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EVALUATING THE EFFECTIVENESS OF A CDIO-BASED SMART SAFETY JACKET FOR DEAF USERS: FASHION TECHNOLOGY EDUCATION

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Abstract:

The integration of wearable technology into inclusive education presents a promising avenue for empowering individuals with disabilities, particularly the deaf community. Despite advancements in smart textiles, few innovations have specifically addressed the intersection of fashion technology education and safety for deaf users. To bridge this gap, this study evaluates the effectiveness of a CDIO (Conceive-Design-Implement-Operate) based smart safety jacket developed for deaf individuals in educational and community settings. The primary objective was to assess the improvement in safety functionality, the accuracy and usability of biometric monitoring components, and the differences in user satisfaction between student and community groups. This quantitative study employed a quasi-experimental design, involving a pre-test and two post-tests, to collect data from two user groups: fashion technology students and community members with hearing impairments. Three key constructs, safety, health monitoring, and usability, were evaluated using structured questionnaires. Inferential statistics, including two-way ANOVA and independent t-tests, were used to evaluate the effectiveness of the intervention. Results revealed significant improvements in safety and health scores over time ($p < .01$), affirming the functional impact of the CDIO-based intervention. Usability scores showed a notable difference between groups ($p = .006$), with students reporting slightly higher satisfaction, suggesting that age-related or technological familiarity effects may be at play. The discussion reflects how CDIO's iterative, user-centred design enhances assistive garment functionality while promoting inclusivity and autonomy. The findings demonstrate that incorporating CDIO principles into smart garment development not only improves safety and health monitoring but also fosters user engagement and educational integration. This research contributes new insights into the convergence of wearable technology, inclusive design, and fashion education for special populations.

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Keywords:

Smart Wearable, CDIO, Deaf Users, Inclusive Education, Fashion Technology

Introduction

The integration of wearable technology in education and healthcare has seen a remarkable surge in recent years, particularly with its applications among vulnerable populations. Among these, individuals who are deaf or hard of hearing (DHH) face a unique set of challenges that wearable technology can directly address, namely, barriers to environmental awareness, real-time communication, and emergency response (Rodríguez-Correa et al., 2023). This intersection of smart wearables, inclusive design, and educational innovation opens new pathways for enhancing accessibility, equity, and participation in learning environments such as fashion technology education, where physical mobility, safety, and sensory awareness are crucial. The advent of smart garments that embed biometric sensors, GPS systems, vibration actuators, and visual feedback mechanisms into clothing has redefined how safety and health monitoring can be delivered discreetly and effectively (Lee & Baek, 2021). Aimed initially at industrial workers and outdoor users, these technologies now present promising applications for the DHH community. Wearables with features such as fall detection, heart rate monitoring, and automated emergency alerts can be reimagined for deaf users by incorporating visual and haptic cues in place of auditory signals (Suthagar et al., 2024). These modifications are not just technical enhancements; they are critical enablers of independence, participation, and confidence for deaf individuals in real-world and educational scenarios.

To address this need, the present study investigates the effectiveness of a CDIO-based smart safety jacket for deaf users**,** developed and tested in a real educational environment involving fashion technology students and community members from the deaf population. Specifically, the study aims to:
(1) Evaluate safety functionality improvements following implementation.
(2) Measure the accuracy and usability of biometric health monitoring features embedded in the garment; and
(3) Assess whether there are usability and satisfaction differences between deaf students and deaf community members.

The following null hypotheses are proposed:
H01**:** There is no significant improvement in safety functionality post-implementation.
H02**:** CDIO-based smart jackets do not enhance biometric monitoring performance.
H03**:** There is no significant usability perception difference between students and community users.

This study contributes to the growing body of research on inclusive wearable technology by bridging technological design and educational innovation through a structured, participatory, and empirically validated approach. The findings are expected to inform educators, designers, and assistive technology developers in creating more effective, accessible, and learner-centred wearable solutions for deaf communities.

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Literature Review

Assistive Technologies for the DHH Population: Current Innovations and Gaps

Research on assistive technologies has highlighted the importance of designing systems that accommodate the specific sensory modalities and preferences of the Deaf and Hard of Hearing (DHH) population. Devices such as smartwatches that translate ambient sounds into vibration signals (Mielke & Bruck, 2016) and IoT-enabled alert systems (Kumari et al., 2015) have shown efficacy in improving environmental awareness. These innovations confirm the potential of wearables to support autonomy and safety. However, a critical limitation of existing systems is that they are developed in isolation from structured pedagogical frameworks. While they offer technological functionality, they often lack contextual relevance, particularly within educational settings. There is also a noticeable absence of systems that blend biometric monitoring, safety alerts, and usability in learning environments. This reveals a gap: the need for integrated solutions that not only enhance safety but also contribute meaningfully to education and engagement.

Smart garments, such as jackets, provide a tangible opportunity to bridge the communication divide between deaf and hearing individuals. Innovations in real-time feedback, gesture recognition, and sign language translation can be embedded into such garments to support interaction, autonomy, and educational involvement (Zhang et al., 2022; Yeratziotis et al., 2022). For instance, wearable tactile alert systems could notify deaf students when teachers call on them, while visual prompts could reinforce classroom instructions, benefiting both DHH students and fostering inclusivity among peers.

The CDIO Framework: A Pedagogical and Design Model for Inclusive Innovation

The CDIO (Conceive–Design–Implement–Operate) framework, initially developed for engineering education, provides a structured, iterative, and user-centric approach to design and learning (Crawley et al., 2014). It guides learners through problem identification and user need analysis (Conceive), solution development (Design), prototyping (Implement), and real-world testing (Operate). This makes CDIO particularly effective in producing educational technologies that are grounded in real-world constraints and user feedback. In wearable technology development, CDIO serves both as an instructional framework and a design methodology. When applied to assistive devices like smart jackets, it ensures that solutions address genuine user needs while also aligning with learning objectives, such as those in fashion technology curricula. These settings require attention to functional challenges, such as washability, battery integration, textile flexibility, and sensor placement, all of which align with CDIO's iterative, hands-on problem-solving ethos.

Fashion students engaging in CDIO-driven development of assistive wearables acquire vital 21st-century skills: design thinking, problem-based learning, empathy-driven innovation, and interdisciplinary teamwork. According to Caporusso and Perrone (2013), this type of action-oriented learning helps bridge the gap between abstract theory and applied knowledge, which is crucial in technical and design-based disciplines. Despite its alignment with educational and technological objectives, few empirical studies have applied the CDIO model in the context of smart wearables for deaf users. Even fewer have quantitatively evaluated their impact on fashion education. This represents an urgent research gap one where pedagogical relevance, technological performance, and user-centred design must be holistically addressed.

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Participatory Design and Mobile Learning: Enhancing User Engagement in Assistive Education

Participatory design is a cornerstone of inclusive and effective assistive technology development, aligning closely with CDIO's user-feedback integration at each design phase. The Quietude project by Marti et al. (2019) exemplifies this through the co-design of vibrotactile jewellery with deaf women, resulting in products that were not only functional but also emotionally and culturally meaningful. Involving DHH individuals in the design process enriches product usability and provides experiential learning opportunities for students. In the context of education, particularly for deaf students, participatory design fosters self-expression, agency, and empowerment, especially when integrated into structured educational programs. Students contributing to wearable development simultaneously gain exposure to engineering, design, and user-centric methodologies, further aligning with CDIO's pedagogical intent.

Complementary research on mobile learning technologies supports the efficacy of personalised, assistive tools in enhancing educational outcomes. Salem and Basaffar (2024) developed a smartphone-based fashion training app for female students with hearing impairments, resulting in notable improvements in engagement and comprehension. Likewise, Parvez et al. (2019) demonstrated that sign-language-enabled mobile applications significantly boosted mathematical performance among deaf children. These studies confirm that technologies tailored to the communication modes and cultural contexts of DHH learners can transform educational experiences. Still, while mobile apps and vibrotactile tools offer significant advances, a critical gap remains in wearable systems especially those that are co-designed, pedagogically embedded, and holistically developed through frameworks like CDIO. Addressing this gap can yield smart wearables that are not only technologically robust but also educationally transformative.

Methodology

Research Design

This study employed a quasi-experimental design with repeated measures, selected for its appropriateness in real-world educational and assistive technology settings where random assignment is impractical or unethical (Hong, 2009; Muse & Baldwin, 2021). Quasi-experimental designs are widely accepted for evaluating interventions involving intact groups or naturally formed populations, such as deaf students and community members (Hallberg & Eno, 2015; Krishnan, 2019). Specifically, this study employed a three-phase repeated measures design, comprising a pre-test (baseline), post-test 1 (Week 2), and post-test 2 (Week 4), to evaluate the effects of a CDIO-based smart safety jacket. Repeated measures enhance statistical power by reducing inter-individual variability and allowing researchers to track temporal changes in participant responses (Lix & Keselman, 2018; Guo et al., 2013). This design is particularly beneficial in studies with relatively small samples, as it controls for within-subject error and maximises sensitivity to intervention effects (Blackwell et al., 2006; Çelikbıçak & Altunay, 2020).

By integrating both frameworks, this research design enabled a robust investigation of user-experienced improvements in safety functionality, biometric monitoring, and usability perceptions over time, without compromising ecological validity (Thyer, 2012; Feser, 2013).

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Participants

The target population comprised individuals with hearing impairments from two distinct but relevant user groups: formal education and community settings. A purposive sampling strategy was employed to ensure that participants reflected the actual end-users of the smart jacket prototype, namely, deaf individuals with varying degrees of exposure to fashion technology.
A total of 30 participants were recruited, divided into two equal groups:

- 15 special education students from a vocational polytechnic specialising in fashion technology
- 15 adult members of the Johor Deaf Association representing community users

Purposive sampling was justified given the specific design requirements of the product and the need for authentic feedback from individuals who would realistically use such a garment (Maciejewski, 2020). All participants provided informed consent, and ethical approval was obtained from institutional review boards aligned with educational research standards.

Instrumentation

To quantitatively evaluate the effectiveness of the CDIO-based smart safety jacket, a structured questionnaire comprising 30 items was developed. The instrument employed a five-point Likert scale, with response options ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). This format enabled the assessment of user perceptions regarding the jacket's safety functionality, biometric monitoring features, and overall usability dimensions, which are considered critical in the adoption of assistive wearable technologies (De Godoi, Garcia, & Valentim, 2020). The questionnaire was organised into three key subscales; each aligned with the study's core objectives:

- Section A: Safety Functionality (10 items)
  This section focused on the extent to which the smart jacket enhanced users' awareness of environmental hazards and personal safety. Sample items included: *"I feel safer when wearing the smart jacket,"* and *"The jacket helps me become aware of nearby dangers."* Prior studies have informed the development of wearable safety systems that incorporate fall detection, emergency alerts, and vibration-based notifications (Lee & Baek, 2021; Suthagar et al., 2024).
- Section B: Biometric Monitoring (10 items)
  This subscale assessed the reliability and ease of use of the jacket's embedded physiological sensors, including those that monitor heart rate and body temperature. Sample items included: *"The heart rate monitor in the jacket works accurately,"* and *"The temperature sensing is reliable and responsive."* This section drew on research addressing the functionality of wearable health-monitoring tools in real-time contexts (Tang & Ji, 2024; Sun et al., 2024).
- Section C: Usability and Comfort (10 items)
  This section evaluated the garment's ergonomic design, comfort during movement, and intuitive interaction with its digital components. Items included: *"The jacket is comfortable to wear during daily activities,"* and *"I can easily understand how to use the smart features."* The design of this section was guided by user-experience principles relevant to the development of inclusive wearables, incorporating insights from participatory design methodologies and smart textile usability research (Marti et al., 2019; Rodríguez-Correa et al., 2023).

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The questionnaire underwent content validation by a panel of experts in special education, assistive wearable design, and fashion technology to ensure construct alignment and relevance. A pilot test involving five deaf participants was conducted to verify item clarity and linguistic appropriateness. Minor revisions were made to improve readability and context suitability. To assess the reliability of the instrument, internal consistency was calculated using Cronbach's Alpha, yielding a value of .89. This score reflects a high degree of internal consistency across all three subscales, in accordance with recommended psychometric thresholds (Cleophas et al., 2012; Park et al., 2009). The final instrument was used to support the study's three primary objectives:

1. To evaluate changes in safety functionality following smart jacket usage.
2. To determine the accuracy and usability of the biometric monitoring components.
3. To assess usability and comfort perceptions across two user cohorts: special education students and community users.

The questionnaire thus provided a robust, user-informed tool for evaluating the real-world functionality and user experience of CDIO-based smart wearable technology in an educational setting.

Procedure

The smart safety jacket was developed through the CDIO (Conceive–Design–Implement–Operate) engineering framework, incorporating user-centred design principles and participatory feedback loops. Participants engaged with the garment under controlled laboratory conditions during three separate sessions, corresponding to the study's repeated-measures structure.

- Pre-test (Baseline): Users were introduced to the prototype and completed the initial questionnaire before interaction.
- Post-test 1 (Week 2): Participants used the jacket in structured, simulated environments (e.g., workshops, classroom walk-throughs) and completed the second evaluation.
- Post-test 2 (Week 4): After continued engagement, participants completed the final questionnaire, reflecting accumulated usability and functionality perceptions.

The procedure was aligned with educational settings, and trained observers supervised data collection to ensure consistency across sessions. This timeline was selected based on best practices in repeated measures research, which suggest that three spaced assessments can sufficiently capture learning curves and evolving user experience (Vickers, 2003; Tango, 2017).

Data Analysis

All statistical analyses were conducted using IBM SPSS Statistics 28. Prior to analysis, the dataset was screened for normality, missing data, and outliers. The following statistical tests were employed:

- Two-Way Repeated Measures ANOVA (Group × Time): Used to assess the interaction effects between time and participant group on safety functionality and biometric monitoring scores (Lix & Keselman, 2018; Park et al., 2009). This test accounted for within-subject correlations across time points, a core requirement in repeated measures analysis (Maas & Snijders, 2003).

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- Independent Samples t-test: Applied to compare overall usability and satisfaction scores between student and community users at the final test phase. This allowed evaluation of whether the smart jacket's effectiveness differed by user background.

Missing data were minimal (<5%) and managed using mean imputation. While linear mixed models or multilevel modeling could be considered in future longitudinal extensions, the current design and data structure were well-supported by ANOVA frameworks with repeated measures (Blackwell et al., 2006; Çelikbıçak & Altunay, 2020).
The integration of both group-level and time-based analysis enabled a comprehensive understanding of how the CDIO-based intervention evolved in user perception, ensuring both between- and within-subjects variance were addressed.

Results

The results from both descriptive and inferential statistical analyses underscore the effectiveness of the CDIO-based smart safety jacket intervention across three main dimensions: safety functionality, biometric monitoring (health), and usability among deaf users in the context of fashion technology education.

Descriptive Analysis

The pre-test mean safety scores, as shown in Table 1, were 3.10 for students and 3.05 for community participants. Following the first intervention cycle (Post 1), student safety ratings rose to 4.00, while the community group improved to 3.95. After the second cycle (Post 2), scores further increased to 4.25 and 4.20, respectively. This shows a consistent upward trend in safety perceptions for both groups. Health monitoring perceptions mirrored this pattern. Both students and community members started at a baseline of 3.00. Post 1 scores increased to 3.90 and 3.85, respectively, and reached 4.10 and 4.05 at Post 2. This trajectory reflects a positive reception of biometric sensors integrated into the jacket. Usability scores revealed a similar trend, with students starting at 3.20 and community participants at 3.15. Post 1 values increased to 4.10 and 4.00, and Post 2 saw final ratings of 4.30 and 4.25. The steady rise suggests improved familiarity with and satisfaction from repeated use of the user interface.

Table 1. Descriptive Summary

Group	Pre-test	Post 1	Post 2
Students – Safety	3.10	4.00	4.25
Community – Safety	3.05	3.95	4.20
Students – Health	3.00	3.90	4.10
Community – Health	3.00	3.85	4.05
Students – Usability	3.20	4.10	4.30
Community – Usability	3.15	4.00	4.25

Inferential Analysis

The inferential analysis in Table 2 further validated these patterns. A two-way ANOVA revealed a significant interaction effect between group and time on safety functionality ($F = 5.67$, $p = 0.004$), indicating that the intervention's impact varied over time and across groups. For health monitoring, the analysis revealed a significant improvement over time ($F = 4.89$, $p = 0.006$), independent of group, indicating strong internal reliability of the biometric

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functionality. Lastly, an independent t-test indicated a significant usability difference between students and community users (t = 2.89, p = 0.006), highlighting potential differences in technological familiarity or age-related adaptation.

Table 2: Inferential Analysis

Test	F/t Value	p-value	Interpretation
Two-Way ANOVA (Safety)	5.67	0.004	Significant interaction effect (Time × Group)
Two-Way ANOVA (Health)	4.89	0.006	Significant improvement over time
t-test (Usability)	2.89	0.006	Significant difference between groups

Discussion

The statistical outcomes confirm the effectiveness of the CDIO-based approach in developing wearable technology for deaf users, aligning with broader findings in the assistive technology literature (Bonato, 2020; Lister, 2021; Rodríguez-Correa et al., 2023). The CDIO (Conceive-Design-Implement-Operate) framework enabled iterative refinements informed by user feedback, which likely contributed to the increasing scores over time.

RQ1: Safety Functionality

The significant improvements in perceived safety scores indicate that the jacket's real-time alert systems, such as vibration-based hazard notifications and emergency call functionality, met the core safety needs of deaf users. These results align with previous studies on wearable safety systems that integrate sensory substitution mechanisms (Sun et al., 2024; Kumari et al., 2015). The consistent rise across both groups, albeit with slightly higher scores among students, suggests that age and technology fluency may mediate the perception of safety enhancements.

RQ2: Biometric Monitoring Accuracy and Usability

The positive trajectory in health-related measures highlights the efficacy and acceptability of integrated biometric tools (Lee & Baek, 2021). Sensors that monitor heart rate and body temperature provide users with real-time health data, thereby increasing their sense of self-monitoring and autonomy. This finding confirms earlier research that wearable biosensors are effective for health management among individuals with specific needs (Suthagar et al., 2024; Blackwell et al., 2006). Furthermore, the significance of time as a main effect (p = 0.006) underscores that repeated exposure and prolonged usage improve user confidence in sensor reliability. These findings support Guo et al. (2013), who emphasised the importance of repeated-measures frameworks for detecting learning and adaptation effects in health tech interventions.

RQ3: Usability Perception and Group Differences

Usability measures saw statistically significant differences between the student and community groups. This can likely be attributed to generational differences in the acceptance of technology. Younger users (students) may have greater exposure to smart devices, which could influence their ease of adoption and comfort level (Rodríguez-Correa et al., 2023; Yeratziotis et al., 2022). While both groups reported increasing usability over time, the higher scores among students suggest the need for tailored onboarding or training for older or less tech-savvy users. These findings support the usability framework outlined by De Godoi et al. (2020),

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which emphasized participatory and age-sensitive design in technology deployment. The participatory element of CDIO aligns well with these best practices by embedding user input throughout the design cycle (Marti et al., 2019).

Relevance of Methodology

The use of a quasi-experimental repeated measures design is particularly suitable for this study. As highlighted by Hong (2009) and Muse & Baldwin (2021), this design enables robust analysis of temporal change while accommodating real-world constraints, such as non-random group assignment. Repeated measurements helped reduce intra-individual error and increased statistical power (Lix & Keselman, 2018). The significance of changes observed across multiple time points demonstrates the utility of such designs in educational and assistive technology research.

Conclusion

This study demonstrates that a CDIO-based smart safety jacket significantly enhances safety, health monitoring, and usability for deaf users in the context of fashion technology education. By integrating participatory design principles, biometric monitoring, and wearable assistive features into a fashion-forward garment, the intervention bridges a critical gap between inclusive education and adaptive technology. The CDIO approach allowed for continuous refinement, grounded in user feedback, resulting in measurable improvements across all assessed domains. Notably, safety and health monitoring functions were well-received, and usability scores reflected strong engagement, especially among student users. These findings suggest that combining engineering education frameworks, such as CDIO, with user-centric assistive technology design holds significant promise for broader adoption in inclusive learning contexts. Moreover, the quasi-experimental repeated measures design provided a robust methodological approach to tracking the evolution of user experiences over time. While this design lacks the control of randomised trials, its ecological validity and adaptability make it ideal for real-world applications in educational settings. Future studies should investigate long-term effects, explore customisation for various disability groups, and consider integration with wearable sign language tools to enhance multimodal communication. This research lays the groundwork for interdisciplinary innovation that combines fashion, engineering, and special education to create more inclusive learning environments.

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