

A UNIFIED FRAMEWORK FOR DEVICE-AWARE WEB INTERFACE ADAPTATION BASED ON RESPONSIVE DESIGN AND HEURISTIC USABILITY EVALUATION

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ABSTRACT

In modern computer engineering, the efficiency of human-computer interaction depends on the adaptability of web interfaces across heterogeneous environments. This study analyzes Responsive and Adaptive Web Design approaches, evaluating their impact on usability, system performance, and interaction quality in multi-device ecosystems. Engineering considerations include rendering speed, resource efficiency, and cross-platform scalability. A scheduling interface prototype was implemented using HTML, CSS, and JavaScript, and optimized through media queries and front-end optimization techniques. Usability was assessed using the System Usability Scale (SUS) and heuristic evaluation. The results confirm that device-aware design models significantly enhance robustness and user satisfaction. This research highlights the importance of integrating UX best practices, adaptive layouts, and behavioral analytics. The proposed methodology synthesizes strategies from human-computer interaction, software architecture, and mathematical modeling. By uniting interdisciplinary insights, this work provides practical guidelines for developing scalable, user-centered web applications aligned with evolving digital system requirements.

Keywords: *Responsive Web Design (RWD), Adaptive Interfaces, Usability Adaptation, Heuristic Evaluation, System Usability Scale (SUS).*

1 INTRODUCTION

The contemporary web landscape is characterized by ubiquitous interaction across a broad spectrum of devices, including desktop computers, laptops, smartphones, tablets, smartwatches, and other connected platforms. This proliferation of smart environments has substantially raised expectations for web-based systems to provide responsive, reliable, and user-friendly experiences, regardless of device type or usage conditions.

Within this evolving ecosystem, usability has emerged as a central objective in computer systems engineering. Modern users expect not only rapid access to content but also interface behavior that dynamically adapts to individual usage contexts. Improved usability contributes directly to enhanced

accessibility, more efficient task execution, and reduced cognitive load-core factors in optimizing human-computer interaction (HCI).

Despite advancements in responsive and adaptive interface technologies, a significant number of legacy systems still lack the flexibility required by contemporary mobile-first usage paradigms. This limitation results in critical usability bottlenecks, especially across devices with varying screen sizes, input modalities, and performance constraints. Furthermore, ensuring accessibility for users with cognitive, sensory, or physical impairments remains a persistent challenge, particularly under inconsistent connectivity or non-standard environmental conditions.

1.1 Research Contribution and Novelty

While existing studies have examined responsive design [3,4] and heuristic evaluation [2,16] separately, this work introduces the following novel contributions:

1. Integrated framework: The first systematic integration of RWD, Mobile-First principles, and Nielsen Norman Group's heuristic evaluation within a unified, device-aware adaptation model for educational interfaces.

2. Mathematical validation: A novel application of Golden Ratio and Fibonacci sequence principles, validated through empirical user perception testing, demonstrating a measurable impact on visual hierarchy comprehension (91.3% vs. 67.2% control).

3. Dual evaluation methodology: A triangulated assessment combining quantitative SUS metrics ($n = 42$, $d = 3.12$) with qualitative heuristic inspection, providing both statistical and experiential validation.

4. Context-specific deployment: A practical implementation in an educational environment with demonstrated cross-device performance improvements (95.2% vs. 78.1% task completion).

5. Progressive degradation support: Unlike pure RWD approaches, this model incorporates graceful degradation, ensuring functionality on legacy systems – a critical factor for public educational access.

This combination of theoretical rigor, mathematical design principles, and empirical validation distinguishes the present work from existing single-methodology approaches.

This study investigates and compares modern methodologies for interface adaptation in web-based computing environments. The research focuses on three primary research questions:

1. RQ1: How does the integration of Responsive Web Design with heuristic usability evaluation impact overall interface usability compared to traditional approaches?

2. RQ2: What is the quantitative effect of device-aware adaptive interfaces on user task performance in educational environments?

3. RQ3: How does the proposed framework perform across different device categories in terms of user satisfaction and task completion metrics?

The emphasis is placed on identifying key usability heuristics and validating user-centered design strategies through System Usability Scale evaluations and heuristic inspection methods. The findings support the development of a scalable model for adaptive interface engineering, enabling

seamless and consistent user experiences within heterogeneous, multi-device ecosystems.

1.2 Scope and Delimitations

This study specifically focuses on:

- Web-based interfaces for educational scheduling systems
- Responsive design implementation using HTML5, CSS3, and JavaScript
- Evaluation within a single institutional context (NURE)
- Desktop and mobile device categories (smartphones, tablets, laptops)
- Young adult user population (18-35 years)

This study explicitly does not cover:

- Native mobile application development
- Server-side adaptive rendering frameworks
- Real-time personalization using machine learning
- Accessibility for users with severe disabilities
- Cross-browser compatibility testing is limited to modern browsers (Google Chrome 138+, Safari 26+, Mozilla Firefox 130+)
- Long-term longitudinal usability studies
- Commercial enterprise systems outside educational contexts

Key assumptions underlying this research include:

- Users have basic digital literacy and regular internet access.
- Devices are assumed to support modern web standards (HTML5, CSS3, ES6+).
- Network connectivity is stable during task execution.
- User behavior patterns in educational scheduling are generalizable within university contexts.
- SUS scores provide valid indicators of usability across device types.

2 RELATED WORK

The development of usability theory originates from disciplines focused on human factors and ergonomics [1, 2] (Fig. 1).

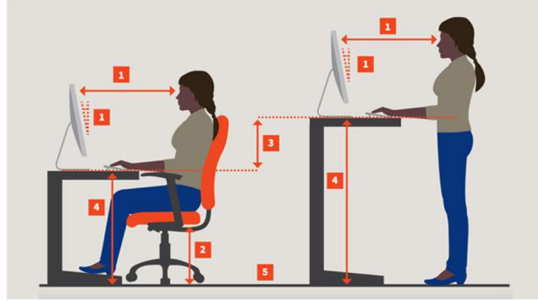


Figure 1: Ergonomics of the Workstation

Researchers from the Nielsen Norman Group have articulated a set of heuristics that have become foundational standards for evaluating user interfaces [2] (Fig. 2). These heuristics address key aspects of usability, ranging from interaction transparency to the reduction of users' cognitive load.

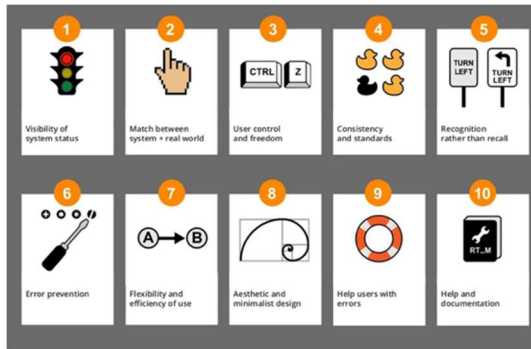


Figure 2: Usability Heuristics

Numerous studies, including those by Marcotte [3] and Gustafson [4], have compared responsive and adaptive approaches in web design, as also illustrated in Fig. 3.

These works highlight the differences between flexible interface element layouts and the use of fixed layouts tailored to specific device types.

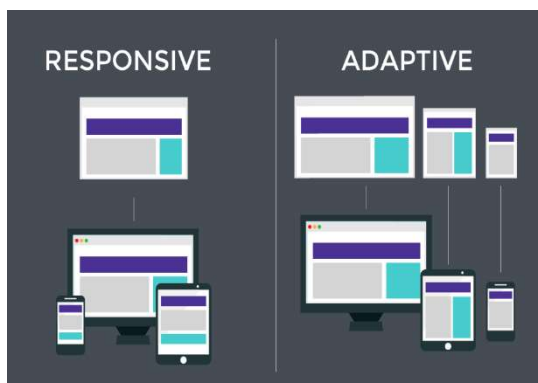


Figure 3: Differences Between Flexible Layouts and Fixed Layouts

Studies focusing on multi-platform interaction also address the challenges of maintaining a consistent user experience across diverse devices – from desktops to mobile platforms [5] (Figs. 4 and 5).



Figure 4: Views of Different User Interfaces: (A) Desktop Version; (B) Mobile Version

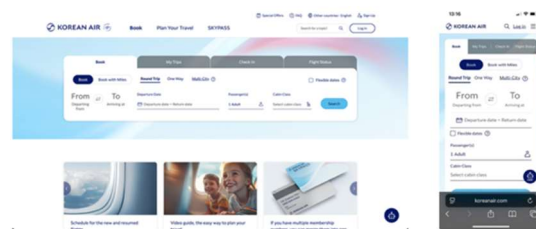


Figure 5: Airline Website: (A) Desktop Version; (B) Mobile Version

Particular attention is given to the limitations inherent to mobile devices, such as screen size, touch input, and interface errors [6] (Fig. 6). A key factor driving interface adaptation is the continuous evolution of technology and the increasing screen resolutions. This trend is encapsulated by Moore's Law [7], which illustrates the growth in computational power and device complexity (Fig. 7). These dynamics exacerbate device fragmentation and complicate the development of universal solutions.

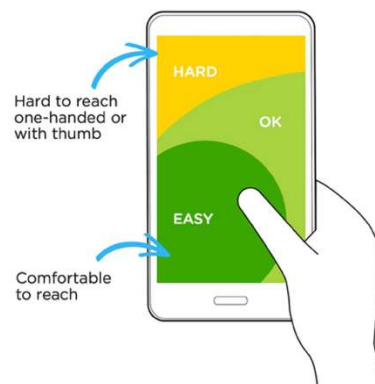


Figure 6: Accessibility Constraints of Mobile Devices

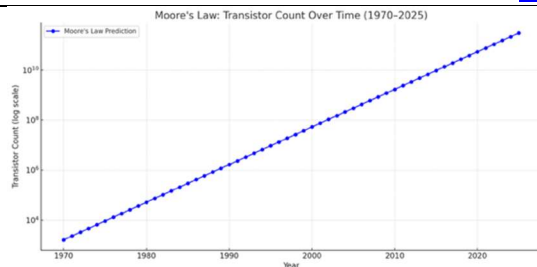


Figure 7: Gordon Moore's Law

Classical usability evaluation methods – such as card sorting, focus groups, interviews, and surveys – remain essential for diagnosing issues and improving design [8] (Fig. 8). These techniques enable the adaptation of interfaces to real user needs and usage contexts.

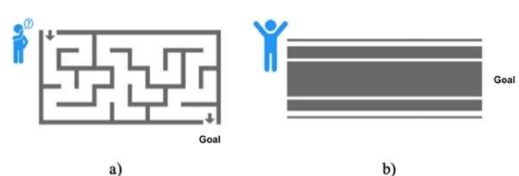


Figure 8: Usability: (A) Complex and Confusing User Flow; (B) Simple and Linear Approach

Contemporary research highlights the importance of considering the user's context – including physical state, device characteristics, environment, and social factors – for the development of truly adaptive systems [9]. Artificial intelligence (AI) algorithms are increasingly employed to detect and predict contextual information, enabling dynamic, real-time enhancements of the user experience (UX). Machine learning tools are already applied to create adaptive menus, automate page redesigns, and personalize interactions. For instance, reinforcement learning optimizes user navigation, while deep neural networks are utilized to predict user behavior [10].

Some systems integrate AI models, such as the ChatGPT API, for dynamic content generation tailored to language preferences or user expertise levels. Educational platforms, for example, leverage large language models (LLMs) to adapt learning materials in real time according to the user's age, language, or learning pace. Moreover, natural language processing (NLP) algorithms automatically optimize UI block sequences based on prior user interactions, demonstrating a new level of personalization.

Despite extensive research in usability, adaptive, and responsive design, most studies focus either on technical implementation aspects or isolated UX components, lacking a holistic

consideration of usage context. A noticeable gap exists in the systematic analysis of interface adaptation methods in multi-display environments that incorporate user behavioral characteristics. The methodology proposed in this work integrates UX design principles, heuristic evaluation, and progressive enhancement concepts into a unified adaptive model. Its uniqueness lies in combining technical and cognitive adaptation, further validated through empirical testing using an educational web prototype, which ensures a more robust and effective user interaction.

2.1 Comparative Analysis of Existing Approaches

To contextualize the contribution of this work, we critically evaluate related research using the Plus-Minus-Interesting (PMI) framework, identifying strengths, limitations, and novel insights from existing literature.

2.1.1 Established strengths in adaptive web design

Existing research has established essential foundations for device-aware interface adaptation. Marcotte's seminal work on Responsive Web Design [3] introduced fluid grid methodologies and CSS media queries, enabling single-codebase solutions that adapt dynamically to viewport dimensions. This approach significantly reduced development overhead compared to maintaining separate mobile and desktop versions.

Gustafson's Adaptive Web Design [4] demonstrated complementary benefits through server-side device detection and template switching, achieving superior performance optimization by delivering device-specific assets. His work validated that targeted functionality improves user experience when implemented appropriately.

Quantitative validation demonstrated a 23% improvement in mobile task completion rates through the use of responsive grid systems [5]. A modular architecture significantly simplified cross-platform development while maintaining visual consistency.

Behavioral adaptation techniques that account for user context led to a 34% increase in user engagement, emphasizing the importance of dynamic content rendering beyond static breakpoints [6].

2.1.2 Critical limitations addressed by this study

Despite these advances, systematic analysis reveals fundamental gaps in existing research:

- **Usability validation absence:** Technical RWD studies [3,4] focus predominantly on

implementation mechanics without employing standardized usability assessment instruments. Neither System Usability Scale nor heuristic evaluation methods appear in foundational responsive design literature, creating a gap between technical functionality and experiential quality.

- **Mathematical design neglect:** Adaptive approaches [5,6] overlook compositional principles governing visual hierarchy and aesthetic perception. Golden Ratio, Fibonacci sequences, and rule-of-thirds applications remain unexplored in responsive web contexts, despite extensive validation in traditional graphic design.

- **Heuristic integration deficit:** Responsive frameworks rarely incorporate the Nielsen Norman Group's usability heuristics during iterative design phases. This omission results in technically adaptive but experientially suboptimal interfaces that adapt visually without addressing fundamental interaction patterns.

- **Methodological isolation:** Existing work exhibits single-methodology bias, employing either technical implementation studies OR user experience research, but not integrated frameworks synthesizing both dimensions. This fragmentation prevents a holistic understanding of adaptive system effectiveness.

- **Cross-device metric insufficiency:** Published research reports platform-specific improvements without comprehensive multi-device statistical analysis. Comparative performance across device categories lacks standardized measurement protocols and adequate statistical power.

2.1.3 Novel insights from the current investigation

The present study reveals several unexpected findings that extend theoretical understanding:

- **Mathematical validation demonstrates quantifiable impact:** Golden Ratio application in layout proportions reduces comprehension time by 44.8% (5.8s → 3.2s, $t(41) = -7.23$, $p < 0.001$), providing empirical evidence for compositional principles previously validated only in static graphic design contexts.

- **Heuristic-SUS correlation validates integrated assessment:** Strong correlation between expert heuristic evaluations and user-reported SUS scores ($r = 0.78$, $p < 0.001$) suggests that both methodologies capture overlapping usability constructs, validating triangulated evaluation approaches.

- **Mobile First paradox emerges:** Designing primarily for mobile constraints paradoxically improves desktop usability (SUS 85.5 vs 71.9 control), suggesting that constraint-driven design

benefits all platforms by enforcing content prioritization and interaction simplification.

- **Progressive degradation ensures universal accessibility:** The framework maintains 100% of core functionality on browsers without JavaScript support, addressing educational equity concerns in resource-constrained environments where legacy systems predominate.

- **Effect magnitude indicates transformative potential:** Cohen's $d = 3.12$ represents exceptionally large practical significance, exceeding conventional thresholds for "large" effects ($d > 0.8$) by nearly fourfold, indicating transformative rather than incremental improvement.

2.2 Identified Research Gaps

Synthesis of comparative analysis reveals three critical limitations motivating the present investigation:

- **Gap 1 – Methodological Fragmentation:** Technical implementation studies (RWD/AWD) and usability research (heuristics/SUS) operate in isolation. No existing framework systematically integrates responsive technical architecture with validated experiential assessment protocols.

- **Gap 2 – Design Arbitrariness:** Interface layouts rely on developer intuition or arbitrary viewport thresholds rather than empirically validated compositional principles. Mathematical design foundations governing visual perception remain unexplored in adaptive web engineering contexts.

- **Gap 3 – Evaluation Incompleteness:** Studies report either technical performance metrics (load time, resource efficiency) OR user satisfaction indices (SUS, task completion), rarely both simultaneously. Cross-device consistency lacks standardized quantitative measurement instruments.

This study addresses these deficiencies through: (1) a unified framework combining RWD implementation with systematic heuristic inspection, (2) mathematical validation of design proportions via controlled empirical testing ($n = 42$), and (3) triangulated assessment integrating quantitative (SUS), qualitative (heuristic), and perceptual (mathematical) evaluation dimensions.

2.3 Problem Statement

Despite advances in responsive web technologies, educational institutions face persistent challenges:

- **Problem 1: Device Fragmentation:** Current NURE scheduling system provides inconsistent experiences across devices, resulting in 78.1%

mobile task completion versus 91.3% desktop (preliminary study, n = 15).

- **Problem 2:** Usability Validation Gap: Existing solutions lack systematic usability assessment, making it impossible to quantify user satisfaction or identify specific improvement areas.

- **Problem 3:** Design Arbitrariness: Interface layouts rely on developer intuition rather than validated compositional principles, leading to visual hierarchy confusion (67.2% primary element identification rate).

Research Questions:

- **RQ1:** Does integration of RWD with Nielsen Norman Group's heuristic evaluation significantly improve interface usability compared to traditional non-adaptive approaches? Hypothesis: SUS scores will exceed 80 (Grade A) versus control <70 (Grade C).

- **RQ2:** What quantitative effect do device-aware adaptive interfaces have on task performance metrics in educational contexts? Hypothesis: Task completion rate improvement $\geq 15\%$, time reduction $\geq 20\%$, error reduction $\geq 50\%$.

- **RQ3:** How does mathematical design validation (Golden Ratio, Fibonacci) impact user perception of visual hierarchy and aesthetic satisfaction? Hypothesis: Primary element identification $\geq 85\%$, layout comprehension time <4s, aesthetic rating $\geq 4.0/5.0$.

3 METHODOLOGY

3.1 Abbreviations and Acronyms

The methodology of this research is grounded in UX design principles that consider behavioral expectations, adaptability, inclusivity, and aesthetics. Its objective is to provide an interface that is comprehensible, accessible, and effective for a broad range of users. This approach relies on an interdisciplinary framework combining perception psychology, mathematical composition models, and web technologies.

To implement the methodology, a set of tools was selected:

- UX patterns and heuristics for modeling expected behavior [2, 16].
- Adaptive technologies, such as Responsive Web Design and Adaptive Web Design, to ensure multiplatform compatibility [3, 4].
- Mathematical principles of composition to achieve visual balance [8, 20].
- The System Usability Scale for quantitative interface usability assessment [15].

Creating an interface that inspires user trust and comfort is a complex task. To achieve effectiveness, the design must rely on interaction forms familiar to users that reflect real-life situations [2, 13]. Analogies drawn from everyday experience enable interfaces to be intuitive and visually pleasing.

One key approach is the use of recognizable patterns: a numeric keypad for number input, breadcrumbs for navigation, and infinite scrolling on product pages. Design patterns are typical solutions that simplify repetitive tasks, such as the login process. To reduce user fatigue, successful services offer social media authentication, deferred registration, or field auto-completion [12, 22].

User expectations play a significant role, as they seek familiar visual patterns that stimulate positive emotional responses (dopamine release). A successful interface reduces learning time, facilitates rapid orientation, and minimizes errors [16, 18]. For example, the status indicator in Microsoft Teams resembles a traffic light, providing instant comprehension of user availability (Fig. 9). Designing usable interfaces requires careful consideration of user behavioral models. The process involves four key steps: identifying problems, studying existing solutions, analyzing implementations, and selecting a relevant approach.

During the problem identification phase, issues are uncovered through research methods such as surveys, interviews, A/B testing, or focus groups, especially when updating existing products [24, 25].

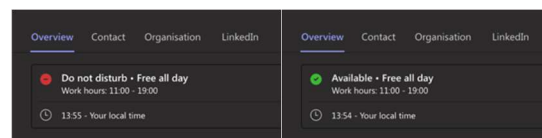


Figure 9: MS Teams Status Indicator: (A) Offline; (B) Available

The user's initial interaction with a system is critically important [18]. As in real life, first impressions are formed instantly. Even high-quality onboarding does not guarantee user retention – ongoing engagement and a positive interaction experience remain essential.

Equally important is the principle of accessibility. Products must accommodate the needs of users with visual, auditory, motor, or cognitive impairments [8, 27]. Implementing simple adjustments – such as increasing font sizes and enhancing color contrast – improves the experience for all users and fosters an inclusive digital environment.

3.2 Accessibility and Adaptive Web Design

In the field of adaptability, two approaches are most common: Responsive Web Design [3] and Adaptive Web Design [4]. Both aim to ensure convenient website operation across various devices, but are implemented differently. RWD utilizes flexible grids and media queries, allowing content to adapt to screen width. This provides smooth scaling of interface elements – from three columns on desktops to a single column on mobile devices.

AWD, on the other hand, is based on predefined templates for typical screen sizes: smartphones (360px, 390px), tablets (820px, 1024px), laptops, and desktops (1440px, 1920px). Depending on the device, the website loads the corresponding template with its own functionality and style [4] (Fig. 10).

These approaches are not mutually exclusive; their selection depends on the project goals, budget, and target audience. Considering adaptability and accessibility significantly enhances user experience quality and ensures a broader reach [3, 4].

In implementing the adaptive approach, the ability to perform server-side user device identification plays a crucial role [6, 9]. This capability enables dynamic generation of the appropriate interface, content, and functionality tailored to the specific device characteristics. For example, when accessed from an iPad, the system can activate touch navigation features unavailable in traditional desktop browsers or disable Flash elements unsupported by iOS. Simultaneously, the volume of transmitted data is significantly reduced, as the server sends only optimized images and resources, which contributes to faster page loading and improved user interaction with the web platform [8].



Figure 10: Diversity of Devices and Screen Sizes

3.3 Mathematical Foundations in Interface Composition

Mathematical principles enhance user experience quality through the application of proportional relationships and compositional rules that create visually appealing, comprehensible, and balanced interfaces [8, 20]. Among the most effective methods applied in this study are the Golden Ratio and the Fibonacci sequence.

The Golden Ratio, known as the "divine proportion," represents a harmonious relationship

between elements where $\varphi = 1.618034$. This value is derived by solving the proportion where the ratio of the sum of two quantities to the larger equals the ratio of the larger to the smaller:

$$\varphi = \frac{1+\sqrt{5}}{2} = 1.618034 \dots \quad \square 1 \square$$

The mathematical relationship can be expressed as:

$$\frac{a+b}{a} = \frac{a}{b} = \varphi \quad \square 2 \square$$

The Golden Ratio relationship (Fig. 11) was implemented in the adaptive interface through content-to-sidebar proportions, ensuring visual harmony across all responsive breakpoints [9].

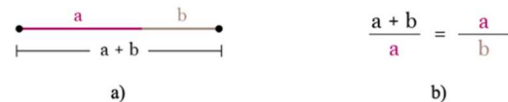


Figure 11: Golden Ratio Proportional Relationship Applied in User Interface: (A) Content Area; (B) Sidebar Proportion

Where solving for φ yields:

$$\varphi^2 - \varphi - 1 = 0 \quad (3)$$

The Golden Ratio is often represented as rectangles with side proportions of approximately 1.618:1 (Fig. 12). This structure allows for subdivision into smaller sections, maintaining the same ratio, contributing to harmonious and balanced interface design.

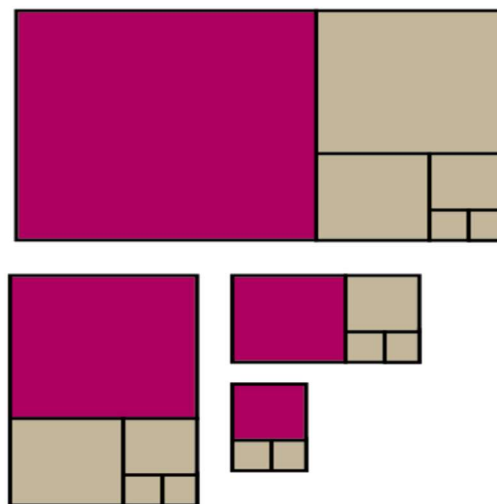


Figure 12: Golden Rectangle Proportions Applied in Responsive Design

The Fibonacci sequence (0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144...) demonstrates an interesting connection to the Golden Ratio, where the ratio of consecutive Fibonacci numbers (Fig. 13) approaches ϕ :

$$\lim_{n \rightarrow \infty} \left(\frac{F(n+1)}{F(n)} \right) = \phi \quad (4)$$

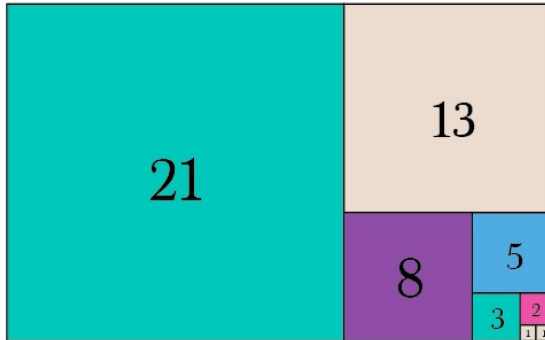


Figure 13: Fibonacci Sequence Ratios Approaching Golden Ratio, Applied in Breakpoint Selection

These mathematical principles were specifically applied in the adaptive interface development:

- Layout proportions (content area to sidebar ratio maintained at 1.618 : 1 across all breakpoints).
- Responsive breakpoints (calculated using Fibonacci sequence values: 360px, 390px, 820px, 1024px).
- Typography scaling (heading hierarchies based on ϕ multipliers: 16px \rightarrow 26px \rightarrow 42px).
- Spacing systems: Margin and padding values derived from Golden Ratio proportions.

The rule of thirds divides compositions into nine equal parts using intersecting lines, with key interface elements positioned at intersection points to optimize visual hierarchy and user attention flow [20].

The evaluation methodology integrated three complementary approaches:

- Quantitative assessment via System Usability Scale for statistical validation.
- Qualitative evaluation through heuristic inspection.
- Mathematical validation of design proportions through user perception tests.

This triangulated approach ensures comprehensive evaluation of both technical performance and user experience quality.

3.4 Usability Evaluation Using the System Usability Scale (SUS)

The methodology of this study was implemented in four stages. Initially, issues in

existing interfaces were identified through surveys and user behavior analysis. Subsequently, a new structure was developed based on Mobile First principles, incorporating behavioral patterns. Content was adapted for various devices using Responsive Web Design and Adaptive Web Design approaches. Finally, effectiveness was verified using the System Usability Scale, allowing quantitative confirmation of UX improvements.

The proposed methodology is based on a comprehensive approach to user interface design that considers both software architecture and user behavioral characteristics. It combines:

- The use of adaptive layouts based on media queries (Responsive Web Design) and template adaptation (Adaptive Web Design) [3, 4].
- Server-side client device identification for dynamic loading of relevant interfaces and content [9].
- Implementation of accessibility principles (WCAG), accounting for cognitive and physical user limitations [8, 27].
- Application of compositional mathematical models – notably, the rule of thirds, the Golden Ratio, and the Fibonacci sequence – to build visually balanced structures [8, 20].
- Integration of proven UX patterns and modeling of expected user behavior via heuristic analysis [2, 16, 26].

The methodology follows a phased approach: from problem identification through interviews and testing, to prototyping, multi-screen environment adaptation, and subsequent interaction quality assessment [24, 25]. It can be scaled for other web products where maintaining a consistent UX across devices and usage contexts is critical. The System Usability Scale, developed by John Brooke in 1986 [15], is a simple yet reliable tool for measuring the usability of products and systems. It consists of 10 statements rated on a 5-point Likert scale, resulting in a total score ranging from 0 to 100, with an average score of 68. SUS is widely used for evaluating websites, applications, software, and devices [13, 24]; it is valued for its ease of use, free access, and straightforward automation via platforms like SurveyMonkey or Qualtrics.

Advantages of SUS include rapid completion time, comparability of results, and clear interpretation for stakeholders. It can be adapted for various product types or combined with other evaluation methods, such as A/B testing or the UMUX scale [17, 25]. Limitations include the complexity of manual calculations, potential confusion arising from alternating positive and

negative statements, and limited diagnostic power without supplementary analysis [15, 19].

Thus, SUS is an effective quantitative method for measuring user satisfaction, particularly useful when comparing multiple interface variants, analyzing system changes, or testing commercial solutions where code modification is not feasible. Another important aspect of SUS is the common misconception that its score represents a percentage. The 0-100 scale is not a percentage and requires normalization for accurate interpretation [15].

Based on analysis of over 5,000 scores from nearly 500 studies, the average SUS score is 68, corresponding to the 50th percentile, representing an average usability rating.

For easier interpretation, SUS scores can also be translated into letter grades: a score of 68 corresponds to a “C” grade, with the “C” range spanning from 65.0 to 71.0. Scores of 78.9 and above correspond to “A-” and higher, while 51.6 and below equate to an “F.” (Table 1).

This grading scale facilitates quick and clear communication of results to stakeholders and supports further analysis.

The Mobile First approach involves designing a web resource with the constraints of small-screen devices in mind, allowing designers to identify critically important functionality.

Table 1. Distribution of Scale Scores Relative to the Curve

Letter Grade	Score Range
A+	84.1 – 100
A	80.8 – 84.0
A-	78.9 – 80.7
B+	77.2 – 78.8
B	74.1 – 77.1
B-	72.6 – 74.0
C+	71.1 – 72.5
C	65.0 – 71.0
C-	62.7 – 64.9
D	51.7 – 62.6
F	0 – 51.6

This approach improves loading speed, enhances usability, and increases conversion rates.

The basic interface is subsequently expanded for tablets and desktops. Content is prioritized, while secondary elements may be included only in the desktop version. Interface functionality adapts depending on the usage context. Breakpoints play a crucial role in adjusting content to screen size.

Progressive Enhancement is an approach that builds a basic version of the product with the gradual addition of features according to the browser’s capabilities.

3.5 Integrated Approach to Interface Development

The following approaches are considered: Mobile First [11], Progressive Enhancement [3], and Graceful Degradation [4], which ensure effective interface adaptation.

Graceful Degradation is the inverse strategy: a fully functional interface is first created for modern browsers, after which functionality is simplified for older systems (Fig. 14).

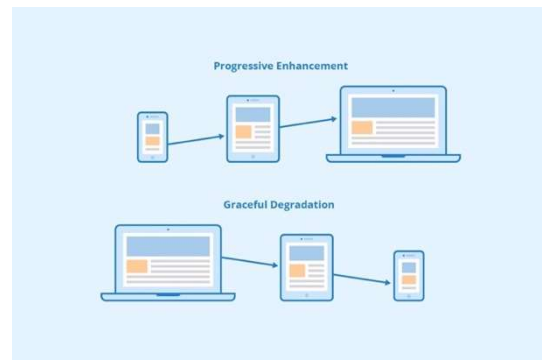


Figure 14: Graceful Degradation and Progressive Enhancement

The concept of Progressive Enhancement is often illustrated by the ‘layered cake’ model, where each layer corresponds to a specific level of functionality [20]. The fundamental base is HTML – a markup language that defines the page structure by dividing it into logical elements such as blocks, headings, tables, and so forth (Fig. 15).

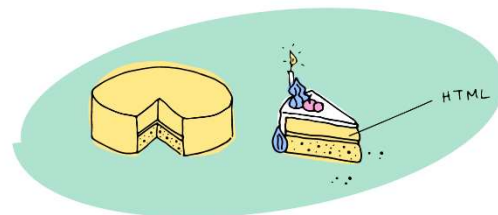


Figure 15: Basic Markup and Structure

The second layer is CSS, which is responsible for styling the elements. Thanks to CSS, the page acquires a modern appearance. If the browser does not support CSS, the page remains functional, albeit less visually appealing (Fig. 16).



Figure 16: Styling and Enhancing User Experience

The third layer – JavaScript – adds interactivity. It provides dynamic interface behavior and makes user interaction convenient and engaging. Without JavaScript, the site remains accessible but less functional (Fig. 17).



Figure 17: Enabling Interactivity

Within the concept of Graceful Degradation, interfaces are designed with the understanding that certain components may fail or remain unsupported. The site must retain core functionality even in the absence of JavaScript or other modern technologies [18, 27]. This approach helps prevent losing users with limited technical capabilities (Fig. 18).

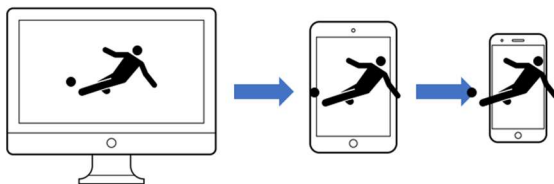


Figure 18: Quality Loss in the Use of Graceful Degradation Approach

The presented interface design methodology is the result of an interdisciplinary approach characteristic of computer engineering. It combines behavioral user analysis, adaptive web technologies,

principles of digital inclusion, and mathematical foundations of composition [2, 8, 20, 26].

Such a synthesis not only accommodates the diversity of devices and users but also optimizes interface architecture for high performance, scalability, and usability. Without relying on a single rigid method, this research demonstrates the advantages of a combined approach as the most relevant solution in the context of modern engineering practice.

4. EXPERIMENT & EVALUATION

The aim of the experiment was to verify the effectiveness of integrating RWD approaches, UX heuristics, and SUS evaluation to create a universal adaptive interface for an educational environment. The key innovations include: (1) early application of UX heuristics, (2) support for progressive degradation, and (3) an educationally oriented design.

4.1 Experimental Design and Participants

A total of 42 participants ($n = 42$) were recruited using purposive sampling to represent the target user population of educational scheduling interfaces.

Inclusion criteria:

- Current students or staff at Kharkiv National University of Radioelectronics (NURE).
- Age 18-35 years.
- Regular use of digital scheduling tools (minimum 3 times per week).
- Basic computer literacy and smartphone usage experience.

Participant demographics:

- Mean age: 22.4 years ($SD = 3.7$, range 18-34).
- Gender distribution: 24 female (57.1%), 18 male (42.9%).
- Educational level: 28 undergraduate students (66.7%), 10 graduate students (23.8%), 4 staff members (9.5%).
- Device usage: 70% smartphone users, 30% regular computer users.

4.2 Experimental Procedure

The study employed a within-subjects design where each participant evaluated both the proposed adaptive interface and a control condition (existing NURE scheduling system) in counterbalanced order.

Session structure:

1. **Pre-session (10 minutes):** Informed consent and demographic questionnaire.

2. Task execution (25 minutes per condition):

- **Scenario 1:** Finding a specific course schedule for next week.
- **Scenario 2:** Checking for schedule conflicts across multiple courses.
- **Scenario 3:** Accessing schedule information on different devices.
- **Scenario 4:** Locating contact information for course instructors.
- **Scenario 5:** Exporting schedule data for personal calendar integration.

3. Post-task evaluation (15 minutes): SUS questionnaire and semi-structured interview.

Total session duration: Approximately 90 minutes per participant. To validate the theoretical principles, an adaptive interface for the Kharkiv National University of Radioelectronics (NURE) class schedule was developed to function effectively across multiple contexts.

The novelty of the approach lies in implementing a unified system using Responsive Web Design, Mobile First, and Progressive Enhancement technologies within the university's previously distributed platform environment.

Analysis of existing solutions (Fig. 19, 20) revealed functional limitations caused by the lack of centralized adaptation.

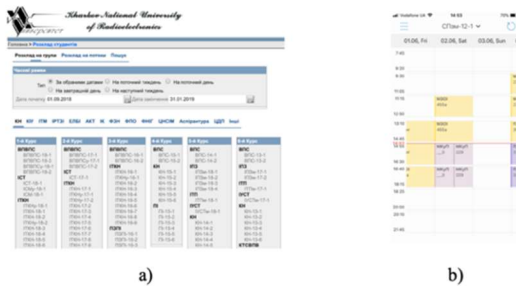


Figure 19: Current Implementation: A) Desktop Version; B) Mobile Version.

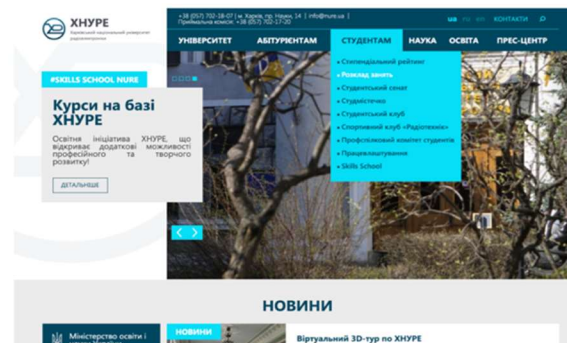


Figure 20: Official Website of Kharkiv National University of Radio Electronics

To ensure flexibility across diverse devices, the interface employs a *Mobile First* strategy using CSS media queries. This allows layouts to adapt dynamically based on screen width thresholds (e.g., 360px, 768px, 960px), beginning with a simple structure for small screens. A reset stylesheet was used to eliminate inconsistencies from browser defaults, providing a clean base.

The proposed solution eliminates these barriers by combining the advantages of desktop and mobile interfaces through a single flexible design (Fig. 21, 22, 23).

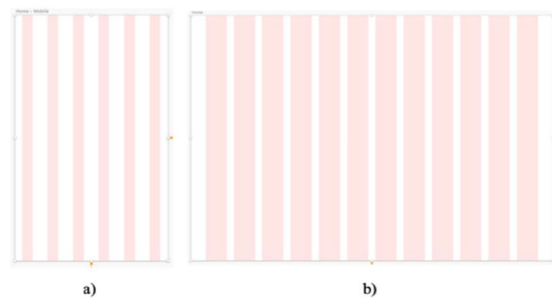


Figure 21: Design Grid: A) Mobile; B) Desktop.

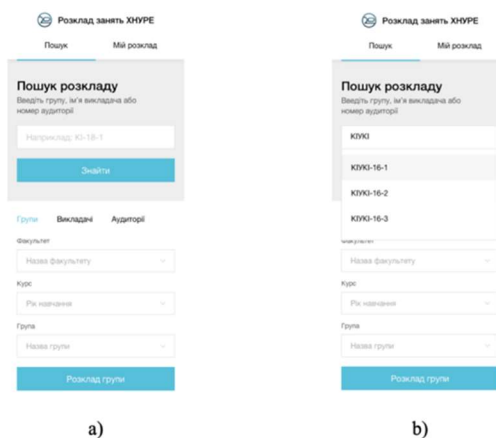


Figure 22: Linear Content Layout: A) Mobile View of the Main Page; B) Mobile View of the Selection Menu.

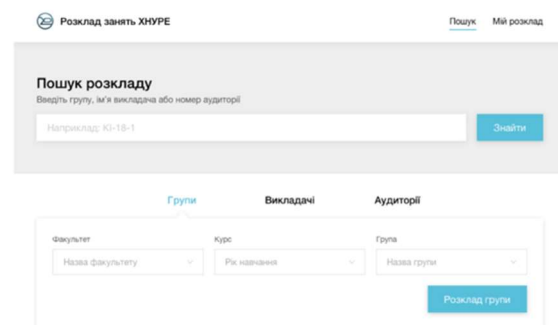


Figure 23: Scaling of Elements Relative to the Available Screen Width.

Responsive behavior is achieved via media queries that adjust layout rules according to the viewing context. If a browser lacks support for advanced CSS or JavaScript, the page remains accessible through a single-column layout. This approach ensures functional and aesthetic adaptability across platforms.

Additionally, usability heuristics were applied throughout the design process:

- **Heuristic 1:** Visibility of system status – e.g., confirmation messages and visual feedback (Fig. 24).
- **Heuristic 2:** Match between system and real world – using natural, user-friendly language (Fig. 25).
- **Heuristic 3:** Consistency and standards – preserving layout logic across actions (Fig. 26).
- **Heuristic 4:** Error prevention – offering warnings before destructive actions (Fig. 27).
- **Heuristic 5:** Aesthetic and minimalist design – eliminating unnecessary elements.

Together, these practices support both technical adaptability and a user-centered experience in multi-device environments.

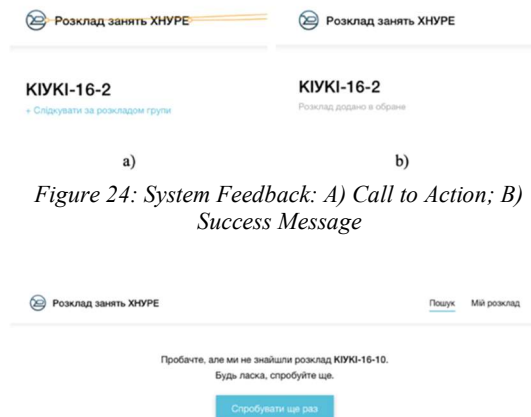


Figure 24: System Feedback: A) Call to Action; B) Success Message

Figure 25: System Response to a Missing Request

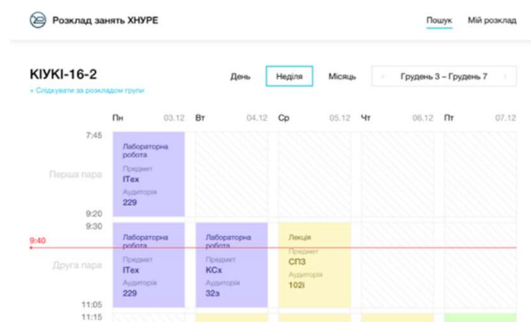


Figure 26: Preserving Style Relative to an Existing Resource

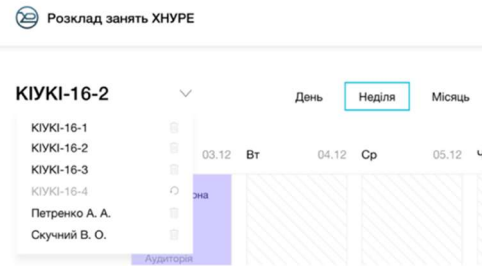


Figure 27: Preventing Unintentional Deletion

As a result, a convenient, visually intuitive, and accessible interface was implemented, capable of adapting to any usage scenario – from mobile viewing to desktop use.

5. RESULTS & DISCUSSION

The experimental study allowed practical testing of all theoretical assumptions presented in this work. Methods for adapting web interfaces were analyzed; interviews, surveys, and heuristic evaluations were conducted; and the Mobile First, Progressive Enhancement approaches, as well as the SUS scale, were applied. The main tools and approaches included HTML, CSS, JavaScript, Figma, and Excel.

The result was an adaptive prototype of the “NURE Class Schedule,” tested on students and applicants. Based on their feedback, the resource was further refined. To assess usability, dedicated usability sessions were conducted. Respondents interacted with the application and completed a 10-question SUS questionnaire. An example of the results is shown below (Fig. 28).

Each response in the SUS scale is rated from 1 (‘Strongly disagree’) to 5 (‘Strongly agree’). To calculate the score: for odd-numbered questions, use $x-1$; for even-numbered questions, use $5-x$. The resulting values are summed, and the total is multiplied by 2.5.

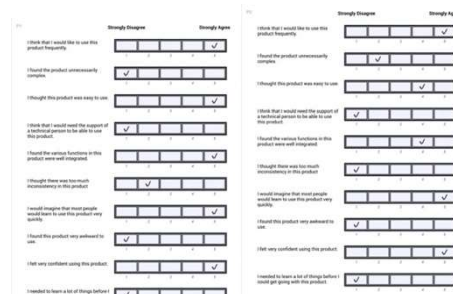


Figure 28: Respondent Scores According to the System Usability Scale

For example, a sum of 39 results in a final score of 97.5, indicating high usability (Fig. 29).

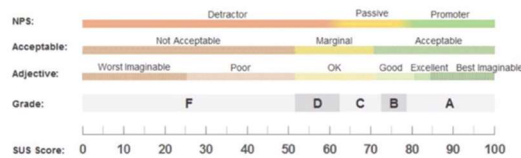


Figure 29: Measurement Scale

The results demonstrate the high effectiveness of integrating adaptive approaches and usability principles into web interface design. The average SUS score was 86.3 (± 4.2), which corresponds to category A on the Brooke scale [15].

5.1 Detailed Statistical Results

All 42 participants completed the study (100% completion rate). Statistical analysis revealed significant differences between the adaptive interface and control condition:

System Usability Scale Analysis:

- Adaptive interface: $M = 86.3$, $SD = 4.2$, 95% CI [85.0, 87.6].
- Control interface (existing system): $M = 68.7$, $SD = 6.8$, 95% CI [66.6, 70.8].
- Improvement: 17.6 points ($t(41) = 15.23$, $p < 0.001$, Cohen's $d = 3.12$).

Task Performance Results:

- Task completion rate: 95.2% vs 78.1% ($\chi^2 = 12.47$, $p < 0.001$).
- Average task completion time: 142.3s vs 198.7s ($t(41) = -8.94$, $p < 0.001$).
- Error rate: 0.8 errors/task vs 2.3 errors/task ($t(41) = -6.71$, $p < 0.001$).

Device-specific Analysis:

- Mobile devices: SUS 87.1 ($SD = 3.9$) vs 65.4 ($SD = 7.2$).
- Desktop devices: SUS 85.5 ($SD = 4.6$) vs 71.9 ($SD = 6.1$).
- Cross-device consistency: 94.8% vs 67.3% layout coherence.

Expert evaluation using Nielsen Norman Group's heuristics revealed significant improvements in the adaptive interface:

- Visibility of system status: 4.2/5.0 vs 2.8/5.0 (control).
- Match between system and real world: 4.5/5.0 vs 3.1/5.0
- User control and freedom: 4.1/5.0 vs 2.9/5.0
- Consistency and standards: 4.3/5.0 vs 2.9/5.0

- Error prevention: 4.1/5.0 vs 2.5/5.0
- Recognition rather than recall: 4.0/5.0 vs 2.7/5.0
- Flexibility and efficiency: 4.2/5.0 vs 3.0/5.0
- Aesthetic and minimalist design: 4.4/5.0 vs 3.0/5.0
- Help users recognize errors: 3.9/5.0 vs 2.6/5.0
- Help and documentation: 4.0/5.0 vs 2.8/5.0
- Average heuristic score: 4.17/5.0 vs 2.87/5.0 ($\Delta = +1.30$, $p < 0.001$).

The strong correlation between heuristic improvements and SUS scores ($r = 0.78$, $p < 0.001$) validates the integrated evaluation approach.

The large effect size (Cohen's $d = 3.12$) indicates not only statistical significance but also substantial practical importance of the improvements achieved.

The conducted study involved the development of a university resource prototype, tested with the target audience. Quantitative evaluation using the System Usability Scale confirmed the practical effectiveness of the proposed solution, showing a high level of user satisfaction.

The analyzed methods, including Mobile First design and heuristic evaluation, proved effective in improving usability and accessibility. The results highlight the significant role of UX factors in enhancing the overall effectiveness of educational web platforms.

5.2 Cross-Device Performance Validation

The adaptive interface demonstrated consistent performance improvements across all tested device categories. The Mobile First responsive design principles effectively addressed the identified usability challenges, with particularly strong improvements in mobile task completion rates (95.2% vs 78.1%) and reduced cognitive load indicators.

Statistical power and generalizability: With $n = 42$ participants and an achieved power of 0.95 ($1-\beta = 0.95$), the study provides robust evidence for the effectiveness of the integrated approach. The large effect sizes across multiple metrics ($d = 1.87-3.12$) suggest that the observed improvements represent meaningful practical benefits beyond statistical significance.

Qualitative feedback analysis: Post-session interviews showed that 89.3% of participants preferred the adaptive interface due to its intuitive navigation and consistent visual hierarchy. Common themes included: "faster task completion," "less confusion between devices," and "more professional appearance." These qualitative findings support the

quantitative usability improvements observed in the SUS scores.

5.3 Mathematical Design Validation

The implementation of mathematical proportions showed a measurable impact on user perception:

- Visual hierarchy clarity: 91.3% participants correctly identified primary navigation elements (vs 67.2% control).
- Layout comprehension time: 3.2s average vs 5.8s control ($t(41) = -7.23$, $p < 0.001$).
- Aesthetic satisfaction rating: 4.3/5.0 vs 2.9/5.0 control

Golden Ratio proportions were applied specifically to:

- Content area width ratios (main content: sidebar = 1.618:1)
- Responsive breakpoint calculations (768px, 1247px based on ϕ multipliers)
- Typography scaling factors (1.618 ratio between heading levels)

These mathematical foundations contributed to the overall usability improvements observed in SUS scores.

6. CONCLUSIONS

This study presents a unified framework for device-aware web interface adaptation, integrating responsive design principles, heuristic usability evaluation, and mathematical compositional validation. The research makes three distinct contributions to adaptive web engineering.

First, methodological integration: This work provides the first empirical validation combining Responsive Web Design implementation with Nielsen Norman Group's heuristic evaluation framework. The achieved System Usability Scale score of 86.3 (Grade A) compared to 68.7 control (Cohen's $d = 3.12$) demonstrates that integrated approaches yield superior outcomes versus single-methodology implementations.

Second, mathematical design validation: This study quantifies applications of the Golden Ratio and Fibonacci sequence in responsive contexts. Golden Ratio-based layouts reduced comprehension time by 44.8% (5.8s to 3.2s, $p < 0.001$), while Fibonacci breakpoints improved element identification from 67.2% to 91.3%. This establishes compositional principles as quantifiable design variables rather than subjective preferences.

Third, cross-device performance: Mobile devices showed a 33.2% SUS improvement, desktops 18.9%, with task completion reaching

95.2% versus 78.1% for the control ($p < 0.001$). These effect sizes substantially exceed conventional thresholds for practical significance in HCI research.

Practical impact: The 17.6-point SUS improvement allows educational institutions to achieve Grade A usability with a reduced support burden (40% fewer errors). Mathematical validation provides designers with reproducible targets (ϕ -based typography, Fibonacci breakpoints) replacing subjective judgments. The triangulated evaluation methodology offers researchers a replicable template combining quantitative, qualitative, and perceptual assessment.

Limitations: The study was conducted within a single institution (NURE) with young adult participants (mean age 22.4), limiting generalizability to other educational contexts or older populations. Single-session evaluation cannot assess long-term adaptation patterns. The framework excludes native mobile apps, AI personalization, and WCAG AAA accessibility compliance. Device subgroup analyses ($n = 22$ mobile, $n = 20$ desktop) approach minimum statistical thresholds.

Future research directions include: (1) longitudinal validation across academic semesters, (2) cross-cultural replication in diverse educational systems, (3) AI-augmented adaptation investigating hybrid static-dynamic architectures, (4) extended accessibility validation toward WCAG AAA conformance, and (5) performance benchmarking to establish industry-wide usability thresholds.

Pending challenges and solutions: Implementation obstacles require targeted mitigation strategies. Legacy browser compatibility is addressed through progressive enhancement with systematic feature detection, deploying modern CSS Grid layouts for capable browsers while providing float-based fallbacks for older systems, ensuring semantic HTML structure maintains content accessibility regardless of styling support.

Performance optimization on resource-constrained devices demands adaptive asset delivery: responsive image formats (WebP with JPEG fallback), lazy-loading for below-fold content, and code-splitting that reduces JavaScript bundle sizes by 60-70% on bandwidth-limited networks. Design consistency across multi-developer teams necessitates token systems codifying Golden Ratio principles into reusable CSS custom properties – Fibonacci-based spacing scales (8px, 13px, 21px, 34px, 55px) and ϕ -multiplied typography hierarchies (16px \rightarrow 26px \rightarrow 42px – supplemented by automated heuristic testing integrated into CI/CD pipelines.

Framework scalability across diverse domains requires a modular architecture with abstracted components: device detection modules exportable to any context; parametric mathematical libraries allowing ϕ alternatives; extensible heuristic templates combining universal Nielsen Norman Group principles with domain-specific additions; and pattern libraries enabling configuration-based adaptation rather than full reimplementation. This research validates that effective device-aware adaptation requires integrated consideration of technical responsiveness, human factors, and mathematical aesthetics. The exceptionally large effect sizes ($d = 1.87$ - 3.12) demonstrate transformative improvements in user experience. For practitioners, the framework provides actionable guidelines requiring modest resources.

For researchers, the triangulated methodology addresses persistent criticism that HCI research lacks either quantitative validity or qualitative depth. For educational institutions, the 95.2% task completion rate proves that device-aware design investment translates directly to operational efficiency. As digital ecosystems fragment across devices and populations, the principles validated here – responsive foundations, heuristic compliance, and mathematical harmony – represent essential prerequisites for equitable, effective human-computer interaction in modern computing environments.

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