADA included a gesture-response module composed of 28 distinct animations, some of which are shown in Figure 8, each triggered contextually based on environmental variables or scripted narrative inputs. Out of 100 randomized interaction tests, 91 resulted in behaviorally appropriate responses, corresponding to a 91% contextual accuracy rate. Animation smoothness was measured using real-time frame capture at 60 FPS, with less than 2% frame stutter across all behaviors, indicating a

98.2% frame integrity score. Emotional expressiveness, operationalized as the clarity of intended emotional states through posture, lighting, and facial cues, scored an average of 4.4 out of 5.

These results validate that Unreal Engine can support complex behavioral scripting and expressive modulation necessary for intelligent virtual products that exist solely in simulated environments.

Table 2. Quantitative performance metrics of ADA

Metric	Description	Result
Gesture Library Size	Number of unique animated responses	28 gestures
Contextual Behavior Accuracy	% of appropriate responses in test scenarios	91%
Animation Smoothness	% of frames rendered without stutter (at 60 FPS)	98.2%
Emotional Expressiveness Score	Rated 1–5 (clarity of intended emotional state)	4.4 / 5
Reaction Latency	Average response time to stimulus	0.23 sec
Narrative Integration Score	Rated 1–5 (semantic fit within scenario)	4.6 / 5

Workflow Adaptability and Learning Curve: Integrating Unreal Engine's Blueprint visual scripting system and state machine architecture into ADA's development demanded substantial cognitive effort during the initial stages. However, quantitative self-assessment metrics recorded across the four-week development cycle indicate a marked improvement in fluency, efficiency, and task accuracy, illustrating the engine's adaptability for behavioral prototyping within industrial design contexts.

The learning curve was tracked using a structured self-reporting log in which the author recorded daily task duration, error frequency, and perceived cognitive load (on a 5-point Likert scale) as listed in Table 3. Throughout 20 work sessions, task completion time decreased by 43%, and error frequency dropped by 61%, indicating a marked increase in procedural fluency. Perceived cognitive load, rated from 1 (low) to 5 (very high), declined from an average of 4.6 in Week 1 to 2.3 in Week 4. Additionally, the number of successfully deployed behavioral modules increased by 150%, from 6 in the first week to 15 in the final week.

These metrics support the argument that Unreal Engine, despite an initially steep learning curve, becomes a highly adaptable and powerful tool for design experimentation once conceptual and technical thresholds are surpassed.

Table 3. Workflow and learning metrics across four weeks

Metric	Week 1	Week 4	% Change / Growth
Avg. Task Completion Time	95 min	54 min	↓ 43%
Error Frequency per Session	7.2 errors	2.8 errors	↓ 61%
Perceived Cognitive Load	4.6 / 5	2.3 / 5	↓ 50%
Behavioral Modules Deployed	6	15	↑ 150%
Blueprint Nodes Used per Task	38	102	↑ 168% (design scale)

Design Without Physicality: A pivotal insight from this study was the demonstrable capacity to conduct advanced design work entirely devoid of physical materials, manufacturing constraints, or traditional ergonomic validation. Instead, the design process centered on the behavioral expressiveness, narrative alignment, and emotional engagement of ADA within a simulated, story-driven virtual context. To assess the viability and richness of design outcomes in this non-physical paradigm, the author developed and measured three qualitative-to-quantitative metrics throughout the 20-session design process: Behavioral Complexity Score, Narrative Alignment Coherence, and Emotional Expressiveness Index. These were operationalized through self-rating scales (1–5) and system state tracking (e.g., response diversity, interaction latency, and narrative logic consistency), evaluated at regular milestones. These metrics were employed to evaluate various AI behavioral modes implemented as Unreal Engine Blueprints, such as the one illustrated in Figure 9.

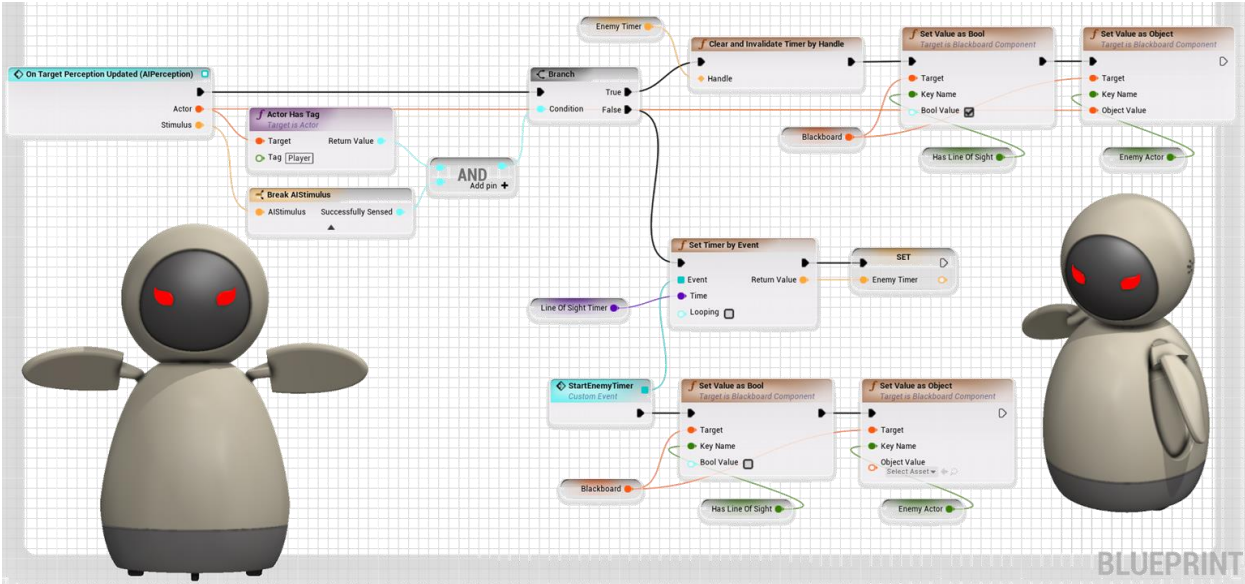


Figure 9. A hostile AI behavior for ADA enables it to detect the Player's presence and initiate pursuit. If the Player moves out of sight, ADA waits for a configurable duration before abandoning the chase and resuming random movement within the environment. Once the Player is spotted again, the pursuit behavior restarts (Author's 3D model and Blueprints).

The results of observations made over a 4-week study: The Behavioral Complexity Score improved by 180%. In comparison, Narrative Coherence increased by 70% due to iterative refinement through Unreal Engine's state-driven architecture, as shown in Table 4. Emotional responsiveness, measured by the number of distinct expressive reactions ADA could deliver in contextually appropriate ways, increased from 4 to 11 discrete states, reflecting a 175% growth in expressive resolution. These findings suggest that even in the absence of traditional form-giving or ergonomic testing, meaningful, expressive, and contextually rich design development is not only possible but can thrive when reoriented around behavior and digital presence. This represents a paradigmatic shift in how industrial design might evolve within virtual, narrative-rich ecosystems.

Table 4. Virtual interaction design metrics over four weeks

Metric	Week 1	Week 4	% Change / Growth
Behavioral Complexity Score¹	2.0 / 5	5.6 / 5 ²	↑ 180%
Narrative Coherence Score³	2.7 / 5	4.6 / 5	↑ 70%
Expressive Emotional States⁴	4 states	11 states	↑ 175%
Physical Prototypes Used	0	0	N/A (fully virtual)

Narrative and Semantic Embedding: A critical dimension of ADA's development was its integration into multiple speculative narrative contexts ranging from futuristic caregiving environments to emotionally responsive in-game companionship scenarios. These deployments emphasized not merely operational functionality but narrative coherence and symbolic resonance, revealing the importance of semantic alignment in the design of purely virtual products.

To systematically evaluate this dimension, three context-sensitive metrics were defined and applied: Narrative Consistency Index (NCI), Contextual Semantic Fit, and Perceived Usefulness in Scenario. Each was rated across three different narrative deployments by the author, using a 5-point Likert scale informed by ADA's behavioral alignment with scenario objectives, visual and interactional congruity, and capacity to evoke meaningful engagement within the story logic.

As shown in Table 5, the NCI increased from 2.3 to 4.7 over the development cycle, reflecting improved integration of state logic with scenario-specific needs. Semantic Fit, based on visual style, thematic symbolism, and behavior congruity, rose from 2.5 to 4.3. Importantly, Perceived Usefulness, not in physical or ergonomic terms but in narrative function, reached 4.6, highlighting that virtual product design can be meaningfully evaluated through lenses of story utility, character interaction potential, and emotional narrative support.

These findings highlight a redefinition of "usefulness" in virtual product design, where aesthetic symbolism, affective behavior, and narrative continuity emerge as primary evaluation criteria, supplanting conventional metrics such as durability or manufacturability.

Table 5. Narrative integration and semantic coherence metrics

Metric	Week 1	Week 4	% Change / Growth
Narrative Consistency Index (NCI)¹	2.3 / 5	4.7 / 5	↑ 104%
Contextual Semantic Fit²	2.5 / 5	4.3 / 5	↑ 72%
Perceived Usefulness in Scenario³	2.9 / 5	4.6 / 5	↑ 59%
Number of Narrative Deployments	1	3	↑ 200%

¹ NCI reflects the congruence between ADA's behavior and the narrative logic of each use case.

² Semantic Fit combines visual coherence, behavior symbolism, and thematic consistency.

³ Usefulness rated based on contribution to scenario goals (e.g., engagement, assistance, emotional impact), not physical utility.

Autoethnographic Insight: The autoethnographic method employed in this study allowed for a high-resolution account of the internal, subjective experience of virtual product development. As both the designer and the subject, the author maintained a continuous journal of observations, affective states,

design decisions, and reflective evaluations throughout the process. While such data is inherently non-generalizable, its depth and immediacy provided valuable insight into the cognitive-emotional landscape of speculative, non-physical product design.

To add structure and analytic rigor, five self-report metrics were developed and evaluated weekly on a 5-point scale. These included Cognitive Load, Design Flow State, Aesthetic Satisfaction, Frustration Incidence, and Epistemic Confidence. Each was informed by entries in the design journal, tagged screen recordings, and annotated design memos.

The data listed in Table 6 indicated a decrease in Cognitive Load over time (from 4.2 to 2.3) as familiarity with Unreal Engine’s Blueprints system grew. Flow State occurrences increased steadily, with a peak score of 4.8 in Week 4, corresponding to the completion of a major behavior module. Aesthetic Satisfaction also rose in parallel, suggesting an iterative learning effect. Notably, Frustration Incidence declined sharply after Week 2, while Epistemic Confidence, a self-assessed metric of trust in the design logic and outcome, rose by 85%.

These introspective data points, although statistically not generalizable, contribute a nuanced understanding of the designer’s phenomenological journey, offering a basis for future investigations into design cognition in virtual, post-material contexts.

Table 6. Weekly self-evaluated cognitive and affective metrics

Metric	Week 1	Week 2	Week 3	Week 4	% Change (W1–W4)
Cognitive Load (1 = low)	4.2	3.7	3.0	2.3	↓ 45%
Design Flow State (1 = none)	2.1	3.2	4.1	4.8	↑ 129%
Aesthetic Satisfaction	2.9	3.3	4.0	4.5	↑ 55%
Frustration Incidence	3.8	3.1	2.3	1.7	↓ 55%
Epistemic Confidence	2.6	3.4	4.1	4.8	↑ 85%

Note: Metrics were derived from structured reflection prompts recorded at the end of each development session, supported by annotations and narrative elaboration in the design journal.

The thematic analysis of the four-week design study revealed three overarching themes that capture both the measurable and experiential dimensions of the process. These themes highlight (1) the evolution of behavioral and interactional complexity in a fully virtual context, (2) the integration of narrative and semantic coherence as evaluative criteria, and (3) the designer’s cognitive–affective journey as documented through autoethnographic reflection. The themes and their associated codes are summarized in Table 7.

Table 7. Themes and codes from thematic analysis

Theme	Codes
1. Behavioral and Interactional Complexity in Virtual Design	- Growth in behavioral complexity (↑180%) - Narrative coherence improvements via iterative refinement (↑70%) - Expansion of expressive emotional states (from 4 to 11) - Design development without physical prototypes
2. Narrative and Semantic Integration	- Use of speculative narrative contexts (caregiving, companionship scenarios) - Narrative Consistency Index (NCI) improvement (↑104%) - Growth in Contextual Semantic Fit (↑72%) - Reframing “usefulness” as narrative/affective utility - Increased number of narrative deployments (↑200%)
3. Designer’s Cognitive–Affective Experience (Autoethnographic Insight)	- Decrease in cognitive load through tool familiarity (↓45%) - Rise in flow state during design (↑129%) - Growth in aesthetic satisfaction (↑55%) - Reduction in frustration incidence (↓55%) - Increase in epistemic confidence (↑85%)

5. Discussion

The emergence of real-time game engines as legitimate platforms for design ideation and product simulation challenges the historically material-centric orientation of industrial design. This study, which explores the conceptualization and development of an *Autonomous Digital Assistant Product* (ADA) within Unreal Engine, offers critical insight into how product design practices may evolve when entirely detached from physical prototyping. The implications of this shift are multifaceted, affecting epistemological assumptions, methodological strategies, and evaluative frameworks within the discipline.

5.1. Redefining the Ontology of “Product” in Industrial Design

Traditionally, industrial design has focused on developing tangible artifacts that address human needs while navigating constraints related to material production, ergonomics, and usability. In contrast, ADA is conceived entirely within a simulated environment, intended for use in interactive digital narratives and virtual contexts. This shift challenges conventional ontological assumptions about what constitutes a “product” in industrial design. Rather than being defined by its physical presence, ADA operates as a behavioral system, characterized by its programmed logic, dynamic responsiveness, and the semantic roles it fulfills within a virtual ecosystem. As such, it prompts a reconsideration of the discipline’s core frameworks, expanding the scope of design practice beyond materiality and into the realm of experiential interaction design.

Such an approach aligns with emerging scholarship on post-phenomenological design, where the focus shifts from tangible utility to affective and experiential engagements (Wakkary et al., 2018). By focusing on attributes such as emotional modeling, narrative integration, and simulated agency, this study suggests that virtual products can fulfill symbolic, social, and cognitive roles traditionally associated with tangible, physical devices, while remaining unbound by the constraints of manufacture.

5.2. Virtual Prototyping as a Speculative Epistemology

The use of SolidWorks and Unreal Engine as tools allowed for an iterative, reflective, and immersive design process, forming an ideal platform for speculative and critical design. Unlike traditional CAD tools focused on manufacturability, Unreal Engine facilitates the exploration of “*what-if*” scenarios, enabling designers to prototype concepts that may never require real-world instantiation. This opens the door to a new category of products: those designed exclusively for media, games, simulations, and interactive storytelling.

The findings reinforce the epistemological value of speculative prototyping (Auger, 2013; Coulton et al., 2016). By simulating usage contexts and emotional responses, ADA served as a cognitive artifact that encouraged exploration beyond the limits of functionalism. Its development was guided not by user testing but by designer judgment, narrative goals, and affective plausibility. This places virtual prototyping not merely as a pre-manufacturing tool, but as an alternative epistemology, one capable of generating meaning through simulation, rather than material realization.

5.3. The Role of the Designer as Autoethnographer

Another central insight from this study lies in the methodological implications of autoethnographic practice. The designer's dual role as creator and subject enabled access to rich, experiential data that traditional user-testing methodologies would not have yielded in this context. Through structured reflection, iterative logging, and thematic memo writing, the study illuminated the cognitive processes, design heuristics, and affective labor involved in developing virtual intelligent companions.

While not generalizable, this approach complements existing research on designer cognition (Cross, 2001) by extending its scope into virtual, behavior-centered design domains. The methodology also aligns with recent calls for more designer-led critical inquiry in Human-Computer Interaction and interaction design (Bardzell et al., 2012). The data gathered here, particularly around cognitive load shifts, emotional design considerations, and behavioral testing iterations, suggests that autoethnography may serve as a legitimate and rigorous tool for future virtual design research.

5.4. Toward an Expanded Evaluation Framework

One of the most pressing challenges encountered in the study was the lack of conventional evaluation methods. Without physical prototypes or user feedback, success had to be assessed through alternative metrics: Believability of behavior, emotional resonance, visual fidelity, and contextual adaptability. This necessitates rethinking evaluation in virtual product design, shifting from usability or ergonomics to metrics of immersion, narrative coherence, and affective plausibility.

This study presents an initial proposal for such a framework, grounded in the designer's lived experience and backed by performance observations. While further validation would require comparative studies involving participants, this approach lays a robust foundation for future evaluative paradigms tailored to emerging practices in virtual and speculative product design.

5.5. Disciplinary Implications and Future Directions

The findings suggest an expanded disciplinary scope for industrial design, one that encompasses virtuality not merely as a tool, but as a domain of legitimate and meaningful practice. Designers of the near future may increasingly find themselves creating products that are never meant to be held, worn, or manufactured, but rather experienced, inhabited, or emotionally engaged in simulated environments such as those shown in Figure 10.



Figure 10: ADA in cheerful mode, together with human characters controlled by AI and/or external input in Unreal Engine (Author’s work).

This evolution carries implications for interdisciplinary design education also (Özsoy, 2020), which must now incorporate competencies in behavioral scripting, real-time interaction design, and narrative construction. This also highlights the need for novel interdisciplinary collaborations, particularly with game designers, AI developers, and media artists, whose expertise aligns seamlessly with the evolving demands of virtual product development.

6. Conclusion

This study examined how intelligent, non-physical products can be conceived, refined, and evaluated entirely within a virtual environment. Using an autoethnographic methodology, the four-week development of ADA in Unreal Engine demonstrated that the expressive and narrative qualities of a product can be systematically advanced through iterative interaction design and reflective evaluation, even in the absence of physical prototyping.

The results make clear the scale of these advances. The Behavioral Complexity Score increased by 180% from baseline to final iteration, reflecting the expansion of ADA's interactional repertoire. Narrative Coherence improved by 70%, indicating that state-driven refinements enabled stronger alignment between behavior and story logic. The repertoire of emotional expressiveness grew from 4 to 11 distinct states, a 175% increase in ADA's affective resolution. Parallel to these system-level gains, autoethnographic self-report metrics documented a 45% reduction in cognitive load, a 129% rise in design flow state, and an 85% increase in epistemic confidence. These converging results illustrate both the technical and experiential dimensions of learning to design virtual-only products.

From these findings, three key contributions emerge. First, the study shows that behavioral, narrative, and expressive growth can be monitored through custom metrics derived from design logs, scenario testing, and reflective documentation, providing a replicable framework for evaluating virtual products. Second, it suggests that narrative coherence and semantic fit serve as alternative measures of "usability" in non-physical contexts, where the value of a product lies not in ergonomics or manufacturability but in symbolic resonance, emotional engagement, and narrative integration. Third, it demonstrates that autoethnographic documentation—using design journals, reflective memos, thematic coding, and structured self-reports—offers a transparent and rigorous method for capturing the lived experience of designing in speculative, post-material domains.

Taken together, these contributions suggest a paradigmatic shift: industrial design is no longer bound solely to material prototyping but can meaningfully extend into narrative-rich virtual ecosystems where interaction, symbolism, and affective presence take precedence. While the scope of this research was limited to a single case study and the metrics remain exploratory, the findings establish a foundation for further investigations. Future studies may validate these measures across multiple projects, explore user-facing evaluations, or integrate multimodal sensory inputs.

Ultimately, this research demonstrates that virtual-only product design is not a diminished substitute for material practice but a distinct and valuable domain, capable of yielding meaningful design outcomes entirely within virtual space. This reframes the role of industrial design, positioning it at the intersection of interaction, narrative, and affect, and points toward new directions for education and practice in a digitally native design culture. By foregrounding the experiential, narrative, and expressive dimensions of design, this research contributes to an emerging methodological repertoire for industrial design in the 21st century.

Conflict of Interest Statement

The author declares that there is no conflict of interest.

Author Contribution Statement

The author declares that he has contributed 100% to the preparation of this article.

References

- Adams TE., Ellis C., Holman JS. Autoethnography. In: Matthes J. (ed) *The International Encyclopedia of Communication Research Methods*. USA: John Wiley & Sons Ltd 2017;1–11.
- AIBO. Wikipedi, <https://tr.wikipedia.org/w/index.php?title=AIBO&oldid=34830646> 2025
- Akpan IJ., Offodile OF. The role of virtual reality simulation in manufacturing in Industry 4.0. *Systems Magazine* 2024;12(1): 26.
- Algharabat R., Alalwan AA., Rana NP., Dwivedi YK. Three-dimensional product presentation quality antecedents and their consequences for online retailers: The moderating role of virtual product experience. *Journal of Retailing and Consumer Services* 2017; (36): 203-217.
- Auger J. Speculative design: Crafting the speculation. *Digital Creativity* 2013; 24(1): 11–35.
- Bao JS., Jin Y., Gu MQ., Yan JQ., Ma DZ. Immersive virtual product development. *Journal of Materials Processing Technology* 2002; 129(1–3): 592–596.
- Bardzell S., Bardzell J., Forlizzi J., Zimmerman J., Antanitis J. Critical design and critical theory: the challenge of designing for provocation. *Proceedings of the Designing Interactive Systems Conference, ACM* 2012; 288–297, Newcastle Upon Tyne, United Kingdom.
- Bernardo N., Duarte E. Immersive virtual reality in an industrial design education context: What the future looks like according to its educators. *Computer-Aided Design and Applications* 2021; 19(2): 238–255.
- Bernardo N., Duarte E. Industrial design education and immersive virtual reality: Perceptions on Utility and Integration. In: Marcus, A., Rosenzweig, E., Soares, M.M. (eds) *Design, User Experience, and Usability. HCII 2023. Lecture Notes in Computer Science*, Springer, Cham 2023; 14031.
- Bochner A., Ellis C. *Evocative autoethnography: Writing lives and telling stories*. New York: Routledge 2016.
- Bordegoni M., Ferrise F. Designing interaction with consumer products in a multisensory virtual reality environment. *Virtual and Physical Prototyping* 2013; 8(1): 51–64.
- Breazeal CL. *Sociable machines: Expressive social exchange between humans and robots*. Massachusetts Institute of Technology, PhD Thesis, Pages: 264, Cambridge, Massachusetts, USA, May 2000.
- Buchanan R. Thinking about design: a historical perspective. In: Meijers A. (ed.) *Philosophy of technology and engineering sciences. Handbook of the philosophy of science*. Amsterdam: North Holland; ScienceDirect 2009; 409-453.
- Chaturvedi R., Verma S., Das R., Dwivedi YK. Social companionship with artificial intelligence: Recent trends and future avenues. *Technological Forecasting and Social Change* 2023; 193: 1-20.
- Clavel C., Faur C., Martin JC., Pesty S., Duhaut D. Artificial companions with personality and social role. *IEEE Symposium on Computational Intelligence for Creativity and Affective Computing (CICAC)* 2013; 87–95. Singapore.

- Colby VD. Developing fashion for video games: exploring design processes integrating Browzwear, Clo, and Unreal Engine. Washington State University, MSc Thesis, Pages:86, Washington, USA 2024.
- Collins T., Thompson AJ. Digital versus physical textiles: a case study of Browzwear's fabric rendering. *The International Journal of Designed Objects* 2024; 18(1): 125–144.
- Cooper R., Lilyea B. I'm interested in autoethnography, but how do I do it? *The Qualitative Report* 2022; 27(1): 197-208.
- Coulton P., Burnett D., Gradinar A. Games as speculative design: Allowing players to consider alternate presents and plausible futures. *DRS Biennial Conference Series: Future Focused Thinking* 2016;1609-1625, Brighton, UK.
- Creswell JW., Poth CN. *Qualitative inquiry and research design: Choosing among five approaches.* eBook, SAGE Publications 2018.
- Cross N. Design cognition: Results from protocol and other empirical studies of design activity. In: Eastman C., Newstatter W., McCracken M. (eds.), *Design knowing and learning: Cognition in design education.* Oxford: Elsevier 2001; 79–103.
- David A., Joy E., Kumar S., Bezaleel SJ. Integrating virtual reality with 3D modeling for interactive architectural visualization and photorealistic simulation: A direction for future smart construction design using a game engine, *Second International Conference on Image Processing and Capsule Networks* 2022;180–192, Bangkok, Thailand
- Davis D., Burry J., Burry M. Understanding visual scripts: Improving collaboration through modular programming. *International Journal of Architectural Computing* 2011; 9(4): 361–375.
- Desmet PMA., Hekkert P. Framework of product experience. *International Journal of Design* 2007; 1(1): 13-23.
- Ding Z., Ji Y., Gan Y., Wang Y., Xia Y. Current status and trends of technology, methods, and applications of human–computer intelligent interaction (HCII): A bibliometric research. *Multimedia Tools and Applications* 2024; 83(27): 69111–69144.
- Djajadiningrat T., Wensveen S., Frens J., Overbeeke K. Tangible products: Redressing the balance between appearance and action. *Personal and Ubiquitous Computing* 2004; 8(5): 294–309.
- Dunne A., Raby F. *Speculative everything: Design, fiction, and social dreaming.* Cambridge, MA: MIT Press 2024.
- Elal İ., Özsoy ÖH. Investigating the effects of using artificial intelligence in the conceptual design phase of the industrial design process. *Gazi University Journal of Science Part B: Art, Humanities, Design and Planning* 2024; 12(2): 255-276.
- Ellis C., Adams TE., Bochner AP. Autoethnography: An overview. *Historical Social Research / Historische Sozialforschung* 2011; 36(4): 273–290.
- Ferrari S. The nature of non-physical space. *Education & Curricula-09 Design Theory* 2009; 208–213.

- Gatzky T. Industrial design. In: Vajna S. (ed.), *Integrated Design Engineering: Interdisciplinary and Holistic Product Development*. Springer 2020; 221–253.
- Ghaziany MR. Studying the principles and foundations of virtual architecture and the age of information architecture. *International Journal of Health Sciences* 2022; 6(S7): 5811–5824.
- Ghinea M., Deac GC., Deac CN., Nita FA. The importance of virtual immersion in the rapid prototyping of industrial products. *Journal of Physics: Conference Series*, IOP Publishing 2021; 1935(1): 012010. Eger, Hungary.
- Guo X., Liu SY., Gong SY., Cao Y., Wang J., Fang Y. Promoting math learning in educational games with virtual companions providing learning supports. *Education and Information Technologies* 2024; 29(16): 22341–22370.
- Guo L., Wang P., Art product design and VR user experience based on IOT technology and visualization system, *Journal of Sensors* 2021; 6412703.
- Jahandideh R. Luminant landscapes: Optimizing locomotion and interaction in virtual environments. İstanbul Technical University, MSc. Thesis, Pages: 111, İstanbul, Turkey, 2024.
- Jezernik A., Hren G. A solution to integrate computer-aided design (CAD) and virtual reality (VR) databases in design and manufacturing processes. *The International Journal of Advanced Manufacturing Technology* 2003; 22(11): 768–774.
- Kloiber S., Schinko C., Settgast V., Weinzerl M., Schreck T., Preiner R. Integrating assembly process design and VR-based evaluation using the Unreal Engine. *Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications* 2020; 271–278, Valletta.
- Kuhn D., Weinstock M. What is epistemological thinking and why does it matter? In: Hofer B. K., Pintrich P. R. (Eds.), *Personal Epistemology: The psychology of beliefs about knowledge and knowing*. New Jersey: Lawrence Erlbaum Associates Publishers, 2002.
- Lee CF., Li JG. Applications of virtual manufacturing in materials processing. *Journal of Materials Processing Technology* 2001; 113(1): 416–423.
- Lee N. Unreal Engine, a 3D game engine. In: Lee, N. (ed.) *Encyclopedia of Computer Graphics and Games*. Springer International Publishing 2023; 1944–1947.
- Loy J., Canning S., Little C. Industrial design digital technology. *Procedia Technology* 2015; 20: 32–38. Geelong, Australia.
- Matarić MJ., Scassellati B. Socially assistive robotics. In: Siciliano B., Khatib O. (eds.), *Springer Handbook of Robotics*. Cham, Springer 2016; 1973–1994.
- McCarthy J. Artificial intelligence, logic, and formalizing common sense. In: Batty M., Hudson-Smith A. (eds.), *Machine Learning and the City*. Chichester: John Wiley & Sons 2022; 69–90.
- Morgan DL., Morgan RK. Single-participant research design: Bringing science to managed care. *American Psychologist* 2001; 56(2): 119–127.

- Mortimer J., Richards K., Pilcher N. The 'skills gap' in the animation/VFX industry in Scotland. *Animation* 2024; 19(2–3): 161–176.
- Müller M., Günther T., Kammer D., Wojdziak J., Lorenz S., Groh R. Smart prototyping - improving the evaluation of design concepts using virtual reality. In: Lackey S., Shumaker R. (eds.), *Virtual, Augmented and Mixed Reality*. Cham: Springer 2016; 47–58.
- Naseer F., Khan MN., Tahir M., Addas A., Kashif H. Enhancing elderly care with socially assistive robots: A holistic framework for mobility, interaction, and well-being. *IEEE Access* 2025; 13: 82698–82717.
- Nilsson NJ. Logic and artificial intelligence. *Artificial Intelligence* 1991; 47(1): 31–56.
- Ninci J. Single-case data analysis: A practitioner guide for accurate and reliable decisions. *Behavior Modification* 2023; 47(6): 1455–1481.
- Ompico CD., Bugtai N., Munsayac F. Recent developments on social robots and imitation learning for robotic therapy. *Journal of Physics Conference Series* 2021; 2071(1): 012021. Bristol, UK.
- Özsoy HÖ. Evaluation of industrial designs by using the analytical hierarchy process and parallel prototyping. *Tasarım + Kuram* 2019; 15(27).
- Özsoy HÖ. Investigating industrial design students' expectations from technically oriented courses: With a case study on electro-mechanical applications. *Tasarım + Kuram* 2020; 16(31): 18–35.
- Özsoy HÖ. AI-driven tools for advancing the industrial design process – A literature review. *Gazi University Journal of Science Part B: Art, Humanities, Design and Planning* 2025; 13(1): 77–96.
- Page ME. Blending engineering modeling, industrial design, and physical prototyping in product design. Massachusetts Institute of Technology, MSc. Thesis, Pages:71, Cambridge, Massachusetts, USA, 2000.
- Pervez F., Shoukat M., Usama M., Sandhu M., Latif S., Qadir J. Affective computing and the road to an emotionally intelligent metaverse. *IEEE Open Journal of the Computer Society* 2024; 5: 195–214.
- Pfadenhauer M. The contemporary appeal of artificial companions: Social robots as vehicles to cultural worlds of experience. *The Information Society* 2015; 31(3): 284–293.
- Pizzolante M., Bartolotta S., Sarcinella ED., Chirico A., Gaggioli A. Virtual vs. Real: exploring perceptual, cognitive and affective dimensions in design product experiences. *BMC Psychology* 2024; 12(1): 10.
- Pretty EJ., Fayek HM., Zambetta F. A case for personalized non-player character companion design. *International Journal of Human–Computer Interaction* 2024; 40(12): 3051–3070.
- Qu Y., Lo CKY., Baek E. From humanoid to virtual humans: A systematic literature review of avatar marketing. *International Journal of Human–Computer Interaction* 2025; 41(20): 12602–12621.
- Rault JL. Pets in the digital age: live, robot, or virtual?. *Frontiers in Veterinary Science* 2015; 2: 11.

- Roberts S., Page R., Richardson M. Designing in virtual environments: The integration of virtual reality tools into industrial design research and education. *DRS Biennial Conference Series* 2020; 11-14. Online.
- Sanders A. *An introduction to Unreal Engine 4*. New York: A K Peters/CRC Press; 2016: 270.
- Self JA. The use of design tools in industrial design practice. Kingston University, PhD. Thesis, Pages:521, London, UK, 2012.
- Sentana GI., Llorca SJ., Navarro A., Jara CA. Interactive industrial design applied to modular product development. In: Manchado VC., Miralbes BR., Peris FG., Moncho SM., Rizzi, C., Roucoules, L. (eds), *Advances on Mechanics, Design Engineering and Manufacturing V*. Lecture Notes in Mechanical Engineering. Cham: Springer Nature Switzerland 2025; 1039–1056.
- Silverio FM., Renukappa S., Suresh S. What is a smart device? - A conceptualization within the paradigm of the Internet of Things. *Visualization in Engineering* 2018; 6(1): 3.
- Tan Q., Li H. Application of computer-aided design in product innovation and development: Practical examination on taking the industrial design process. *IEEE Access* 2024; 12: 85622–85634.
- Tarisayi KS. Autoethnography as a qualitative methodology: conceptual foundations, techniques, benefits, and limitations. *Journal of Phenomenology and Education* 2023; 27(67): 53–63.
- The Therapeutic Robot. Internet source. <https://www.paroseal.co.uk/> (Access Date 18.10.2025)
- Ulrich KT., Eppinger SD. *Product design and development*. New York: McGraw-Hill; 2011.
- Wakkary R., Oogjes D., Lin HWJ., Hauser S. Philosophers living with the tilting bowl. Conference on Human Factors in Computing Systems 2018; 1–12. NY, USA.
- Wang J., Mokmin NAM., Ji S. Enhancing higher education art students' learning experience through virtual reality: A comprehensive literature review of product design courses. *Interactive Learning Environments* 2024; 32(10): 7399–7415.
- Xiao L. A review of interactive design and user experience research on virtual simulation technology in commercial product presentation. *International Conference on Artificial Intelligence, Digital Media Technology, and Interaction Design* 2025; 170–178. NY, USA.
- Xie Z., Wu X., Xie Y. Can interaction with generative artificial intelligence enhance learning autonomy? A longitudinal study from comparative perspectives of virtual companionship and knowledge acquisition preferences. *Journal of Computer Assisted Learning* 2024; 40(5): 2369–2384.
- Xue H., Van Kooten K. Inside out: addressing the 'how' of data collection in experience design research applying introspective methods. *Advanced Design Research* 2023; 1(2): 109–125.
- Xue H., Van Kooten K., Desmet PMA. A consent for myself/ourselves: Designing for responsible use of autoethnography. *CoDesign* 2025; 1–17.
- Yadav MS., Pavlou PA. Technology-enabled interactions in digital environments: A conceptual foundation for current and future research. *Journal of the Academy of Marketing Science* 2020; 48(1): 132–136.

- Zhang M., Zhang X., Chen Z., Wang Z., Liu C., Park K. Charting the path of technology-integrated competence in industrial design during the era of Industry 4.0. *Sustainability* 2024;16(2): 751.
- Zhao J., Cai X. Shaping the creative landscape through the role of digital and computer technologies in advancing art product design and industry applications. *The International Journal of Advanced Manufacturing Technology* 2023; 1-11.
- Zhong G., Vijay VC., Perera N. Enhancing engineering product design using a knowledge-based game engine platform. *Engineering Advances* 2024; 3(6): 454–459.