Geografia-Malaysian Journal of Society and Space 19 issue 3 (149-170)
© 2023, e-ISSN 2682-7727 https://doi.org/10.17576/geo-2023-1903-11

Principles and elements of interactive multimedia teaching aids design for hearing-impaired students

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Received: 26 April 2023; Accepted: 6 August 2023; Published: 30 August 2023

Abstract

Interactive multimedia teaching aids are one of the effective tools for enhancing the learning experiences of students with disabilities. However, there is still a lack of evidence on the availability and appropriateness of such aids for hearing-impaired students. To address this issue, this study conducted a comprehensive contextual document review with a focus on a diverse range of scholarly sources, ensuring a robust foundation for the research through 31 established scholars. The primary objective is to identify the best principles and elements for designing effective interactive multimedia teaching aids that cater to the unique needs of hearing-impaired students. The analysis revealed 11 key principles, including clarity, multimedia, temporal contiguity, harmony, consistency, coherence, familiarity, spatial contiguity, embodiment, control, and contrast. The findings from this study provide valuable insights into the development of effective interactive multimedia teaching aids to fulfill the needs of hearing-impaired students, enabling them to receive a more inclusive and accessible education. More importantly, the findings represent vital guidance for educators, designers, and policymakers to create a more accessible learning environment for all students.

Keywords: Hearing-impaired students, multimedia design principles, multimedia design elements

Introduction

Educational technology is increasingly significant in today's world due to its potential in enhancing and transforming the learning process. The use of multimedia teaching aids such as images, videos, audio, and interactive features can create a more engaging and effective learning experience for students (Masran et al., 2017; Seels & Richey, 2012). Therefore, in the design of interactive multimedia teaching aids, it is critical to ensure that they are visually appealing and user-friendly to facilitate the delivery of the content in order to convey important information in a meaningful way (Suarsana, 2021).

Interactive multimedia teaching aids have been established as one of the most effective tools to improve the learning experiences of students with disabilities. Currently, there is an urgent need to focus on the development of effective hearing-impaired teaching aids that can create an engaging and accessible learning experience for hearing-impaired students (Riza et al., 2018). Its importance cannot be overstated as the literature has highlighted a scarcity of evidence with regard to the availability and appropriateness of interactive multimedia hearing aids for hearing-impaired students (Abbas et al., 2019; Boza-Chua & Andrade-Arenas, 2022). Addressing this gap, a comprehensive contextual document review was conducted, utilizing a

diverse range of scholarly sources, through 31 established scholars. This study aimed to identify the best principles and elements for designing interactive multimedia teaching aids for hearing-impaired students.

Multimedia design for hearing-impaired students

In the past, numerous studies have emphasized the transformative impact of interactive multimedia on education. One notable enhancement is the utility of interactive multimedia in the field of education, whereby technology has been integrated as a teaching aid/ tool/ medium to simplify the process of learning by making it more memorable, productive, and engaging for learners (Wang, 2021). This is a development that should be expanded to hearing-impaired teaching aids as hearing-impaired students require special teaching aids that cater to their unique needs (Aljedaani et al., 2022; Ridha & Shehieb, 2021). As outlined in a recent study, multimedia materials should be structured in a way to facilitate the students in accessing, understanding, and retaining the information (Razali et al., 2020). Similarly, Mayer (2021) also outlined effective ways to structure multimedia materials to maximize the learning process. He especially emphasized the importance of incorporating visual and auditory elements in the materials, as well as the relationship between them. Based on numerous past experiments, the findings can be categorized into 15 principles that (in part) constitute the "cognitive theory of multimedia learning" and its guiding principles on how to create effective multimedia presentations for learning.

To begin, effective learning experiences are conceived by incorporating different design approaches based on the customized needs of students (Kamaruddin, 2014). This includes information design, i.e., the organization of information in a way that is easy to understand and follow. Next, interaction design focuses on creating a user-friendly interface that encourages user interaction with the teaching aid. Lastly, interface design refers to the design of the visual and interactive elements that make up the teaching aid.

Designing an interactive multimedia teaching aid specifically for the hearing-impaired typically involves a combination of how it looks (visual), how it feels to use (user experience), and how the information is presented (content). Therefore, the purpose, the user needs, the components needed to achieve the desired outcome, and the user's interaction with the multimedia must be clarified beforehand. More importantly, the design of interactive multimedia teaching aids for hearing-impaired students should take into account their unique needs, such as the use of sign language, captioning, and visual aids (Jabar & Ahmad, 2018; Pratiwi et al., 2019).

Theoretically, the integration of educational technology can instill novelty in the learning process to motivate hearing-impaired students to study and understand better (Alshawabkeh et al., 2021). However, the scarcity of published studies on the significance of principles, elements, and characteristics of multimedia design and interface on teaching aids for the hearing-impaired can be a potential barrier to the development of an effective interactive multimedia teaching aid (Alias et al., 2022). Therefore, an in-depth understanding of the principles and elements of interactive multimedia design to determine the most suitable multimedia content, usability, and the interface is vital to establish effective teaching aids for hearing-impaired students.

Method

A contextual document review

In the literature, numerous scholars suggested the application of principles and elements in various guidelines of interactive multimedia design. The fundamentals included using clear and effective visual communication. The studies also reflected an ongoing evolution of interactive multimedia design and education, in general, as well as in the field of special need education focused on hearing-impaired disability in particular. Following the screening, only 31 key texts remained on the final list. In the comprehensive review, all the elements and guiding principles were extracted onto a dataset. The selection criteria for the literature were: (i) Characteristics, elements, and principle guidelines of the multimedia design listed in the study (ii) The study was significantly cited as a guiding principle by authors, and (iii) A holistic guideline was provided for principles and elements of multimedia design for effective teaching aids. The included literature were 11 books, 3 research theses, and 17 scholarly journals (Bowen, 2009; Bretschneider et al., 2017). Following that, all the principles, elements, and characteristics were organized into major themes, categories, and code examples (Elo & Kyngäs, 2008). The list of literature compiled and reviewed is shown in Table 1.

Table 1. List of literature compiled and reviewed

No.	Author	Title	Source
1.	Mohd Hashim & Tasir (2020)	An e-learning environment embedded with sign language videos: Research into its usability and the academic performance and learning patterns of deaf students	Journal
2.	Kourbetis et al. (2016)	Multimodal accessibility for deaf students using interactive video, digital repository, and hybrid books	Journal
3.	Pelayo et al. (2018)	Códice: Assisting vocabulary learning for students with deafness	Journal
4.	Boudreault et al. (2018)	Bilingual cancer genetic education modules for the deaf community: Development and evaluation of the online video material	Journal
5.	Anindhita & Lestari (2016)	Designing interaction for deaf youths by using user-centered design approach (Case study: Educational media for learning English as foreign language)	Journal
6.	Riza et al. (2018)	A concept and implementation of instructional interactive multimedia for deaf students based on Inquiry-Based Learning Model	Journal
7.	Jabar & Ahmad (2018)	The design of multimedia interactive courseware for teaching reading to hearing impaired students	Journal
8.	Abbas et al. (2019)	Exploring the elements of multimedia needed for deaf and hearing-impaired students in polytechnics	Journal
9.	Ahmadi et al. (2015)	Design and implementation of a software for teaching health-related topics to deaf students: The first experience in Iran	Journal
10.	Saud & Nasruddin (2017)	Design of e-learning courseware for Hearing Impaired (HI) students	Journal
11.	Saman et al. (2019)	i-Sign: Sign language learning application via gamification	Journal
12.	Alias et al. (2016)	Exploring the effects of teaching and learning using visual images among hearing impaired children	Journal
13.	Efendi et al. (2020)	Utilizing multimedia-based learning materials in scouting education program for deaf students	Journal
14.	Sidek et al. (2021)	Interface design: Guidelines on layout and content arrangement for students with special needs (MBK)	Journal
15.	Suarsana (2021)	Developing interactive digital mathematics book with multi representation approach for deaf students	Journal
16.	Razalli et al. (2021)	Development of prayer mobile application software for the hearing impaired (Deaf) based on Malaysian sign language	Journal
17.	Hadi & Özdemir (2017)	Development of learning software for deaf: A sample of language learning material	Journal
18.	Mayhew (1992)	Principles and guidelines in software user interface design	Book

19.	Marschark & Hauser (2012)	How deaf children learn what parents and teachers need to know	Book
20.	Nielsen (1993)	Usability engineering	Book
21.	(Galitz, 2007)	The essential guide to user interface design: An introduction to GUI design principles and techniques	Book
22.	Mayer (2021)	Multimedia learning	Book
23.	Chapman & Chapman (2009)	Digital multimedia	Book
24.	Vaughan (2011)	Multimedia: Making it work	Book
25.	Knoors & Marschark (2014)	Teaching deaf learners	Book
26.	Jamaludin (2005)	*Multimedia dalam pendidikan*	Book
27.	Harun & Tasir (2003)	*Multimedia dalam pendidikan*	Book
28.	Muhamad Ali (2021)	*Multimedia dan perisian pendidikan: Panduan praktikal reka bentuk dan penyelidikan*	Book
29.	Kamaruddin (2012)	Interface design in interactive science courseware for the Malaysian smart school projects in smart school project	Thesis
30.	Sulaiman (2019)	Interface design principles, elements, and characteristics in multimedia teaching aid for non-creative design field in Malaysian tertiary education	Thesis
31.	Ibrahim (2017)	Development of a graphic design learning module based on technology and hearing impairment students' learning styles	Thesis

Source: Sources are from the compiled literature

Result and discussion

The most frequently reported principles and elements of multimedia design in the literature

a. Most frequently reported principles of interactive multimedia teachings aids for the hearing-impaired

The data analysis shows that each scholar has established different principles and elements rooted in the various viewpoints, research frameworks, and development of the multimedia design. Based on the analysis, the scholars emphasize the understanding of various aspects of multimedia design, including usability, readability, and interactivity, and a focus on fulfilling user needs. In addition, it is vital to ensure that the multimedia design is user-friendly and effective in facilitating content delivery. Furthermore, emphasizing the necessity of hearing-impaired students, it becomes imperative to ensure that the interactive multimedia design is not only visually appealing but also accessible and highly effective in facilitating content delivery. Based on the numerous principles and elements established by the scholars, the list was then arranged based on keywords to form a shorter list of similar principles and elements. For example, Jakob Nielsen's Principle of Visualization and Richard Mayer's Principle of Coherence conveyed similar meanings. Similarly, Muhammad Ali's Principle of Presentation Style resembled Richard Mayer's Principle of Multimedia. Thus, a widely used and identified keyword has been applied to include and represent both terms. Therefore, based on the outcome of the analysis, a total of 31 principles from 30 authors was obtained, of which 11 principles were most commonly applied. The analysis can be visualized in a literature matrix of the most frequent principle of interactive multimedia design (Table 2).

Table 2. Literature matrix of most frequently reported principles of interactive multimedia design

Authors	Theme																													
	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P 10	P 11	P 12	P 13	P 14	P 15	P 16	P 17	P 18	P 19	P 20	P 21	P 22	P 23	P 24	P 25	P 26	P 27	P 28	P 29	P 30
1	■	■			■	■				■		▪		■	■				■	■			▪				■			
2	■					■	▪		▪	■		▪						■	■	■										▪
3	■	■	▪		■	■	▪			■		▪		■					■	■			▪				■		▪	
4		■			■	■	▪			■	▪	▪		■					■	■	▪		▪	▪			■			
5		■					▪			■	▪			■	■				■	■						▪	■	■		
6	■	■			■	■			▪	■	▪		▪	■	■	▪	▪	■	■	■	▪		▪				■	■		
7	■				■	■						▪		■	■			■										■		
8	■	■			■	■			▪	■				■	■												■			
9	■	■				■	▪		▪	■				■	■													■	▪	
10	■				■	■	▪			■	▪			■	■			■	■	■			▪				■	■	▪	
11	■						▪				▪			■	■			■	■	■			▪	▪		▪		■		
12	■				■	■	▪			■				■	■			■	■	■							■			
13	■					■				■				■					■	■										
14		■							▪			▪	▪	■	■		▪	■	■				▪	▪			■	■	▪	
15	■	■			■	■	▪		▪	■	▪	▪		■	■			■	■	■				▪		▪				
16	■				■	■			▪	■		▪		■	■				■				▪				■			
17	■	■			■	■			▪	■					■						▪									
18													▪					■		■	▪	▪	▪	▪						
19	■				■	■				■				■	■			■		■							■			
20		■											▪	■	■			■		■	▪			▪	▪	▪				
21	■	■	▪			■						▪	▪	■		▪	▪	■	■	■	▪	▪	▪							
22	■	■	▪	▪	■	■	▪	▪	▪	■	▪								■								■			
23		■										▪		■	■			■	■		▪		▪				■	▪		
24		■				■									■			■					▪				■	▪	▪	▪
25	■	■			■	■		▪		■	▪			■				■		■			▪	▪			■	▪		
26					■									■	■			■		■			▪				■	▪	▪	▪
27	■	■			■		▪							■	■			■	■	■			▪				■	▪		
28	■	■		▪	■	■	▪	▪	▪					■		▪		■	■											
29													▪					■		■	▪			▪						
30															■			■									■	▪	▪	
31	■	■				■				■	▪			■	■			■	■							▪				

P1: Multimedia
P2: Coherence
P3: Signalling
P4: Redundancy
P5: Spatial Contiguity
P6: Temporal Contiguity
P7: Segmenting
P8: Personalization
P9: Voice
P10: Embodiment
P11: Generative Activity
P12: Accessibility
P13: Aesthetically Pleasing
P14: Clarity
P15: Harmony
P16: Compatibility
P17: Configurability
P18: Consistency
P19: Control
P20: Familiarity
P21: Flexibility
P22: Responsiveness
P23: Simplicity
P24: Efficient feedback
P25: Recognition
P26: User Task
P27: Contrast
P28: Hierarchy
P29: Balance
P30: Copyrighted

b. Most frequent principles and elements of interactive multimedia design occurred in the literature (By keywords)

Based on the content analysis of the keywords obtained from the literature, the most frequent principles of interactive multimedia design established by scholars are summarized in Table 2. The key texts are based on the most frequently identified principle and elements in descending order of frequency. As shown in Table 3, there are 11 most frequent principles of interactive multimedia design, namely clarity, multimedia, temporal contiguity, harmony, consistency, coherence, familiarity, spatial contiguity, embodiment, control, and contrast. In addition, for the most frequent elements of interactive multimedia design, the ten most frequently identified elements based on the frequency that occurred are sign language video, video, image, audio, graphic/icon, animation, screen, color, text, and navigation.

Table 3. A summary of the most frequent principles and elements of interactive multimedia design in the literature (By keywords)

Text	Principle	Element	By Keywords
1.	Clarity Control Familiarity Harmony Multimedia	Video Animation Text Graphic/Icon Image	Integrated the element, Interactively engage Relevance, Avoid extraneous, Simple, Straightforward, Understandable, Equipped with related elements, Placement nearby, Simultaneously appear, Accurate time narration, Suitable, Appropriate

	Coherence Embodiment Spatial Contiguity Temporal Contiguity	Sign language video	Understandable signs, High-embodiment, Accurate gestures, Factual signs
2.	Consistency Control Familiarity Multimedia Embodiment Temporal Contiguity	Video, Audio Sign language video Text, Screen, Animation, Image, Graphic/Icon Navigation	Integrated the element, Interactively engage, Easily interact, No time limit, Repeatable, Allow on/off function Simultaneously appear, Accurate time narration, Signs, High-embodiment Caption throughout, Consistent, Placement throughout, Real-life concepts Familiar function
3.	Clarity Coherence Contrast Control Familiarity Multimedia Embodiment Spatial Contiguity Temporal Contiguity	Video Sign language Video Image, Text	Relevance, Avoid extraneous, Easily interact, Integrated the element, Interactively engage Instructor, Gesture, Signs, Simultaneously appear, Accurate time narration Real-life concepts, Recognizable, Static signs, Readable, Enlighten, Contrast colored, Placement nearby, Relevance, Equipped with related elements
4.	Clarity Contrast Control Familiarity Coherence Embodiment Spatial Contiguity Temporal Contiguity	Sign language video Animation, Text, Video, Graphic/Icon, Image, Audio, Screen	High-embodiment, Embodiment cues, High-quality, Understandable signs, White background, Dark attire Avoid extraneous, Placement nearby, Relevance Simultaneously appear, Accurate time narration Real-life concepts, Understandable, Easily interact, No time limit, Repeatable, Allow on/off function Simple, Straightforward, Understandable
5.	Clarity Contrast Control Familiarity Harmony Coherence Embodiment	Animation Sign language video Screen Text Video Image Graphic/Icon	On-point information, Relevance, Avoid extraneous Instructor, Synchronized, Emphasized, Embodiment cues Aesthetically pleasing, Suitable bright colors, Appropriate design, Various sizes Simple, Straightforward, Understandable, Suitable size, Balanced, Placement, Easily interact, No time limit, Repeatable Real-life concepts, Suitable Common icon, Recognizable
6.	Clarity Consistently Contrast Control Familiarity Harmony Coherence Embodiment Multimedia Spatial Contiguity Temporal Contiguity	Video Screen Sign language video Graphic/Icon Text Image Audio Animation	Integrated the element, Interactively engage, High-quality, Good resolution, Easily interact, No time limit, Repeatable, Simultaneously appear, Accurate time narration Avoid extraneous, Contrast background and foreground Relevance, Avoid extraneous, Instructor, Gestures, Emphasized Embodiment cues, Placement bottom-right, Position at bottom-right throughout, Proper lighting, Contrast background, Clear, Understandable signs Bright color, Common icons, Linguistic symbols, Recognizable, Appropriate sizes, Bright color, Aesthetically pleasing, Emphasized, Relevance Distinctively color caption, Legibility typeface, Recommend Tiresias Screen type, Straightforward, Simple, Short, Suitable duration, Readable caption, Cluster typeface, Various sizes, Aesthetically pleasing Color, Proper lighting, Narrative, Aesthetically pleasing, Placement nearby, Relevance Clear, High-quality, Clear, Suitable speed Real-life concepts, Relevance, Clear transition, Suitable duration, Aesthetically pleasing

7.	Clarity Consistency Harmony Multimedia Spatial Contiguity Temporal Contiguity	Video	Integrated the element, Interactively engage, Simultaneously appear, Accurate time narration
		Graphic/Icon, Text	Placement nearby, Relevance, Appropriate, Suitable Consistent size, Various sizes, Simple, Understandable, Easy
		Sign language video	Consistent signs
8.	Clarity Coherence Contrast Embodiment Harmony Multimedia Spatial Contiguity Temporal Contiguity	Video	Integrated the element, Interactively engage
		Audio, Text, Image	Simultaneously appear, Accurate time narration Placement nearby, Relevance, Avoid extraneous Simple, Straightforward, Understandable, Clear
		Sign language video	High embodiment, Embodiment cues, Expression, Gestures, Appropriate, Suitable duration, Understandable,
		Screen	Avoid striking color
		Animation	Colored animated, Appropriate, Suitable duration, Understandable
9.	Clarity Harmony Coherence Embodiment Multimedia Temporal Contiguity	Video	Integrated the element, Interactively engage, Simple, Straightforward, High-quality, Relevance, Incorporated, Appropriate elements
		Sign language video	High-embodiment, Embodiment cues, Slow pace, Voice, Instructor, Placement half-screen, Relevance, Clear, Understandable
		Audio	Slow speed, Clear, Synchronize, Relevance
		Screen	Placement, Suitable size, Clear
		Text	Simultaneously appear, Accurate time narration, Simple, Straightforward, Understandable, Relevance
		Animation	Understandable, Animated
		Images	Real-life concepts, Suitable
10.	Clarity Consistency Contrast Control Familiarity Harmony Multimedia Embodiment Spatial Contiguity Temporal Contiguity	Video	Integrated the element, Interactively engage, High-quality, Good resolution, Appropriate, Understandable, Real-life concepts, Recognizable
		Sign language video	Gestures, Emphasized, Embodiment cues, Clear, Easily interact, Engage, No time limit, Standardize signs, Simultaneously appear, Accurate time narration, Understandable, Signs
		Image	Narrative, Gestures, Embodiment cues, Clear, Placement nearby, Relevance, Appropriate, Understandable, Interesting, Real-life concepts, Recognizable, Contrast with background
		Animation, Graphic/Icon	Easily interact, Engage, No time limit
		Text	Readable, Avoid decorative, Animated, Group colored, Appropriate, Contrast with background, Legibility, Capital letter, Sentence case, Placement nearby, Relevance, Simultaneously appear, Accurate time narration
11.	Clarity Consistency Control Harmony Multimedia	Video	Integrated the element, Interactively engage
		Image	Simple, Understandable
		Text	Cluster, Consistent typeface, Readable, Hierarchal by heading
		Navigation	Consistent functional option
		Graphic/Icon	Consistent placement
		Screen	Easily interact, Allow on/off function
12.	Clarity Contrast Harmony Multimedia Embodiment Spatial Contiguity Temporal Contiguity	Video	Integrated the element, Interactively engage, Simple, Easy, Narrative, Appropriate
		Text, Image	Placement nearby, Relevance, Aesthetically pleasing, Appropriate, Suitable, Group colored
		Sign language video	High-embodiment, Clear, Signs, Expression, Gestures, Relevance, Simultaneously appear, Accurate time narration
		Animation	Simple, Easy, Narrative, Attract attention, Aesthetically pleasing, Appropriate, Suitable
		Graphic/Icon	Appropriate, Suitable, Group colored

13.	Clarity Control Familiarity Multimedia Embodiment Temporal Contiguity	Video Sign language video Audio, Text Animation Image, Graphic/Icon, Screen	Integrated the element, Interactively engage, Easily interact, Engage, Repeatable High-embodiment, Instructor, Narrator Simultaneously appear, Accurate time narration, Synchronized Real-life concepts, Interesting, Aesthetically pleasing, Avoid abstract
14.	Clarity Consistency Contrast Control Harmony Coherence	Video Text Screen	Easily interact, Engage, No time limit, Repeatable Structured, Consistent typeface, Consistent size, Sans serif, Cluster color, Various sizes, Cluster, Avoid overlapping, Avoid capital, Contras with background, Evade interference, Readable, clear, Avoid animated Consistent layout, Focused, Suits the user's user need, Easily interact, Engage
		Image Graphic/Icon, Animation	Avoid overlapping, Understandable, Appropriate Understandable, Appropriate
15.	Clarity Consistency Control Familiarity Harmony Multimedia Coherence Embodiment Spatial Contiguity Temporal Contiguity	Video Screen Animation Sign language Video Audio Image Graphic/Icon Text	Integrated the element, Interactively engage, Instructional, Appropriate, Clear, No time limit, Easily interact Avoid extraneous Relevance, Avoid extraneous, Selective, Placement nearby, Simulation, Representation Integrated the element, High-embodiment, Signs, Placement throughout, Avoid extraneous Simultaneously appear, Accurate time narration, Synchronized Proportional, Balanced, Relevance, Real-life concepts, Recognizable, Appropriate Consistent size, Relevance, Avoid extraneous Consistent typeface, Relevance, Avoid extraneous, Selective, Simple, Straightforward, Understandable, Placement nearby
16.	Clarity Contrast Control Harmony Multimedia Embodiment Spatial Contiguity Temporal Contiguity	Video Sign language video Text, Graphic/Icon, Animation Screen Audio Navigation,	Integrated the element, Interactively engage High-embodiment, Placement throughout, Signs Simple, Straightforward, Understandable, Simultaneously appear, Accurate time narration, Placement nearby, Relevance, Suitable, Appropriate, Group colored, Pleasant color Easily interactive, Engage, No time limit Suitable, Appropriate, Clear Simple, Suitable, Functional option
17.	Harmony Multimedia Coherence Embodiment Spatial Contiguity Temporal Contiguity	Video Animation, Text, Graphic/Icon Audio	Integrated the element, Interactively engage Relevance, Equipped with related elements, Appropriate, Cluster, Synchronize, Grouping, Simultaneously appear, Accurate time narration, Placement nearby, Relevance Synchronize with the elements
		Sign language video Image	High-embodiment, Emphasized, Embodiment cues, Gestures, Relevance, Equipped with related elements Narrative, Signs, Gestures
18.	Consistency Familiarity	Graphic/Icon, Screen, Text Animation, Video, Image	Similar action, Similar object Real-life concepts, Recognizable
19.	Clarity Consistency Contrast	Video Image, Text	Integrated the element, Interactively engage, Suitable, Clear Placement nearby, Relevance, Simultaneously appear, Accurate time narration, Real-life concepts, Appropriate Signs

	Familiarity Harmony Multimedia	Sign language video	Interactively, Emphasized, Embodiment cues, Proportional, Consistent signs, Emphasized expression, Integrated elements, Clear, Space consideration
	Embodiment	Animation	Real-life concepts, Suitable, Clear
	Spatial Contiguity	Screen	Pleasant, Noticeable
	Temporal Contiguity	Graphic/Icon	Animated, Accurate time narration
20.	Clarity Consistency Familiarity Harmony	Animation, Video, Image, Screen	Clear, Displayed closely, Minimal, Accessible, Sequence, Relevance, Avoid extraneous, Group element, Limit color, Consistent throughout, Harmony, Appropriate, Understandable, Clear
	Coherence	Text	Clear concept, Suits the user, Identical instruction
		Graphic/Icon	Clear, Understandable
		Screen	Identical instruction, Consistent layout
21.	Clarity	Video	Integrated the element, Interactively engage
	Consistency Control	Audio	Relevance, Equipped with related elements, Avoid extraneous, Synchronized with the elements
	Familiarity Coherence Multimedia	Animation, Image, Graphic/Icon	Simple, clear, Understandable, Similar look, Avoid extraneous, Avoid blinking, Real-life concepts, Suits the user, Recognizable
	Temporal Contiguity	Navigation	Consistent functional option, Operated similarly, Easily interactive, Engage
		Text	Placement, Hierarchical, Relevance, Organize, Proportioned, Aesthetically pleasing, Capitalization
		Screen	Organize, Balanced, Contrast
22.	Contrast Control	Video	Integrated the element, Interactively engage, Easily interactive, Engage, No time limit, Repeatable
	Coherence Embodiment Multimedia	Animation, Image	Relevance, Avoid extraneous, Simple, Synchronized with the elements, Accurate time narration, Understandable, Simultaneously appear
	Spatial Contiguity Temporal Contiguity	Text	On point information, Straightforward Bold, Relevance, Placement nearby
		Screen	Effectively communicate, Placement
		Graphic/Icon	Hierarchical animated, Importance component
		Sign language video	High embodiment, Gestures, Emphasized, Embodiment cues, Placement throughout
23.	Clarity Consistent	Screen	Structure, Organized, Clear, Well produced, Easily interactive, Engage, No time limit
	Contrast Control	Text	Cluster, Readable, Unobtrusive, Legibility, High tonal contrast, Simple, Summaries
	Harmony	Video	Clear, Contrast, Appropriate, Suitable, Relevance,
	Coherence	Image, Audio, Graphic/Icon, Animation	Appropriate, Suitable, Relevance, Group, Avoid extraneous effects
24.	Consistency Contrast Harmony Coherence Temporal contiguity	Text	Structured, Limited typeface, Cluster, Various weights and sizes, Aesthetically pleasing, Suitable shaped, Sans serif, Plain, Bold, Legibility, Appropriate effects, Avoid hot color, Orderly, Hierarchical by style, Simultaneously appear, Accurate time narration, , Relevance
		Audio	Suitable placement, Relevance, Synchronized with the elements
		Graphic/Icon	Avoid hot color, Group colored, Appropriate effects
		Animation	Suitable, Sequences, Appropriate effects, Avoid extraneous effect
		Image	Colored, Clear, Appropriate effects, Avoid hot color
		Video	Clear, Avoid backlighting, Appropriate effects
25.	Clarity	Video	Integrate the element, Interactively engage, Understandable
	Consistency Contrast	Sign language video	Aesthetically pleasing, Relevance, High embodiment, Integrated the elements
	Familiarity Coherence Embodiment	Text	Relevance, Simultaneously appear, Accurate time narration, Synchronized with the elements, Well-structured, suitable sizes, Colored, Readable

	Multimedia Spatial Contiguity Temporal Contiguity	Image	Placement nearby, Real-life concepts, Suits the user need, Relevance, Equipped with related elements, Focused, Avoid extraneous, Avoid redundancy
		Animation	Clear, Narrative, Understandable, Real-life concepts, Suits the user need.
26.	Clarity Consistency Contrast Familiarity Harmony Spatial Contiguity	Video	High-quality, Narrative, Clear, Illustrate process
		Screen	Effective combination, Simple, Balanced, Consistent, Orderly
		Text	Effects, Legibility, Consistent group color, Typeface style, Avoid decorative, Readable, Cluster, Non-scattered, Accurate, Limited typeface, Identical color, Clear, Readable, Simple, Appropriate, Suitable
		Image	Placement nearby, Balanced, Relevance, Real-life concepts, Simulation, Illustration
		Graphic/Icon	Avoid decorative, Readable, Cluster, Non-scattered, Accurate, Identical color, Understandable
		Audio	Clear, Simple
		Animation	Simulate real situations, Clear, Narrative, Appropriate
27.	Clarity Consistency Contrast Control Familiarity Harmony Coherence Multimedia Spatial Contiguity	Video	Integrated the element, Interactively engage, Easily interactive, No time limit, Repeatable, Allow on/off function, Clear, Narrative, Understandable
		Text	Contrast color, Emphasized, Avoid similar color with elements, Avoid red, Appropriate, Cluster, Readable, Precise, Simple, Clear, Selective, Consistent style, Consistent color, Hierarchal, Placement nearby, Relevance
		Graphic/Icon	Appropriate, Understandable, Easy, Clear, Accurate, Placement, Suits the user, Avoid biases of ethnicity and religion, Relevance
		Image	Animated, Suitable time narration
		Audio	Relevance, Avoid effects, Avoid extraneous, Interesting, Lively, Simple, Clear
28.	Clarity Consistency Control Coherence Multimedia Spatial Contiguity Temporal Contiguity	Image	Integrated the element, Interactively engage, Understandable, Narrative
		Text	Placement nearby, Balanced, Hierarchal, Simultaneously appear, Relevance, Focused, Concise, Sans serif, Readable
		Animation	Accurate time narration, Relevance, Concise, Narrative, Understandable
		Audio	Relevance, Focused, Concise
		Video	Easily interactive, Engage, No time limit, Repeatable, Allow on/off function
		Screen	Consistent, Orderly, Hierarchal
		Graphic/Icon	Clear, Simple, Understandable
29.	Consistency Familiarity	Graphic/Icon	Relevant, Clear, Identical, Positioning
		Navigation	Color changes
		Screen	Clear, Orderly
		Text	Limit styles
		Video	Introduction montage by pages
		Animation	Understandable, Logical character, Real-life concepts
30.	Consistency Contrast Harmony	Text	Avoid all capital, Limit length, San serif, Avoid decorative, Contrast background, Limited typeface, Integrate with elements, Appropriate, Avoid bright color, Consistent font, size, Placement, Color
		Color	Contrast background and foreground, Consider culture, Aesthetically pleasing, Appealing, Consistent throughout pages
		Graphic/Icon	Avoid background images, Contrast, Avoid cluttered
		Video	Contrast, Clarity, Integrated elements, Understandable
		Animation	Attention, Understandable, Cues, Aesthetically pleasing, Appropriate, Function, Simple, Suitable speed, Consistency throughout the content
		Audio	Pleasant, coherent, Consistency throughout

		Graphic/Icon	Animated, Appropriate, Synchronize, Simple, Consistent placement throughout pages
31.	Clarity Consistency Control	Video	Integrated the element, Interactively engage, High-quality, Clear, No time limit, Repeatable, Allow on/off function, Synchronize, Effective
	Harmony	Text	Clear caption, readable
	Coherence	Audio	Suitable, High-quality, Relevance
	Embodiment Multimedia Temporal Contiguity	Sign language, Text	Simultaneously appear, Integrate the elements, Synchronize, Signs

Source: Sources are from the data analysis

Principles, elements, and characteristics identified for interactive multimedia teaching aids for the hearing-impaired

The details pertaining to the summary of the principles and elements of interactive multimedia design are discussed in the following section, in order of the frequency of appearance in the content analysis.

a. Clarity within the interactive multimedia design

In the content analysis throughout the literature, the most commonly occurring element centers on the importance of clarity in interactive multimedia design. The literature highlights the importance of presenting all the relevant content in a clear and understandable manner to effectively communicate with the users (Chapman & Chapman, 2009; Galitz, 2007; Knoors & Marschark, 2014). The clarity applies across all elements that involve text, video, sign language video, images, animation, graphics/icons, audio, and screen. Very often, vocabulary is very challenging for hearing-impaired students because they are not taught the best way to remember the learning content (Nasir et al., 2021). Therefore, for this special group, the design of multimedia content should focus on providing easy, readable information in legible texts for them to better comprehend the content (Boudreault et al., 2018; Pelayo et al., 2018). Riza et al. (2018) and Saud & Nasruddin (2017) also emphasized that sign language videos should incorporate high-quality and clear videos with embodiment cues, and all video content should be simple with a clear narrative. Last but not least, other elements such as images, graphics/icons, audio, and the screen should also utilize clear and understandable content to facilitate the users, especially if they are hearing impaired (Galitz, 2007; Jamaludin, 2005).

b. Multimedia integration within the interactive multimedia design

Based on the content analysis, the principles of multimedia were shown to emphasize the importance of integrating various multimedia elements, including sign language videos, audio, text, images, graphics, and animations, to enhance interactive learning and user engagement (Mayer, 2021). It also stresses the need for clear and user-friendly interfaces that encompass accessible features such as interactive subtitles, audio, and navigation menus (Kourbetis et al., 2016). The inclusion of sign language videos with clear gestures and visual lip movements, accompanied by images and text, has been shown to be an effective method of conveying information (Mohd Hashim & Tasir, 2020). Additionally, Ahmadi et al. (2015) highlighted the importance of incorporating various elements of presentation such as audio recording of oral speech with the text and images, as well as providing subtitles for sign language videos to enhance the learning experience.

c. Temporal contiguity of contents in interactive multimedia design

Next, the Principle of Temporal Contiguity also frequently occurred, just like the Principle of Multimedia and Harmony. Temporal contiguity refers to the synchronicity of different elements in multimedia content such as sign language videos, videos, images, animations, audio, and text. It is crucial for all the relevant elements to be presented simultaneously to ensure an aligned narration for the benefit of the users (Saud & Nasruddin, 2017). Moreover, captions and auditory descriptions must also be synchronized with the presentation to ensure maximum comprehension (Muhamad Ali, 2021; Suarsana, 2021). In summary, temporal contiguity is essential for the effective delivery of multimedia content and thus, should be given adequate attention to enhance learning outcomes (Mayer, 2021). The Principle of Temporal Contiguity is similar to the Principle of Spatial Contiguity, another important principle that emphasizes the importance of presenting information in a logical and sequential order.

d. Harmony of the elements in interactive multimedia design

The Principle of Harmony is applied when there is a need to create a sense of visually appealing multimedia content to the user and its application can create a sense of uniformity. It is essential to create effective multimedia content that is engaging and understandable for users. Harmony is also applied in interactive multimedia design to achieve balance and coherence among the various elements, such as sign language video, video, image, animation, audio, text, and color (Vaughan, 2011). In order to apply harmony, each element must be appropriately integrated and presented based on the user's level of comprehension (Chapman & Chapman, 2009). For example, instructional videos should include suitable audio, sign language video, text, graphics, animation, or images to capture the attention of users and enhance their understanding (Abbas et al., 2019). Images and graphics should be aesthetically pleasing. Furthermore, placement and hierarchy should be well-balanced to prevent users from being overwhelmed with too much information (Hadi & Özdemir, 2017; Sidek et al., 2021). By establishing suitable audio-visual aids and aesthetic choices at an appropriate level, harmonious multimedia content that effectively conveys information to users can be developed.

e. Consistency within the interactive multimedia design

The Principle of Consistency is important in creating a cohesive and effective design for multimedia content. Consistency is applicable within all the elements in the multimedia design, from the aspect of the availability and position of sign language video, as well as of the use of standard sign language and facial expression in any of the videos, images, audio, and subtitles throughout the multimedia content (Jabar & Ahmad, 2018; Kourbetis et al., 2016; Saud & Nasruddin, 2017). Similarly, Galitz (2007) and Kamaruddin (2012) also emphasized that graphic/ icons, navigation, and font usage should be standardized in terms of their appearances, sizes, and modes of operation. Consistent placement should be practiced to avoid blinking effects. In terms of screen design, consistency is important in the design of a clear layout and structured elements by using similar interfaces for similar actions or objects, placing important items consistently, as well as providing the same instructions throughout the multimedia (Mayhew, 1992; Nielsen, 1993).

f. Coherence of contents in the interactive multimedia design

Coherence refers to the use of elements related to the learning topic in multimedia design to deliver the learning content (Mayer, 2021). In terms of sign language video, (Hadi & Özdemir, 2017; Knoors & Marschark, 2014) suggested that the inclusion of relevant elements such as

images, videos, audio, and text can aid in understanding. It is important to keep the content simple, clear, and straight to the point. More importantly, unrelated, or irrelevant elements should not be added. Similarly, in videos and animation, coherence can be achieved by presenting the information clearly in a sequential manner, besides equipping it with relevant elements as well as keeping it short and focused (Harun & Tasir, 2003). The use of extraneous and irrelevant elements and effects should be avoided. To ensure that users can understand the message or information being presented in the multimedia design, relevant elements should be used, and irrelevant ones should be avoided.

g. Familiarity with content in the interactive multimedia design

The importance of familiarity in multimedia design, particularly in sign language videos, images, graphics/icons, animations, screens, audio, text, and navigation, cannot be overstated. The multimedia design should prioritize real-life scenarios to enhance the understanding of the users and to improve their engagement (Kamaruddin, 2012; Pelayo et al., 2018). For sign language videos, factual signing codes and understandable gestures should be used while videos and images should utilize familiar concepts (Boudreault et al., 2018; Mohd Hashim & Tasir, 2020). Graphics and icons should be clear and easy to understand to avoid unnecessary biases and contradictions. The animation must be relatable to the users by incorporating scenes from daily lives and familiar characters (Anindhita & Lestari, 2016; Riza et al., 2018). As for screens and audio, the interface and audio should mimic user behavior patterns and aim to be understandable and relatable for all (Galitz, 2007). For instance, the text should include familiar words, phrases, and concepts, while the navigation should be user-friendly and suited to the user's level of acceptance (Harun & Tasir, 2003; Knoors & Marschark, 2014). In short, it is important to design multimedia content that is familiar and understandable to the target audience to enhance their engagement and learning as well as improve the overall user experience.

h. Spatial contiguity of content in interactive multimedia design

The Principle of Spatial Contiguity refers to the arrangement of related elements in close proximity to one another for better understanding and retention of information (Mayer, 2021). Abbas et al. (2019) and Pelayo et al. (2018), both suggested for related elements be placed near each other, whether it is sign language video, video, animation, audio, image, text, or graphic/icon as the placement of related elements with text can result in clear presentation and communication (Razalli et al., 2021). Jamaludin (2005) also stressed that placing the text on top of the image is better than the other way around as users should read any text before viewing the animated graphic. The placement of text in correspondence to the graphic or images on the screen can lead to effective communication with the users. Overall, spatial contiguity plays a crucial role in the effectiveness of multimedia presentation, and it helps in improving the retention of information.

i. Embodiments of contents in interactive multimedia design

Embodiment is a critical aspect in designing multimedia content that is effective in teaching and learning, especially for hearing-impaired students. This principle emphasizes the use of a real instructor who displays physical movements and gestures that can help the learners to better understand the concepts that are being taught (Mayer, 2021). The use of sign language videos is an excellent example of high embodiment, in which actual signing is shown throughout and cues such as eyes, mouth, expression, finger, as well as hand and body gestures

are all highlighted (Anindhita & Lestari, 2016; Ibrahim, 2017). In the video and on the screen, the inclusion of an instructor who explains the content can also improve embodiment. The size of the instructor should also be proportional to the screen size and the sign language video should be positioned at the bottom right corner of the multimedia (Riza et al., 2018). Interactive integration of sign language video and text in the video can be beneficial. As for images, Saud & Nasruddin (2017) emphasized that a narrative sign language image with clear styling movement, as well as embodiment cues such as images of hands signing the sign language, can also improve understanding. Using high embodiment and talking at a slow pace is effective in complementing the use of dynamic visual displays that are accompanied by instructors' sound descriptions to ensure that the learning process can be visualized and understood by hearing-impaired students (Ahmadi et al., 2015).

j. Control within the interactive multimedia design

The Principle of Control emphasizes the importance of allowing users to be in control of their learning experience as it can greatly enhance their engagement and learning outcomes. To apply this principle in the video content, it is important to provide options for users to control the pace and the way to engage with the content, such as allowing users to play, pause, and repeat the video at their own pace, as well as providing the relevant subtitles or on/off functions(Efendi et al., 2020; Harun & Tasir, 2003). Such control allows users to customize their learning experience according to their needs and preferences (Saud & Nasruddin, 2017). Similarly, for screen interfaces, users should have control over the interface, i.e. the ability to customize the interface based on their preferences, besides providing options for them to navigate and interact with the interface in a way that feels intuitive and natural to them (Chapman & Chapman, 2009). In short, greater control over the learning experience results in a conducive learning environment and promotes greater engagement and retention of information among the users.

k. Contrast within the interactive multimedia design

In the last principle, contrast is an important factor to consider in designing effective multimedia content for interactive learning. Contrast can be applied to various elements, such as color, background, foreground, and font to modify the visibility, legibility, and overall appeal of the content (Chapman & Chapman, 2009; Saud & Nasruddin, 2017). For sign language videos, Boudreault et al. (2018) suggested to for the narrator to wear a dark-colored shirt in front of a white background to provide a good contrast. Furthermore, a clear and contrasting video with proper lighting is also recommended for regular videos. When applying contrast in images and graphics, colorful and interesting visuals can attract users but it is important to avoid applying text to images and pictures as backgrounds. Instead, a large icon with bright colors can draw attention as well as improve comprehension and retention. When it comes to animation, the use of bright colors against a contrasting background can improve the visual appeal of the content (Riza et al., 2018). As for texts, the use of contrasting font formats can help in highlighting important information whereas a good execution of contrasts in size, weight, brightness, and thickness can improve legibility (Sulaiman, 2019). However, Vaughan (2011) expressed those certain colors such as bright reds and magenta, as well as decorative and script fonts, all-caps text, and light-colored text on dark backgrounds should be avoided. In short, a good application of contrast in designing effective multimedia content is to emphasize the visual appeal and engagement of the learning aid to make it more conducive.

Overall, the outlined principles and elements highlight the importance of integrating multiple principles in interactive multimedia design to create effective educational materials

for hearing-impaired students specifically. Figure 1 shows the final illustration process of the principles, elements, and characteristics of the recommended interactive multimedia teaching aid for the hearing-impaired based on the studies in the literature review.

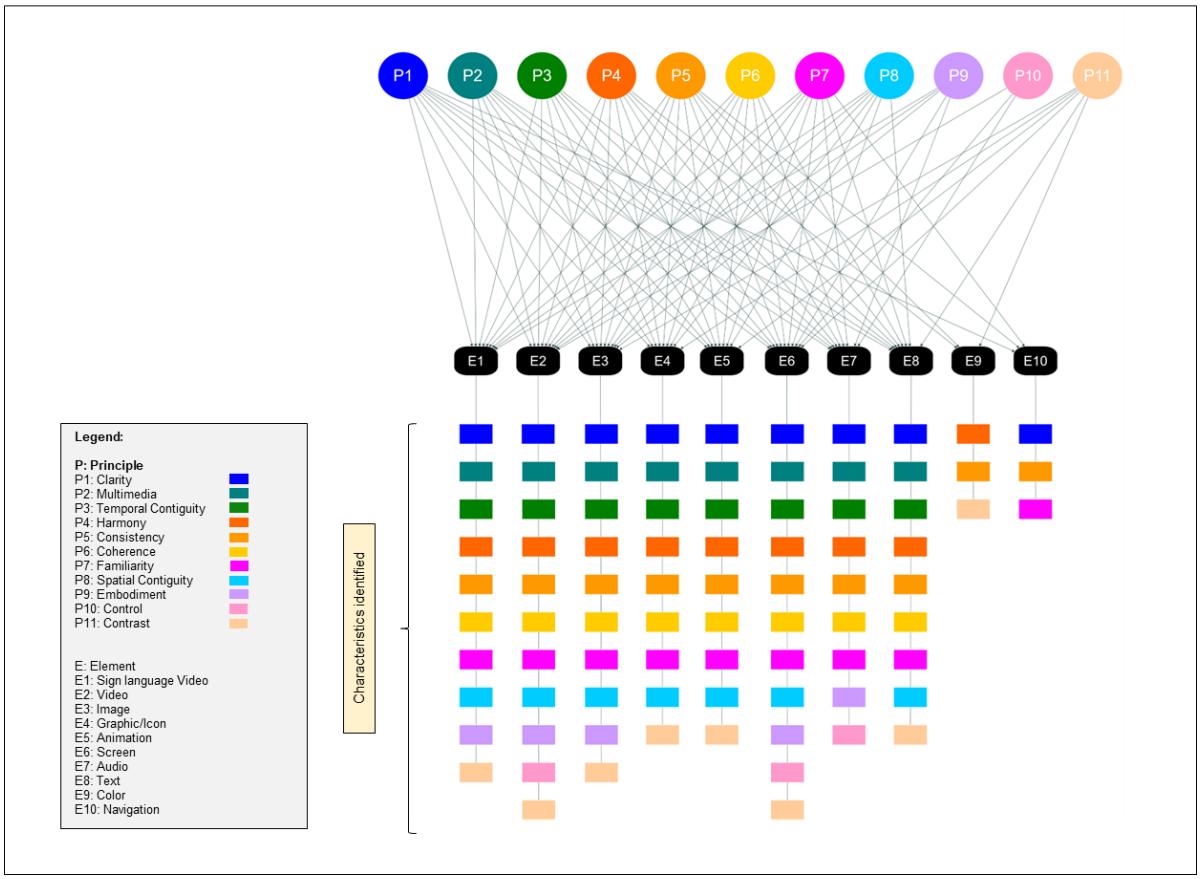

Figure 1. Illustration process of the principles, elements, and characteristics identified for interactive multimedia teaching aids for the hearing-impaired

In summary, there are 84 characteristics from the ten elements of the interactive multimedia design of sign language video, video, image, audio, graphic/icon, animation, screen, color, text, and navigation identified. The most common elements in interactive multimedia designs are video, screen, image, sign language video, graphic/icon, animation, audio, and text. In comparison, navigation and color are mentioned less frequently. Accordingly, the characteristics of each element have been identified, with video and screen being featured most frequently, and navigation the least. The characteristics that have been identified are as follows in descending order, i.e., 11 characteristics for video and screen, followed by ten characteristics for sign language video and images, nine characteristics for graphics/icons, animation, audio, and text, and lastly three characteristics for color and navigations.

Based on the outcomes, most of the elements shared similar characteristics, such as the Principle of Temporal Contiguity. In terms of synchronicity, each element in the multimedia content requires temporal contiguity. Thus, each element must apply accurate display time and narration for sign language videos, videos, images, animations, audio, and text display. Table 4 explains the characteristics of the elements of interactive multimedia design for hearing-impaired as identified from the contextual document review through the 11 most identified principles of interactive multimedia outlined earlier.

Table 4. Characteristics of the 11 identified principles and elements of interactive multimedia teaching aids for hearing-impaired

Principle	Element	Characteristic (By Keywords)
Clarity	Sign language Video	• High-quality, Clear, Easy, Narrative, Embodiment cues, Space consideration
	Video	• High-quality, Good resolution, Integrated text, Simple and Straightforward, Understandable, Easy, Narrative, Interesting, Avoid abstract, Clear, Equipped with signing
	Image	• Clear, Understandable, Interesting, Simple, Understandable, Interesting, Avoid abstract, Simple, Narrative
	Graphic/Icon	• Interesting, Aesthetically pleasing, Avoid abstract, Simple, Suitable, Functional option, Understandable, Clear
	Animation	• Simple, Easy, Narrative, Interesting, Avoid abstract, Understandable, Clear, Understandable, Simulate real situations
	Screen	• Interesting, Aesthetically pleasing, Avoid abstract
	Audio	• High-quality, Clear, Simple
	Text	• Simple, Straightforward, Understandable, Readable, Understandable language, Legibility typeface, Recommend Tiresias Screen type, Easy, Avoid decorative, Hierarchal by heading, Interesting, Aesthetically pleasing, Avoid abstract, Precise, Clear caption
	Navigation	• Simple, Suitable, Functional option, clear, Understandable
Multimedia	Sign language video Video Image Graphic/Icon Animation Screen Audio Text	• Integrated the element, Interactively engage, Understandable
Temporal Contiguity	Sign language video Video Image Graphic/Icon Animation Screen Audio Text	• Simultaneously appear, Accurate time narration, Synchronized with the elements
Harmony	Sign language Video	• Appropriate, Suitable duration, Understandable, Integrated elements
	Video	• Suitable, Balance, Placement, Appropriate, Suitable duration, Understandable, Animated, Integrated elements, Effective
	Image	• Suitable size, Balance, Placement, Narrative, Aesthetically pleasing, Suitable, Appropriate, Understandable, Appropriate Signing, Integrated elements
	Graphic/Icon	• Suitable, Appropriate, Suitable size, Aesthetically pleasing, Emphasized, Understandable, Simple, Integrated elements
	Animation	• Suitable, Appropriate, Suitable size, Balance, Placement, Suitable duration, Understandable, Aesthetically pleasing, Function, Simple, Accurate time narration, Integrated elements
	Screen	• Appropriate, Suitable size, Balance, Placement, Suitable duration, Group color
	Audio	• Clear, Suitable speed, Integrated elements, Appropriate, Understandable, Synchronize, Simple, Pleasant, coherent, and consistent
	Text	• Suitable size, Balance, Placement, Readable caption, Cluster typeface, Various sizes, Aesthetically pleasing, Appropriate, Understandable, Animated, Group colored, Cluster, Limited typeface, Integrate with elements, Avoid bright color, Accurate time narration

	Color	• Consider culture, Aesthetically pleasing, Appealing
Consistency	Sign language Video	• Consistent, Placement throughout, Position at bottom-right throughout, Consistent signing, Standardize signing, Emphasized expression
	Video	• Consistent, Orderly, Introduction montage by pages, Integrated elements
	Image	• Narrative, Proportional, Balance, Consistent, Orderly, Hierarchal
	Graphic/Icon	• Consistent size, Similar action, Similar object, Similar look, Avoid blinking, Identical color, Consistent placement throughout
	Navigation	• Similar action
	Animation	• Proportional, Balance, Integrated elements, Consistency throughout
	Screen	• Consistent layout, Similar action, Similar object, Identical instruction, Organize, Contrast, Structure, Organized, Clear, Well produced, Simple, Balanced, Consistent, Orderly, Clear
	Audio	• Suitable placement, Consistency throughout
	Text	• Caption throughout, Consistent size, Consistent typeface, Structured, Placement, Hierarchical, Organized, Proportioned, Aesthetically pleasing, Cluster, Readable, Unobtrusive, Consistent color, Hierarchal, Orderly, Limit styles
	Color	• Consistent throughout pages
Coherence	Sign language Video	• Relevance, Avoid extraneous, Equipped with related elements, On-point information, Simple, Clear, Understandable
	Video	• Relevance, Avoid extraneous, Equipped with related elements, On-point information, Group element, Simple, Straightforward, Avoid extraneous effects, Understandable
	Image	• Relevance, Avoid extraneous, Equipped with related elements, Understandable
	Animation	• Relevance, Avoid extraneous, Equipped with related elements
	Screen	• Avoid extraneous, On-point information, Minimal, Relevance, Group element
	Audio	• Avoid extraneous, On-point information, Relevance, Equipped with related elements, Avoid effects, High-quality
	Graphic/Icon Text	• Relevance, Avoid extraneous, Equipped with related elements, Avoid extraneous effects, Focused
Familiarity	Sign language Video	• Factual signing, Real-life concepts, Recognizable, Suits the user
	Video Image Animation	• Real-life concepts, Recognizable, Suits the user, Understandable, Logical character
	Graphic/Icon	• Real-life concepts, Recognizable, Common icons, Linguistic symbols, Clear, Understandable, Suits the user, Avoid biases of ethnicity and religion, Logical character
	Screen Audio	• Real-life concepts, Suits the user, Recognizable
	Text	• Real-life concepts, Recognizable, Understandable, Clear concept, Suits the user, Understandable
	Navigation	• Familiar function, Suits the user
Spatial Contiguity	Sign language Video Video Animation	• Placement nearby, Relevance
	Image Text	• Placement nearby, Relevance, Placement nearby, Balance, Hierarchal, Simultaneously appear
	Graphic/Icon	• Placement nearby, Relevance, Hierarchical animated, Importance component
	Screen	• Effectively communicate, Placement
Embodiment	Sign language Video	• High-embodiment, Factual signing, Gesture, Signing, Emphasized Embodiment cues, Interactively, Placement throughout
	Screen Video	• Placement throughout, Signing, High-embodiment, Integrated element, Suitable size, Clear

	Image	• Static signing, Narrative, Signing, Gesture
	Audio	• Slow speed, Clear, Synchronize, Relevance
Control	Video Screen Audio	• Easily interactive, Engage, No time limit, Repeatable, Allow on/off function, Engage with the element
Contrast	Sign language Video	• White background, Dark attire, Proper lighting, Contrast background, Attract attention, Aesthetically pleasing
	Video	• Attract attention, Aesthetically pleasing, Pleasant, Noticeable, Clear, Contrast, Clear, Avoid backlighting, Appropriate effects, Clarity
	Image	• Colored, Appropriate color, Contrast with background, Attract attention, Aesthetically pleasing, Avoid overlapping, Pleasant, Noticeable
	Graphic/Icon	• Bright color, Attract attention, Aesthetically pleasing, Pleasant, Noticeable
	Animation	• Attract attention, Aesthetically pleasing, Pleasant, Noticeable, Suitable bright colors
	Screen	• Aesthetically pleasing, Contrast background and foreground, Attract attention, Pleasant, Noticeable, Effective combination
	Color	• Contrast background and foreground
	Text	• Contrast colored, Distinctively color caption, Readable, Contrast with background, Legibility, Attract attention, Aesthetically pleasing, Contrast with background, Evade interference, Pleasant color, Legibility, Sans serif, Hierarchical by style, Colored, Readable, Emphasized, Avoid similar color with elements, Avoid red, Avoid all capital, Limit length, San serif, Avoid decorative

Source: Sources are from the data analysis

Conclusion

The study identified and outlined the 11 most cited principles of interactive multimedia design with a special focus on hearing-impaired teaching aids. The 11 principles in descending order are clarity, multimedia, temporal contiguity, harmony, consistency, coherence, familiarity, spatial contiguity, embodiment, control, and contrast. Among the 11 most frequently occurring principles, ten elements of interactive multimedia design are identified specifically for hearing-impaired teaching aids, namely sign language video, video, image, audio, graphic/icon, animation, screen, color, text, and navigation. From the summarized guideline of the principles and elements, a total of 84 characteristics of guiding principles for the ten elements show that the most common elements in the interactive multimedia design are video, screen, image, sign language video, graphic/icon, animation, audio, and text. Navigation and color are mentioned less frequently. In addition, the study revealed that a well-designed and developed interactive multimedia teaching aid that adheres to these principles can significantly facilitate teaching delivery and enhance the learning experiences of hearing-impaired students, ultimately leading to a more inclusive and accessible education. Therefore, when designing interactive multimedia teaching aids customized for the hearing impaired, it is important to prioritize their needs by making the teaching aid engaging, interactive, and intuitive to use. The characteristics of the principles and elements are important guides for the design of an effective interactive multimedia teaching aid for hearing-impaired students.

Furthermore, this study recommended a more extensive and systematic approach is vital in the designing of interactive multimedia teaching aids that can cater to the needs of hearing-impaired students. Subject matter experts, educators, and designers should be invited to be a part of the design and development process. In summary, this study provides valuable insights into the improvement of effective interactive multimedia teaching aids to fulfill the unique needs of hearing-impaired students, allowing them to be part of a more inclusive and

accessible education. The findings represent important implications for stakeholders such as educators, designers, and policymakers who strive to create a more accessible learning environment for all students.

Acknowledgment

The author would like to thank all parties of the academic supervision and the Ministry of Education (MOE) for their support in making this project possible. This work is supported by the Research Management Centre (RMC) of Universiti Teknologi MARA under Geran Insentif Penyeliaan (GIP) RMI File No. 600-RMC/GIP 5/3 (046/2023) and approved by the UiTM Research Ethic Committee (Ref. number: REC/02/2022 (PG/MR/11).

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