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# Blending Digital and Physical Interfaces: A Cognitive Ergonomics approach to smart usability while practicing for Academia

**[1*]Parag Sarma, [2*]Nipan Das, [3]Dr. Vijay Shah**

1*Assistant Professor, Product Design Department,
School of Design, Anant National University, Ahmedabad, Gujarat
2* Assistant Professor, Foundation Department,
Unitedworld Institute of Design, Karnavati University, Gandhinagar, Gujarat
3 Professor, Foundation Department,
Unitedworld Institute of Design, Karnavati University, Gandhinagar, Gujarat

**Abstract**

The research paper examines and explores the role of Cognitive Ergonomics (CE) in interface design by examining how the integration of digital and physical elements enhances user experience, usability, and accessibility while practicing for academia. The study, conducted as part of a design education module, involved students redesigning interfaces for products like coffee machines, vending machines, induction stove interfaces, digital cameras, and laser-cutting machines' interfaces.

Traditional teaching methods in CE, such as lectures, case studies, and structured instructional design, focus on addressing principles like usability, accessibility, and user-centered design. These methods emphasize theoretical understanding and its application, with students expected to produce diverse deliverables, including improvised prototypes, usability reports, and research papers, to demonstrate their comprehension and ability to apply these principles to redesign (Gruber, C., Vergara, L. G. L., & Gontijo, L. A., 2019). However, students require more qualitative feedback on their outcomes in real-world scenarios. These outputs from students are not entirely appropriate unless they are incorporated with tangible mock-ups that provide the feel of real products. To examine this, we conducted research with students. The research done with a combination of qualitative methodologies, including case studies, user testing, prototyping, and observational analysis.

Results reveal that while initial digital prototypes offer a strong foundation, their effectiveness is markedly improved when integrated with physical, tactile models. The hybrid approach (digital + tangible blends) not only uncovers usability issues that may remain hidden in digital-only iterations but also facilitates an interactive, user-centered learning environment. Iterative feedback cycles—bolstered by exhibition-based peer reviews—prove critical in refining design concepts, ultimately leading to more intuitive and accessible interfaces. This study advocates for a balanced, user-centric design strategy that couples digital innovation with tangible interaction. Such an approach effectively lowers cognitive strain, enhances overall product usability, and enriches the design process through active, iterative learning. The evidence supports the broader integration of CE principles in interface development, positioning the synergy of digital and physical modalities as a cornerstone for future advancements in human-computer interaction.

**Keywords:** Cognitive ergonomics · Interface design · Usability · Human-computer interaction
Tangible interaction · Digital-physical integration · User experience · Product design · Interaction design · Design education · Accessibility · Hybrid interfaces

## 1. Introduction: A glimpse of Cognitive Ergonomics in Interface Design

A few days back, we took a 10 days module Cognitive Ergonomics (CE) for Masters of Integrated Product Design. The aim of the module was an introduction to the subject of CE, which forms a sub-domain of the scientific discipline Ergonomics/Human Factors Engineering. This discipline focuses on mental processes, such as perception, memory, information processing, reasoning, and motor response, as they affect interactions while interacting interfaces either tangible or, intangible display among humans and other elements of a system. The module outcome was to create an intuitive seamless-experienced solutions for tangible/intangible display by using CE. Students picked-up existing products like Induction Cooktop, Digital Camera, Coffee machine, Vending machine touch display, and Laser cutting machine control display. Students did deep research on parameters of CE e.g., perception, memory, information processing, reasoning, motor responses, usability with error prevention on selected existing products. Students got various information while they were finding CE issues on selected product/s and got constructive feedbacks when they tested their re-designed products from users and even from each other's and mentor also. Students started to analyze feedbacks and implemented on their proposed solutions. Students came to mentor and told 'sir, if we will present our work via digital, then we might be not getting proper valuable feedback, better we will add tangible model which incorporates digital model of CE.

## 2. Pedagogical Approaches and Experiment

Our observation was that student's dedications towards explorations of proposed solutions for CE of tangible and intangible display, and we decided to do an experiment- does an exhibition with blended models of CE outcomes (digital and tangible model) will help to get more valuable constructive feedback for student. Finally, students were setup an exhibition with their final re-designed tangible and intangible product/solutions blended with tangible model for others at the university campus. Student's dedications and expressions for the exhibition, and found that the exhibition is really very important while a design mentor/faculty is taking a module of CE. Cognitive Ergonomics is a domain where people study deeply various factors like mental processes, perception, memory, reasoning, motor response etc. to enhance productivity, reduce human error, and provide insight into how people interpret information when interacting with a system or product (digital/tangible). It would seem reasonable that presenting through exhibition skills and it would preserve all the benefits of showcasing student work while also providing the added advantage that students would acquire a variety of other skills like communications, presentations, peers learning, and absorb various +ve and -ve comments/statements etc. Exhibitions are highly engaging and interactive learning activity that emphasizes the interactive aspects of the presentation. Even when students saw many people checking out the exhibition space, the students were very ecstatic. All the students found that it was beneficial to show their work to a wider audience since it let many people realize they had industry-ready talents. Visitors for the exhibition were tried to interact with re-designed blended display of tangible and intangible. The detailed outlines that our study looked for are well-designed, interactive, captivating, thought-provoking, eye-opening, educational, powerful, pertinent, and influential (Norman & Draper, 1986; Shneiderman & Plaisant, 2016)

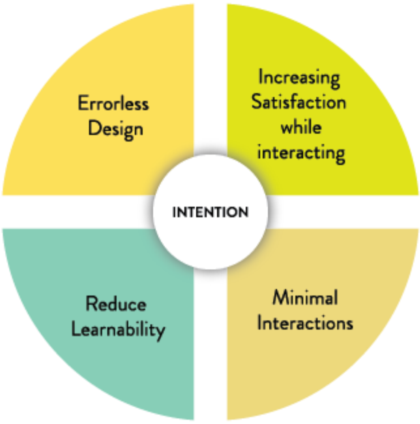


***Fig: 1** The intention of Cognitive Ergonomics while re-design interface either tangible or, intangible (Source: Author)*

**3. Research investigation methods: Case studies (Qualitative method)**

Some of student's work who attended the module and they gave statements that why they got encourage to blend both digital and physical mock-up.

**3.1 Case Study: Coffee machine interface re-design**

Tanaya, a student undertook the challenge of redesigning a coffee machine interface with a focus on CE. Her process began with comprehensive research into existing products, where she identified several cognitive and usability issues. These included limited usability due to screen-based interactions, ambiguous icons, high cognitive load from insufficient navigation feedback, low user engagement during waiting periods, over-reliance on visual elements affecting accessibility, and a lack of insights into physical interaction challenges. Initial prototyping was restricted to digital interfaces, tested on laptops, or printed screens, which limited the simulation of real-world interactions.


***Fig: 2** Existing coffee machine and initial concept for coffee machie interface re-design (Source: Author)*

During usability testing, Tanaya observed that users struggled with menu icons, coffee and milk quantity indicators, and availability information. Users also reported boredom during the coffee preparation process, as interaction was limited to passive visual feedback. To address these concerns, she introduced an animated progress loader, which provided real-time feedback and kept users engaged during waiting periods. This solution not only improved user engagement but also reduced perceived waiting time. Recognizing the limitations of focusing solely on digital interfaces, Tanaya expanded her approach to include physical interaction. She began prototyping various control layouts and tactile elements, integrating both digital and tangible components. This blended prototyping approach allowed her to observe how users interacted with the machine as a whole, leading to valuable insights into usability and comfort. Although time constraints prevented the development of a fully interactive prototype, she created an animated digital interface displayed on a laptop alongside her physical model, enabling hands-on testing. Presenting her blended prototype to peers and gathering exhibition feedback proved instrumental. Real user interactions and diverse perspectives highlighted usability gaps that were not apparent in digital-only testing. The feedback emphasized the importance of intuitive icons, clear menu structures, and accessible design. Users appreciated the addition of coffee and milk quantity indicators and availability information, which enhanced transparency and control. The results demonstrated significant improvements. Usability was enhanced by combining digital interfaces with physical controls, reducing cognitive load, and improving navigation. User engagement increased through the addition of animated feedback during waiting periods. The interface was made minimal and user-friendly, addressing cognitive load and accessibility concerns. Blended prototyping enabled realistic interaction scenarios, resulting in more comprehensive feedback and iterative design improvements. Tanaya’s case study underscores the value of integrating cognitive ergonomics principles with both digital and physical design elements. Her iterative, user-centered approach led to a more intuitive, engaging, and accessible coffee machine interface, highlighting the necessity of blending digital and tangible experiences for optimal user interaction.

***Fig: 3*** *Final blended prototype of coffee machine interface (Source: Author)*

| **ASPECT** | **DIGITAL APPROACH (BEFORE)** | **PHYGITAL APPROACH (AFTER)** |
|---|---|---|
| **Usability** | - Limited to digital screen-based interactions<br>- Users faced challenges understanding icons and navigation<br>- High cognitive load | - Combined digital and physical controls<br>- Intuitive icons to reduce cognitive load<br>- Improved navigation |

| | | |
|---|---|---|
| **User Engagement** | - Users disengaged during waiting periods (e.g., coffee preparation)<br>- Interaction was limited to visual feedback on the screen | - Animated progress loader to engage users<br>- Engaging feedback during waiting time (e.g., coffee making process)<br>- Increased user involvement |
| **Cognitive Loads** | - High cognitive load due to unclear icons and complex menu structures | - Minimal, user-friendly interface<br>- Clear menu structure to reduce cognitive strain |
| **Accessibility** | - Over-reliance on visual elements<br>- Limited accessibility | - Clear and minimal design<br>- Improved accessibility for diverse users |
| **User Feedback** | - Focused on usability issues only digitally<br>- Limited insight into physical interaction (e,g., 20% coffee are inside) | - Comprehensive feedback on both digital and physical aspects<br>- Improved transparency (e.g., quantity indicators like icons for quantity markers) |
| **Prototyping** | - Digital prototypes tested on screens/laptops<br>- Limited real-world simulation | - Blended prototypes enabled hands-on, testing provided realistic interaction scenarios<br>- Better understanding of user – interaction |
| **Efficiency** | - Slower, less intuitive interactions<br>- Higher error rates | - Streamlined, intuitive workflow<br>- Reduced errors<br>- Faster task completion |
| **Exhibition Feedback** | - No - | - Blended prototypes received more comprehensive feedback<br>- Highlighting both digital and physical usability improvements. |

***Fig: 4*** *Comparison of digital and phygital approaches in coffee machine interface re-design (Source: Author)*

**Findings:** This research explored the redesign of a coffee machine interface using CE principles, emphasizing both digital and physical user interactions. Initial findings from digital-only prototypes revealed significant usability challenges, including ambiguous icons, high cognitive load, and limited user engagement, especially during waiting periods. The introduction of animated progress loaders and clear quantity indicators improved engagement and reduced cognitive strain, but further testing highlighted the limitations of focusing solely on digital solutions. By integrating tangible controls and prototyping physical layouts alongside digital interfaces, the research uncovered additional usability and accessibility improvements. Hands-on testing with blended prototypes provided more realistic interaction scenarios, revealing gaps that digital testing alone could not identify. Feedback from exhibitions and peer reviews confirmed that combining digital and physical elements resulted in a more intuitive, accessible, and engaging user experience. Overall, the research demonstrates that an integrated approach—merging digital and tangible design guided by CE—significantly enhances usability, user engagement, and accessibility in interactive product interfaces.

**3.2 Case Study: Laser cutting machine interface re-design**

Smit, a student set out to improve the control interface of laser cutting machines by applying CE principles. His initial research focused on identifying cognitive and usability issues in existing interfaces. Early user testing of his digital prototypes revealed several critical challenges: users struggled to understand icons and navigation, experienced high cognitive load due to the absence of tactile feedback, and found the small button controls difficult to use. Engagement was low, as information provided in manuals was not interactive, and user interaction was limited to visual feedback on the screen. The digital-only approach also failed to address the lack of physical tactile feel, limiting accessibility, and providing little insight into physical interaction challenges. Prototyping on laptops or printed screens further restricted the ability to simulate real-world use.

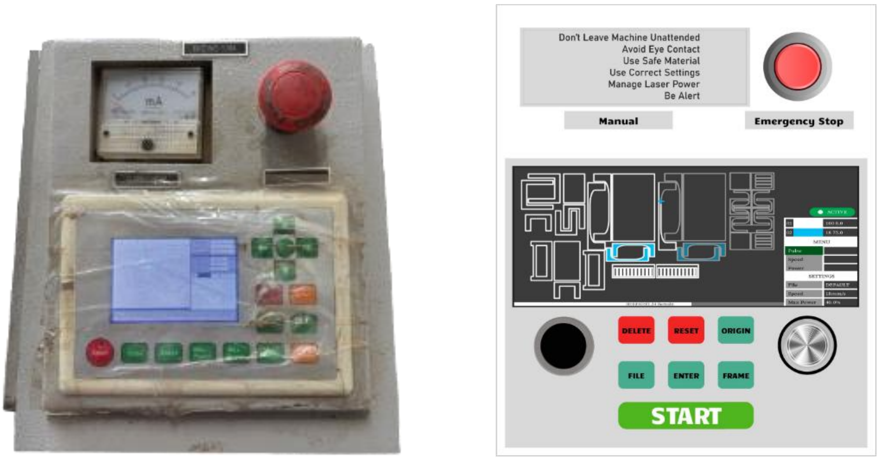


***Fig: 5*** *Existing laser cutting machine interface and iinitial concept for interface re-design (Source: Author)*

Recognizing these limitations, Smit shifted his approach to integrate tangible, physical models alongside digital solutions. This blended method allowed him to observe how users interacted with both the screen and the physical controls, uncovering additional usability issues, and generating more actionable recommendations. Through extensive user testing, analysis, and reflection, Smit iteratively refined his design. Key improvements emerged from this hands-on exploration. Usability was enhanced by introducing a large, easily identifiable start button and reshaping all controls into capsule buttons for better ergonomics. User engagement increased with the addition of intuitive icons in the manual, facilitating clearer communication between users and the machine. To reduce cognitive load, Smit implemented color-coded physical buttons, making it easier for users to identify functions quickly. Accessibility was addressed by designing larger emergency stop and start buttons, reducing the risk of error and making the interface more inclusive. User feedback mechanisms were also improved: any errors in the laser-cutting process were now reflected on the display screen with clear pop-up messages, ensuring users were promptly informed and could take corrective action.

The development of blended prototypes enabled hands-on, realistic testing, providing valuable insights into how digital and physical elements could work together to create a seamless user experience. Presenting the final product at an exhibition offered further opportunities for feedback, peer learning, and critical reflection, enriching Smit's design process. This case study demonstrates the importance of integrating cognitive ergonomics with both digital and tangible design elements. Smit's iterative, user-centered approach resulted in a more intuitive, accessible, and engaging control interface for laser cutting machines, highlighting the value of holistic prototyping and real-world testing in interactive product design.

*Fig: 6 Final blended prototype of laser cutting machine interface (Source: Author)*

| ASPECT | DIGITAL APPROACH (BEFORE) | PHYSGITAL APPROACH (AFTER) |
|---|---|---|
| **Usability** | - Unclear icons with small Buttons<br>- No tactile feedback | - Larger, color-coded, tactile Buttons<br>- Intuitive layout to reduce cognitive load |
| **User Engagement** | - Limited to visual feedback<br>- Non-intuitive manuals and low engagement | - Interactive icons for engaging Manual<br>- Real-time feedback for higher engagement |
| **Cognitive Loads** | - High cognitive load due to lack of physical cues and complex navigation | - Physical buttons and color codes reduce cognitive strain |
| **Accessibility** | - Small button controls with no tactile feel<br>- Limited accessibility | - Large start and emergency buttons<br>- Improved accessibility for all users |
| **User Feedback** | - Limited insight into physical interaction<br>- Digital-only feedback | - Clear error messages on display<br>- Feedback from both digital and physical use |
| **Prototyping** | - Tested on screens/laptops<br>- Less interactive with limited real-world simulation | - Blended prototypes allow hands-on realistic testing and iteration |

| | | |
|---|---|---|
| **Efficiency** | - Slower, less intuitive operation<br>- Higher error rates | - Streamlined workflow<br>- Faster, more accurate operation for fewer errors |
| **Exhibition Feedback** | - No - | - Constructive feedback on both digital and physical usability<br>- More actionable insights |

***Fig: 7*** *Comparison of digital and phygital approaches in laser cutting machine interface re-design (Source: Author)*

**Findings:** This research showed the integrating CE principles with both digital and physical elements in the redesign of a laser cutting machine control interface led to significant improvements in usability and user experience. Initial digital-only prototypes revealed issues such as unclear icons, high cognitive load, and lack of tactile feedback, which limited engagement and accessibility. By introducing tangible controls—such as larger, color-coded buttons and clear error feedback— addressed these challenges, making the interface more intuitive and reducing the risk of user error. Hands-on testing with blended prototypes provided realistic interaction scenarios, uncovering usability gaps that digital testing alone could not identify. This approach enabled more comprehensive feedback and iterative improvements. The research demonstrates that a holistic, user-centered design process, which combines digital and physical prototyping, is essential for creating efficient, accessible, and engaging interfaces for complex machines, ultimately enhancing both user satisfaction and operational safety.

**3.3 Case Study: Induction stove interface and interaction re-design**

Vanshika, a student undertook the challenge of redesigning the interface of an induction stove by applying CE principles. Her initial research focused on rearranging the buttons and controls of existing products to address usability and inclusivity issues. Early usability testing revealed several critical challenges: users struggled with the abundance of controls and unclear indications, including an ambiguous on/off button. Excessive interactivity led to disengagement, while the overload of buttons increased cognitive strain. Additionally, the lack of tactile feedback and inclusive design limited accessibility, and digital prototypes tested on printed screens or laptops failed to simulate real-world interactions effectively.


***Fig: 8*** *Existing induction stove and initial concept for interface re-design (Source: Author)*

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Recognizing these limitations, Vanshika refined her approach by focusing on minimalism and inclusivity. She redesigned the interface to reduce the number of buttons, introducing only meaningful and intuitive interactions. The new design featured tactile elements, such as a round button with embossed line indicators, making it user-friendly for both regular and partially disabled users. This tactile feedback not only improved accessibility but also reduced cognitive load by simplifying the interface. By eliminating unnecessary interactivity, Vanshika enhanced user engagement, ensuring the interface was functional and easy to navigate. User feedback played a pivotal role in the iterative design process. Testing with physical prototypes revealed new insights into how users interacted with the interface, highlighting the importance of combining digital and tangible elements. This hands-on approach allowed Vanshika to bridge the gap between conceptual design and real-world usability, resulting in a more intuitive and accessible product. The integration of physical models provided a deeper understanding of user behavior, enabling her to address both digital and physical interaction challenges effectively. Presenting her work at an exhibition further enriched the design process. Observing real user interactions, receiving direct feedback, and engaging in peer discussions offered valuable perspectives that helped refine the design. This iterative process reinforced the importance of continuous learning and adaptation in design, particularly when addressing cognitive ergonomics in real-world contexts. The final design demonstrated significant improvements in usability, engagement, cognitive load, and accessibility. By combining digital and physical prototyping, Vanshika created an interface that was intuitive, inclusive, and user-friendly. Her work highlights the value of iterative, user-centered design and the integration of cognitive ergonomics principles to create interfaces that cater to diverse user needs while enhancing overall usability and interaction.

***Fig: 9*** *Final blended prototype of induction stove interface (Source: Author)*

| ASPECT | DIGITAL APPROACH (BEFORE) | PHYSGITAL APPROACH (AFTER) |
|---|---|---|
| **Usability** | - Too many buttons and unclear controls;<br>- Ambiguous on/off button for high risk of user error | - Minimal, intuitive controls<br>- Clear on/off button<br>- Tactile feedback and user- friendly for all |
| **User Engagement** | - Excessive, unnecessary interactivity<br>- Disengaging | - Reduced to essential Interactions<br>- More focused and engaging |
| **Cognitive Loads** | - Overloaded with buttons<br>- High cognitive load and no tactile feedback | - Simple, minimal design<br>- Tactile elements reduce cognitive strain |
| **Accessibility** | - No tactile feel<br>- Not inclusive, difficult for users with disabilities | - Tactile BIG round button with Embossed indicators<br>- Inclusive for regular and disabled users |
| **User Feedback** | - Limited insight into physical interaction<br>- Digital-only feedback | - Physical models revealed new Insights<br>- Deeper understanding of user needs |
| **Prototyping** | - Tested on printed screens/laptops<br>- Not interactive and lacked realism | - Blended digital and physical Prototypes<br>- Hands-on realistic testing |
| **Efficiency** | - Complex, error-prone operation<br>- Slow learning curve | - Streamlined, efficient operation<br>- Faster learning and fewer errors |
| **Exhibition Feedback** | - No - | - Comprehensive feedback from real users and peers<br>- Actionable improvements |

***Fig: 10*** *Comparison of digital and phygital approaches in Induction stove interface re-design (Source: Author)*

**Findings:** This research demonstrates that applying cognitive ergonomics principles and integrating both digital and physical prototyping significantly improves the usability and inclusivity of induction stove interfaces. Initial digital-only designs with numerous buttons and unclear controls led to high cognitive load, user confusion, and limited accessibility. By simplifying the interface, introducing tactile feedback, and focusing on minimal, meaningful interactions, the redesigned control area became more intuitive and accessible for all users, including those with disabilities. Hands-on testing with physical prototypes provided deeper insights into real user interactions, revealing usability gaps that digital testing alone could not identify. Exhibition feedback and peer discussions further refined the design, emphasizing the importance of iteration and user-centered approaches. Overall, the findings highlight that blending digital and tangible elements, guided by CE, is essential for creating user-friendly, inclusive, and efficient interfaces in everyday appliances.

### 3.4 Case Study: Kodak digital camera and it's interaction re-design

Tulika, a student embarked on the redesign of the Kodak EasyShare C140 digital camera interface with the goal of enhancing usability and reducing interface clutter through the application of CE principles. Her initial efforts centered on reorganizing the digital display to create a more seamless and interactive user experience. However, early usability testing with her digital prototype revealed several critical issues. Users found the interface overloaded with controls, making navigation between screens complex and unintuitive. The cluttered display reduced user engagement and increased cognitive load, while the absence of tactile feedback and reliance solely on

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digital screens limited accessibility. Additionally, the prototype, being a 1:1 printout, failed to capture the nuances of physical interaction, resulting in limited and less actionable user feedback.

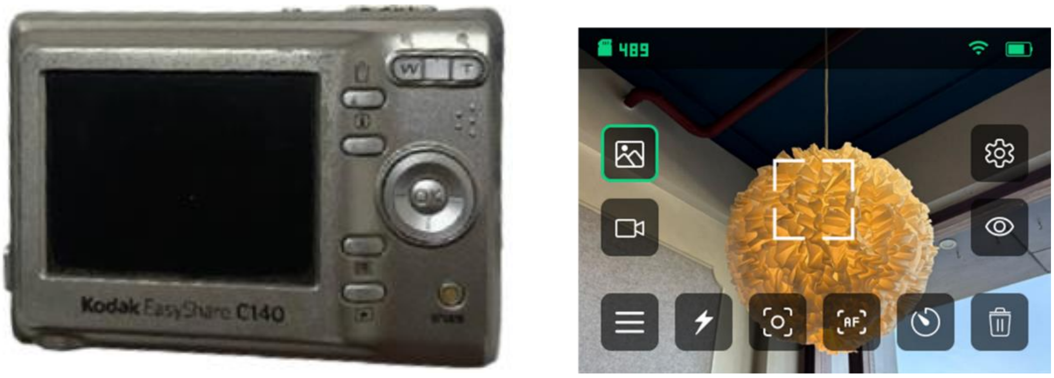


***Fig: 11*** *Existing EasyShare C140 digital camera and initial concept for interface re-design (Source: Author)*

Recognizing these shortcomings, Tulika shifted her approach to incorporate tangible elements into her design process. Guided by user feedback and mentor suggestions, she refined her prototype to focus on minimalism and intuitive interaction. The redesigned interface featured only essential and frequently used features, significantly reducing information clutter and cognitive load. She introduced physical buttons for critical functions, such as a tactile switch for toggling between picture and video modes, while eliminating unnecessary controls. This not only improved accessibility but also provided users with a more intuitive and satisfying interaction. The adoption of a phygital (physical + digital) prototyping approach proved transformative. By blending a refined digital screen interface with tangible, 3D-printed physical controls, Tulika enabled users to interact with the camera in a manner closely resembling real-world use. This hands-on experience allowed for more realistic and comprehensive user feedback, as users could physically hold and operate the model, revealing insights that digital-only prototypes could not provide. Collaboration with peers further enriched the design process, as Tulika explored contemporary digital camera trends to inform her decisions on which controls to minimize or integrate into the UI, ensuring that essential buttons remained easily accessible. Presenting her work and observing user interactions at various stages reinforced the importance of iterative design and continuous learning. Tulika's case study demonstrates the value of integrating cognitive ergonomics with both digital and tangible design elements. Her iterative, user-centered approach resulted in a more intuitive, accessible, and engaging camera interface, highlighting the necessity of phygital prototyping for optimizing user experience in consumer electronics.


***Fig: 12*** *Final blended prototype of EasyShare C140 digital camera and interface (Source: Author)*

| ASPECT | DIGITAL APPROACH (BEFORE) | PHYGITAL APPROACH (AFTER) |
|---|---|---|
| **Usability** | - Cluttered controls<br>- Complex navigation and high likelihood of user errors | - Minimal, intuitive controls<br>- Seamless navigation to reduce user errors |
| **User Engagement** | - Cluttered information on screen<br>- Reduced engagement | - Simplified interface increased engagement |
| **Cognitive Loads** | - High cognitive load due to excessive information and unclear icons | - Reduced cognitive load with minimal icons and clear indications |
| **Accessibility** | - No tactile feedback<br>- Reliance on digital-only interface | - Physical buttons for key functions<br>- Tactile switch for picture/video mode which improved accessibility |
| **User Feedback** | - Limited feedback due to static, printed prototypes | - Realistic feedback from blended digital and physical prototypes |
| **Prototyping** | - Tested on printed screens/laptops so Lacked interactivity | - Phygital prototypes with 3D-printed models enabled hands-on testing |
| **Efficiency** | - Complex interface<br>- Slower operation so higher error rates | - Streamlined interface<br>- Faster operation and fewer errors |
| **Exhibition Feedback** | - No - | - Adoptable feedback from realistic user interactions and peer discussions |

***Fig: 13*** *Comparison of digital and phygital approaches in EasyShare C140 digital camera interface re-design (Source: Author)*

**Findings:** This research demonstrates that integrating CE principles with both digital and tangible prototyping significantly improves the usability and user experience of digital camera interfaces. Initial digital-only prototypes of the Kodak EasyShare C140 revealed issues such as cluttered controls, high cognitive load, and limited accessibility due to the absence of tactile feedback. By adopting a phygital approach—combining a minimal, intuitive digital display with essential physical buttons—reduced information overload, enhanced user engagement, and made the interface more accessible and user-friendly. Hands-on testing with a 3D-printed model provided realistic feedback and deeper insights into user interactions, which digital prototypes alone could not capture. Overall, the findings highlight that blending digital and physical design, guided by CE, is essential for creating intuitive, efficient, and satisfying user experiences in consumer electronics.

### 3.5 Observation: Vending machine display and its interaction re-design

Kratika, a student undertook a comprehensive study of a vending machine's interface to better understand and improve user interactions through the application of cognitive ergonomics (CE) principles. Her initial approach focused on the digital user interface, where she visualized and iteratively improved various concepts. She developed a prototype, printed it, and conducted usability testing with real users to identify design shortcomings. Early user testing revealed several critical issues. The interface was not user-friendly, with small touch targets and the exclusive use of text labels, which hindered seamless interaction. Navigation elements, such as next and back buttons, were missing, making it difficult for users to move through the process. The interface lacked intuitiveness and engagement, particularly during product selection and payment, which was found to be complex and confusing. The absence of a clear information hierarchy led to increased cognitive load, as users were unsure of the next steps and did not receive adequate payment confirmation. Accessibility was also a significant concern; the design did not accommodate users in wheelchairs, and the screen height was not optimized for reachability. Feedback from initial testing focused on these usability and interaction issues, while the digital-only prototypes failed to simulate real-world interactions effectively.

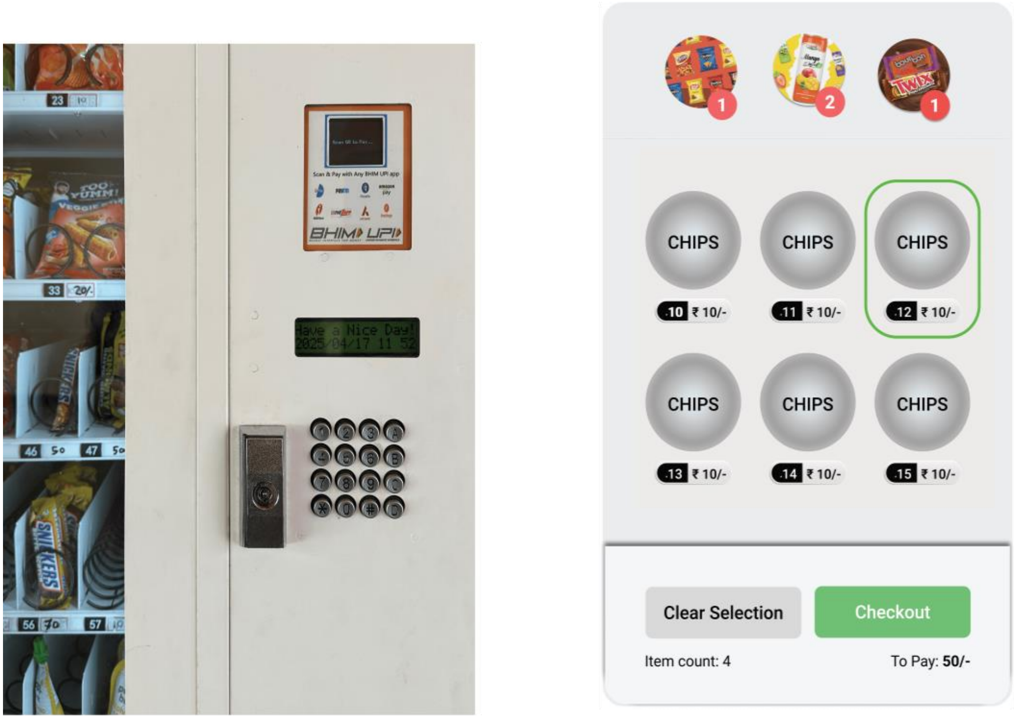


***Fig: 14*** *Existing vending machine and initial concept for interface re-design (Source: Author)*

Recognizing these limitations, Kratika engaged in further user interviews and showcased her prototype at an exhibition, which provided valuable feedback and exposed her to diverse user perspectives. This iterative process led to substantial improvements in her design. She created a more user-friendly interface by incorporating product images alongside labels, making selection more intuitive. The updated design featured smooth product selection options and simplified payment processes, enhancing user engagement. She established a clear information hierarchy to guide users and facilitate error recovery, thereby reducing cognitive load. Accessibility was significantly improved by designing a full-height display that allowed all users, including those with disabilities, to select products easily. Inclusivity considerations were integrated into the interface layout and interaction flow. User feedback mechanisms were enhanced, and the addition of interactive transitions improved usability. By blending digital and physical prototyping, Kratika enabled hands-on testing and more realistic interaction scenarios, which provided deeper insights into user behavior. Exhibition feedback highlighted the ease of use and seamless experience of the blended prototype, reinforcing the importance of combining digital and tangible elements. Through this process, Kratika identified key design factors such as optimal screen height and intuitive navigation, deepening her understanding of cognitive ergonomics and user-centered design. Her hands-on, iterative approach resulted in a more accessible, engaging, and user-friendly vending machine interface.

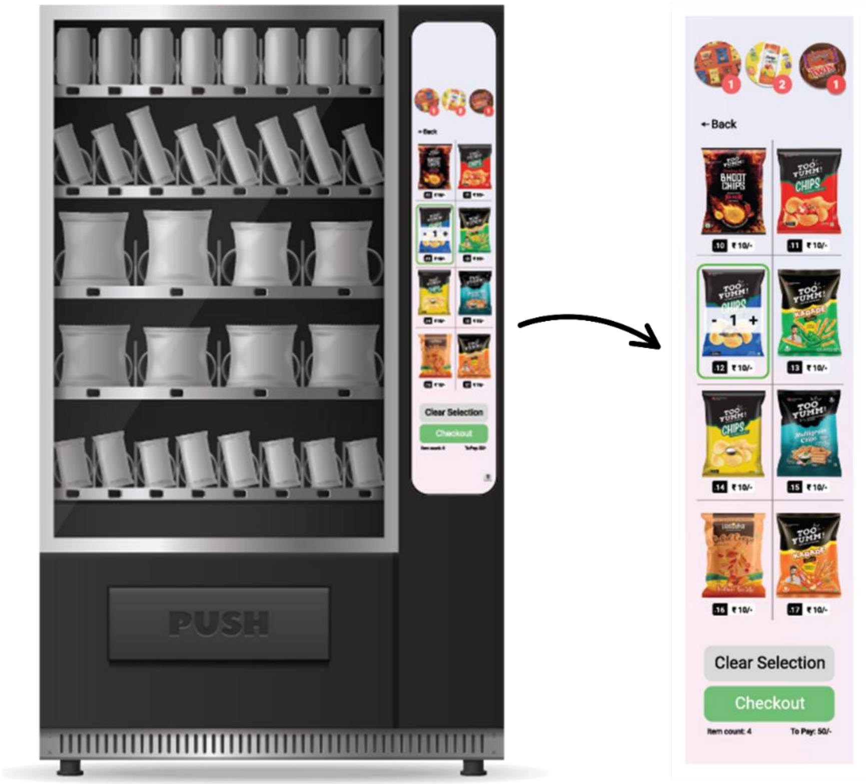


***Fig: 15** Final blended prototype of vending machine interface (Source: Author)*

| ASPECT | DIGITAL APPROACH (BEFORE) | PHYGITAL APPROACH (AFTER) |
|---|---|---|
| **Usability** | - Small, only labels for items indications – - Unclear navigation like no next/back buttons | - User-friendly interface with product images and clear navigation |
| **User Engagement** | - Complex product selection and payment Process<br>- Low engagement | - Smooth product selection and easy payment process<br>- Higher engagement |
| **Cognitive Loads** | - No information hierarchy<br>- Users confused about how to go next steps | - Clear information hierarchy<br>- Reduced cognitive load and error recovery options |
| **Accessibility** | - Missing accessibility for disabled people<br>- Poor reachability due to screen height | - Full-height display<br>- Inclusive design for disabled users |
| **User Feedback** | - Limited feedback due to static and printed prototype | - Realistic feedback from blended digital and physical prototypes |

| | | |
|---|---|---|
| **Prototyping** | - Tested on printed screens/laptops so lacked interactivity | - Blended prototypes enabled testing very easily |
| **Efficiency** | - Complex interface design<br>- Higher error rates due to slower operation | - Streamlined interface<br>- Faster operation so, fewer errors |
| **Exhibition Feedback** | - No - | - Feedback to improve user interactions, peer learning, and discussions |

***Fig: 16*** *Comparison of digital and phygital approaches in vending machine interface re-design (Source: Author)*

**Findings:** This research demonstrates that integrating CE principles with both digital and physical prototyping leads to a significantly more accessible, intuitive, and user-friendly vending machine interface. Initial digital-only designs suffered from poor usability, lack of engagement, high cognitive load, and limited accessibility, especially for users with disabilities. By incorporating product images, clear navigation, and optimizing the interface height for all users, the blended approach addressed these challenges. Hands-on testing with a physical model provided realistic feedback and revealed usability gaps that digital prototypes alone could not capture. Exhibition feedback further refined the design, emphasizing the importance of inclusivity and seamless interaction. Overall, the findings highlight that a holistic, user-centered design process—combining digital and tangible elements—greatly enhances usability, engagement, and accessibility in public interfaces.

Exhibitions are the most effective tools in the learning process and that require several days of effort and expense, but they also foster a sense of competition among all students.

***Fig: 17*** *Students are making their prototypes in the studio of the university (Source: Author)*

***Fig: 18** A glimpse of students' exhibition (Source: Author)*

**4. Key insights from Case Studies: CE and its influences in Interface Design**

User-centered design, which stresses methodical design processes overseen by skilled designers and consistently puts the user's viewpoint first, gained international recognition in the 1980s (Norman A D., Draper W S., 1986). Since information systems, technology, and multimedia are the cornerstones of contemporary interactive systems and goods, CE places a great emphasis on these areas. Globally, CE is frequently referred to by a few names, such as display and control systems (Shneiderman, B., & Plaisant, C., 2016), human-machine interface, and human-computer interaction (Card, S. K., Moran, T. P., & Newell, A., 1983). When it comes to creating smooth and user-friendly interfaces, these disciplines are essential. Our above case studies' key insight is that redesigning a number of product interfaces, such as digital cameras, induction cookstoves, Laser cutting machine controller interfaces, vending machine interfaces, and coffee machine interfaces, showed that good design includes physical interactions in addition to the user interface. More intuitive and user-friendly designs were produced as a result of the process, which included physical prototyping and real-world testing. The case studies' main takeaways are the necessity of a smooth transition between digital and physical components, the value of user-centered and iterative design, and the relevance of lowering the cognitive load. A deeper understanding of CE and usability was gained through prototyping, while peer learning and insightful feedback were fostered by showcasing redesigned prototypes at exhibitions. Given the circumstances, insights highlight the need for a seamless fusion of digital and physical design components, stressing ongoing user interaction and iterative enhancements to promote efficient and deliberate design processes. Implementing CE principles into interface design reduces the learning curve and makes goods more accessible to a wider variety of users by matching users' cognitive processes. Additionally, productivity and efficiency are greatly increased since well-optimized designs enable users to do jobs rapidly and with few mistakes.

| CASE STUDY | INITIAL FOCUS | KEY INSIGHTS | FINAL RESULTS |
|---|---|---|---|
| **Coffee Machine Interface** | Redesigning the digital interface to reduce human error and improve usability | - Users struggled with icons and navigation<br>- Engagement was low during waiting periods<br>- Accessibility and physical interaction challenges were overlooked | - Blended digital and physical prototypes improved usability<br>- Cognitive load was reduced<br>- Animated feedback enhanced user engagement<br>- Added quantity indicators for milk and coffee which reduced cognitive load |
| **Laser Cutting Machine Interface** | Improving the control interface to reduce cognitive load and errors | - Unclear icons and small buttons caused confusion<br>- High cognitive load and lack of tactile feedback<br>- Accessibility was a major issue | - Phygital design with tactile buttons and color coding reduced errors<br>- Accessibility and user experience was improved |
| **Induction Stove Interface** | Reorganizing buttons and controls to improve usability and inclusivity | - Too many buttons increased cognitive load<br>- Lack of tactile feedback and inclusivity | - Minimal, intuitive controls with tactile feedback improved usability.<br>- Inclusive design enhanced accessibility. |
| **Digital Camera Interface** | Reorganizing the digital display to reduce clutter and improve usability | - Cluttered controls and lack of tactile feedback increased cognitive load<br>- Navigation was complex and accessibility was limited | - Simplified interface with minimal icons and tactile buttons improved engagement<br>- Blended prototypes enhanced accessibility |
| **Vending Machine Interface** | Designing a user-friendly UI for seamless product selection and payment | - Small, text-only interface with unclear navigation<br>- Poor accessibility and high cognitive load due to lack of information hierarchy | - Full-height, inclusive interface with product images and clear navigation<br>- Blended prototypes enhanced usability and engagement |

***Fig: 19** consolidated analysis Case studies, and Results (Source: Author)*

**User Types and Design Considerations:**
We observed some remarkable points for typical user types in the study and we need to consider as well.

| USER TYPE | DESCRIPTION | DESIGN CONSIDERATIONS |
|---|---|---|
| **New Users** | First-time users with no prior experience | Provide clear directions, guided paths, and onboarding tutorials |
| **Novice Users** | Users with minimal familiarity with the product | Ensure a smooth, intuitive, and easy-to-use interface |
| **Regular Users** | Users familiar with the main features and use the product regularly | Focus on efficiency and quick access to frequently used features |
| **Power Users** | Experienced users who know all features and push the product to its limits | Provide advanced functionalities and customizable options for meaningful experiences |
| **Accessibility Users** | Users with disabilities requiring assistive technology or specific design considerations | Ensure low learning curves, accessible features, and compatibility with assistive technologies |

***Fig: 20** Design considerations for different user types (Source: Author)*

## 5. Conclusion

This study highlights the importance of CE in creating user-friendly interfaces that effectively blend digital and physical elements. Through hands-on experiments, student observations, and real-world testing, it became clear that relying solely on digital approaches often fails to provide an intuitive and accessible user experience. By integrating tangible components with digital interfaces, designers can reduce cognitive load, enhance usability, and facilitate smoother interactions. A key takeaway from this research is the necessity of an iterative, user-centered design process that continually refines solutions based on user feedback. The presentation of mixed prototypes not only encouraged valuable peer learning but also emphasized the industry relevance of this methodology. Additionally, this study acknowledges the diverse spectrum of users, from beginners to advanced users and those with accessibility needs, each requiring tailored design considerations to optimize interaction efficiency and accessibility. Ultimately, this research advocates for a balanced approach to interface design, where digital innovations are supported by tangible interaction elements.

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**7. Authors**

**1* Parag Sarma,** Assistant Professor, Department of Product Design,
School of Design, Anant National University, Ahmedabad, Gujarat, India
parag.sarma@anu.edu.in , parag.srm@gmail.com

**2* Nipan Das,** Assistant Professor, Foundation Department,
Unitedworld Institute of Design, Karnavati University, Gandhinagar, Gujarat
Nipandas02@gmail.com

**Dr. Vijay Shah,** Professor, Foundation Department,
Unitedworld Institute of Design, Karnavati University, Gandhinagar, Gujarat
vijayshah@karnavatiuniversity.edu.in

**8. Conflict of Interest**

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