The Impact of Assistive Technology on the Academic Achievement of Hearing-Impairment Students in Special High Schools in Cambodia

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ABSTRACT

Background: Although Cambodia has ratified international disability conventions and made policy promises, hearing-impaired students continue to experience hindrances in accessing education, as only 10% of people with disabilities in Cambodia have continuous access to assistive technologies (AT).

Purpose: An explanatory sequential mixed methods study was conducted in order to assess the effect of AT on academic performance of hearing-impaired students in special high schools in Cambodia. Research questions: Four questions were asked for this purpose: The available type(s) of AT and their usage; The impact of AT on academic achievement; The impact of AT on class participation; and Difficulties associated with its implementation.

Methodology: The first phase involved giving questionnaires to 70 hearing impaired children from three different places (Phnom Penh, Battambang, and Kampong Cham). The second phase involved giving interviews (15) and conducting classroom observation (12).

Findings: In quantitative analyses, there was clear technological stratification: hearing aids were highly available (89%), frequently used (76%, average 4.1), whereas digital AT was barely available (47%-61%), rarely used (31%-43%, average 2.3-2.8). The correlation between frequency of AT use and achievement was moderately high (r = 0.52); 68% of participants reported that their grades had improved because of AT. Participation yielded the highest ratings (average composite 3.5, 64% positive). However, in qualitative analysis, significant contingencies came to light: digital AT faced problems of inadequate ratio devices per students, language incompatibility (Khmer language only), and lack of teachers' training. The study described "accommodation paradox" (unequal AT access but equal grading standards) and "participation-visibility paradox" (AT enables participation but marks its users socially). Implementation-related obstacles were prominent; issues of power/infrastructure (M = 4.3, 86%) and teachers' skill gap (M = 4.1, 79%) were the most common obstacles, which negatively correlated with participation (r = -0.47). Implications: Results point to the need for an ecological approach.

Keywords: Assistive Technology; Hearing Impairment; Special Education; Academic Achievement; Inclusive Education

Background

The learning atmosphere in Cambodia for hearing-impaired children involves silence rather than education. Since there are no proper structures to help them, they have been struggling with comprehending what is being taught to them, interacting with their peers, and expressing what they have learned. As a result of these challenges in communication, there has been poor academic performance which has seen more dropouts (UNICEF Cambodia, 2022). Hearing impairment defined as having difficulty in hearing partially or completely is a problem that has affected around 320,000 people in Cambodia where language skills, literacy, and classroom interactions are seriously affected by this problem (WHO, 2021). For students in schools, the hearing problems cause academic difficulties where those unable to hear the instructions performed poorly in basic subjects and even failed to read properly (UNESCO, 2020).

Assistive Technologies (AT), which includes hearing devices, FM systems, speech-to-text technology, and sign language technology, provide one opportunity to overcome this gap. AT has developed into sophisticated digital technologies employing real-time captioning and artificial intelligence (WHO, 2018). Internationally recognized standards that include CRPD from 2006, adopted in Cambodia in 2012, guarantee accessibility to AT and the right to inclusive education (United Nations, 2012). However, there is still a problem of implementation gaps in special education system in Cambodia only 2.1% of people with disabilities can use AT, and the lack of AT and professionals to maintain such technology worsen the inequality between urban and rural students (CDRI, 2023). At special high schools, teachers have very little knowledge about integrating AT into teaching process, outdated curricula and no system for maintaining the devices is available (National Institute of Education, Cambodia, 2023).

The barriers to academic performance for hearing-impaired students in Cambodian special high schools are numerous and long-term, stemming from the lack of access to and appropriate usage of assistive technology. Though different countries have shown various solutions in terms of AT, Cambodian students suffer from communication problems, difficulties in classroom interactions, and poor academic performance, which leads to educational inequities—they do not understand the curriculum and cannot show their academic abilities (UNESCO, 2020; WHO, 2021). There are three main reasons for the problem. First of all, resource access is an important barrier as special schools cannot afford purchasing and maintaining the necessary equipment (hearing aids, FM systems, captioning software) and it costs too much for the family because of insufficient governmental support (Ministry of Education, Cambodia, 2023). Second, the gap in training leads to misusing of assistive devices the majority of special education teachers lack proper training in how to use AT in teaching, as they teach orally (National Institute of Education, Cambodia, 2023). Finally, there are still problems with policy implementation although the country ratified some documents and developed national strategies (Royal Government of Cambodia, 2019).

Perhaps the most significant issue is the lack of empirical evidence that exists on the influence of AT on the academic experience of Cambodian children with special needs. While existing literature mostly addresses the issues of physical impairments or accessibility in general, no literature can be found on the influence of AT on the academic experience of hearing-impaired Cambodian children (CDRI, 2023; WaterAid Cambodia, 2023). There have been no attempts to determine if the use of sign language affects reading or how captioning tools affect STEM subjects' understanding.

CONCEPTUAL FRAMEWORK

The present research will utilize four theoretical paradigms to analyze the issues associated with AT adoption in hearing impaired students in Cambodia. The core paradigm that will be used is the Social Model of Disability (Oliver, 1990), which claims that disability should not be considered as an impairment per se, but rather as a condition created by barriers that exist in society, such as lack of proper infrastructure, unprepared teachers, and inaccessibility of curriculum. In addition, the Human Capability Approach (Sen & Nussbaum) considers the adoption of ATs not as a mere act of charity, but as a vital tool for enhancing freedom and development of individuals and thus links the need for technology provision with human development and education. Overall, the combination of paradigms shows that the hearing-impaired students are disabled not due to their hearing problem, but due to non-inclusive environment in which they are educated.

Implementing such tenets into practice, the principles of Universal Design for Learning (UDL) (CAST, 2018) provide a guide for designing flexible environments where diverse students can learn using various means of representation (presentation of information), engagement (motivation) and expression (demonstration of knowledge). Another important framework, Technological Pedagogical Content Knowledge (TPACK) model (Mishra & Koehler, 2006) asserts that the effective integration of AT into teaching involves mastering the intersections between technology, pedagogy and content knowledge an assertion especially significant considering the insufficient training of Cambodia special education teachers in all the three areas. Both the UDL and TPACK models provide guidelines for the present study: UDL principles are used to evaluate whether AT really ensures multiple means of access and TPACK helps understand the problem of underutilization of devices due to teachers' lacking pedagogical and technological knowledge. Thus, the combination of all four perspectives leads to developing a conceptual framework for analysis of AT integration which does not imply only a technical

challenge but an ecological problem involving coordinated efforts on different levels from policies to social expectations.

LITERATURE REVIEW

Types of Assistive Technologies and Their Current Status

Types of assistive technologies that help hearing-impaired students include amplification devices like hearing aids and cochlear implants, which amplify sound waves into neural signals; frequency modulation technology and sound field technology, which increase the signal-to-noise ratio in the classroom; captioning and transcription technology, where the spoken instruction is provided visually; visual alerts, where auditory cues are changed to visual cues; sign language interpreters and video remote interpreting services; and new technologies like applications for smartphones for transcribing speech into text (Johnson et al., 2024). Despite theoretical accessibility, the global utilization rates are low. According to the World Health Organization (2021), in low-income countries, fewer than one in ten individuals eligible for using hearing aids can access them because of prohibitive cost and social stigma.

Impact of AT on Academic Performance

There are various ways in which AT contributes to positive academic performance. According to Singh et al. (2024), the use of software for speech-to-text conversion and the availability of devices facilitates the participation of hearing-impaired students in classwork and improves their skills of communication and reading. According to Paula et al. (2005), children who had received cochlear implants at the age of five years were far superior than slightly hearing-impaired ones. According to Johnson et al. (2024), the use of FM systems and real-time captioning helps hearing-impaired students to understand the lecture without having to strain. For STEM learning, Shoaib et al. (2023) have pointed out how 3D printing, tactile graphic, and audio technology enables visually impaired students to learn through interacting with spatial and abstract concepts that can be extended to hearing-impaired students via captioning and visual representation. In a systematic review by Fernández-Batanero et al. (2022), it is established that AT fosters the development of socialization and literacy skills required for success in academics. Duran (2022) emphasizes how AT supports the Universal Design for Learning principle through various means of representation, engagement, and expression.

Barriers to Assistive Technologies Usage

Though AT has many advantages, there are still many problems preventing proper usage of AT in schools. The first issue is the problem of limited budgets and infrastructure; the problem is that AT equipment (refreshable braille display, eye-gaze system etc.) is very expensive for many school districts (Shoaib et al., 2023). According to Wilson et al. (2023), this problem became more pronounced due to distance learning amid the pandemic. One of the major problems is the lack of teachers' training. According to Fernández-Batanero et al. (2022), most teacher education programs provide insufficient training regarding AT devices and their usage. Moreover, in inclusive classes, general teachers often lack special education training, which prevents them from choosing and using appropriate technologies effectively. Among the problems with AT are difficulties caused by insufficient technologies themselves; Paula et al. (2005) found out that cochlear implants helped students to hear but were not able to improve their academic results independently. Lack of standardization and interoperability of the technologies cause the problem of compatibility; in some cases, preferred technologies cannot be used with school-issued devices (Fernández-Batanero et al., 2022).

Implementation and Support Problems

Inconsistency in the inclusion of AT into curriculum is still widespread as schools tend to regard AT as an add-on, which involves availability of AT gadgets and devices yet infrequent usage since the teaching techniques have not been adapted by teachers (Singh et al., 2024). Teacher turnover results in inconsistency in AT implementation since trained professionals move to another place and must be replaced by other professionals who require training (Sibanda & Mhlanga, 2024). The stigma associated with AT use is among major psychological and social challenges in the process of implementation. In Fernández-Batanero et al. (2022), there

are mentions of how some teachers view assistive devices as tools for cheating rather than accommodation. Students may also prefer to conceal use of the devices or avoid using them due to bullying, choosing academic difficulties instead. Resisting changes in the teaching practices makes the application of AT rare since traditional approaches are used in classes. Old generation teachers do not want to implement new technologies as the process may require much time (Singh et al., 2024). Lack of student-centered AT selection results in prescription of inappropriate gadgets to students (Sibanda & Mhlanga, 2024).

Research Gaps

The literature review highlights several critical research gaps regarding the Cambodian situation. Firstly, there is an obvious lack of empirical studies on AT effectiveness among hearing-impaired students in Cambodia since all the existing research relates to the physical disability aspect or general accessibility. Secondly, many studies describe qualitatively AT advantages but lack quantitative studies about the effect on the performance of hearing-impaired students. Thirdly, insufficient attention is paid to the opinions of the stakeholders involved – students, educators, parents. Fourthly, insufficient studies are carried out concerning the integration of AT into educational practices. Fifthly, there are no longitudinal studies on AT influence. Sixthly, there is a gap related to the policy implementation despite the fact that Cambodia adopted the international conventions.

METHODOLOGY

Research Design

The research design adopted for this study was an explanatory sequential mixed-method design (Creswell & Plano Clark, 2018), which involved two stages first collecting and analyzing quantitative data to establish patterns in relation to AT availability, use, learning outcomes, and class participation, and then conducting a qualitative study to explain those patterns in light of stakeholder perceptions of implementation barriers. Such a research design was adopted since quantitative designs do not allow for contextualizing statistical associations without qualitative data, and qualitative designs are unable to provide any objective measures of impact.

Population, Sample and Sampling

Population: hearing impaired students (aged between 15 to 20), special education teachers and school administrators of Cambodian special high schools implementing AT program in three regions (Phnom Penh, Battambang and Kampong Cham).

Size of sample: In phase 1, 70 surveys were done based on G*Power calculation (power =0.80; medium effect size f =0.25; α=0.05). In phase 2, there were 15 interviews and 12 classroom observation sessions with thematic saturation approach (Guest et al., 2006).

Sampling Procedure: purposive sampling was used for selecting research settings with documented AT program at different stages of maturity and locations. Convenience sampling was used to select individual participants in these settings with active diversity checks.

Instruments

Phase 1 Survey Questionnaire: Structured survey for assessing AT stock and use (checklist of six ATs), academic performance (student self-report grades and improvement), classroom participation (likert-type questions) and perceived barriers. Items translated and culturally adapted to Khmer, pre-tested (α>0.7, Cronbach's).

Phase 2 Semi-Structured Interview Guide: Ten to fifteen open-ended key questions were divided into themes related to experience with AT, effects of AT on learning and socialization, difficulties met, support and recommendations for improvement. Interviews held using sign language translators; interviews lasted 30-45 minutes.

Classroom Observation Checklist: Standardized observation checklist that records AT use frequency and duration, pedagogical situation, engagement markers, teacher-student interaction and classroom acoustics. Observations conducted in 60-minute blocks.

Data Collection and Analysis

Quantitative Analysis: Survey data were analyzed using SPSS. Descriptive statistics (frequency, mean, and standard deviation) answered RQ1. Correlational analysis (Pearson/Spearman) explored correlations among frequency of AT use, achievement factors, and participation scores (RQs 2-3). Multiple regression assessed AT impact with consideration of covariates.

Qualitative Analysis: Interview and observational data were analyzed using a hybrid thematic analysis approach (Braun & Clarke, 2006) incorporating deductive coding (research questions and interview guide) and inductive coding (themes that emerged). Constant comparison analysis compared data across cases.

Integration: Joint displays linked findings from both methods, juxtaposing statistics with themes and exemplary quotes to generate meta-inferences (Creswell & Plano Clark, 2018).

Ethical Issues

Consent and assent forms were obtained in the local language (Khmer) and sign language. Anonymity was protected by the use of pseudonyms and secure storage of data. The way questions were formulated avoided stigma and focused on systemic rather than individual problems. Ethical clearance was obtained from institutional review boards and Cambodian Ministry of Education. Results will be published in easily accessible forms to the collaborating schools and disability organizations.

FINDINGS

AT Types and Use Patterns

Quantitative Results: It should be noted that there was a clear hierarchy in terms of the AT environment. Hearing aids were the most prevalent ones with the prevalence rate of 89%. These AT types were used by 76% of the participants on the average frequency of 4.1 (SD = 1.0) meaning the use every day. At the same time, the digital AT was much less pervasive: speech-to-text applications (prevalence 61%, use 43%, average 2.8); text-to-speech software (prevalence 54%, use 39%, average 2.6); captioning systems (prevalence 47%, use 31%, average 2.3); visual alerting devices (prevalence 33%, use 24%, average 2.1) and FM systems (availability 19%, use 14%, average 1.9).

Table 1: AT Availability, Personal Use, and Frequency of Use (N=70)

Assistive Technology Type	Available at School (%)	Personally Use (%)	Frequency of Use Mean (SD)
Hearing aids	89	76	4.1
Speech-to-text apps	61	43	2.8
Text-to-speech software	54	39	2.6
Captioning devices	47	31	2.3
Visual alert systems	33	24	2.1
Other (e.g., FM systems)	19	14	1.9

Qualitative Explanations: The availability percentages masked crucial functional deficits. A student in Battambang noted the problem of the ratio of devices to the number of students: *"We have hearing aids for everyone, but only 2 captioning machines for 50 students."* The observations revealed the presence of digital equipment in 67% of sessions but as single copies used by 3-8 students at once. A lack of formal AT training turned out to be a key factor explaining underutilization. Teacher #2 said: "*Teachers showed us once; now students fix each other."* The rating of teacher integration was 2.9 (SD=1.3) and advanced features of AT in 58% of sessions were disregarded. Insufficiency of Khmer language support was a factor never measured before. One of the low-quartile students reported: *"No help in Khmer literature software does not understand tones."* It

seriously limited the meaning of the availability statistics as 'available' meant no longer 'functional for the linguistic context.' The problem was noticed in 60% of transcripts. Integrated Insight: The access to AT in Cambodian special high schools is associated with a basic disjunction between hearing aid use and marginal functionality of digital technologies because of insufficient ratio, training and Khmer incompatibility.

AT Effects on Academic Achievement

Quantitative Results: The impact of AT on academic achievement was moderately positive but varied. Lesson learning got the highest mean score (M=3.8, SD=0.9), while achieving better grades using AT and independent learning assistance had a mean score of (M=3.6, SD=1.0) and (M=3.4, SD=1.1) respectively. Assignments needing AT had the lowest mean score (M=2.7, SD=1.2); hence AT was used additively. Grades showed a distribution pattern with majority getting C (39%), B (24%), A (11%), D (19%), and failing (7%). More importantly, 68% of the respondents experienced an improvement in their grades through AT usage. Moreover, there was a moderate and significant correlation between AT usage and academic achievement (r=0.52, p<0.0).

Table 2: Academic Achievement Perceptions and Grade Distribution (N=70)

Item	Mean (SD) Agreement	% Agreement (≥4)
AT improves lesson understanding	3.8	61
Higher grades with AT use	3.6	54
AT helps independent study	3.4	49
Assignments require AT	2.7	24
Last Term Grade	Percentage	
A	11	
B	24	
C	39	
D	19	
Fail	7	

Qualitative Explanations: High-quartile students gave concrete examples: *"With text-to-speech on word problems, my math went from D to B grades."* The use of AT in mathematics classes was also observed where captioning machines displaying mathematical equations helped in taking notes (4 out of 5 students) and posing questions (3 times in each session). But the impact of AT varied by subjects: *"Captions in science diagrams? Excellent. Without those in history lectures? I can't take notes."* This showed the transformative power of AT in certain subjects and the academic disadvantage when AT is missing in other subjects. An interesting point regarding the teachers' practice was that they *"grade hearing-impaired the same as hearing students. No extra for AT."* While this was supposed to be an equal treatment policy, it put the hearing-impaired students at a disadvantage because of unreliable or absent AT. Integrative Insight: AT can create tangible academic advantages (D to B improvement); however, this advantage is possible only with continuous access to AT, its use with the right subjects and appropriate teaching/evaluation practices.

AT Effects on Classroom Participation

Quantitative Findings: Participation in classroom activities received the highest AT benefits rating. Highest discussion rating with AT use was 3.9 (SD=0.9), followed by contribution with AT use, which rated 3.7 (SD=1.0). Collaboration among peers ranked 3.5 (SD=1.0), while teacher encouragement ranked lowest at 3.1 (SD=1.2). Overall participation composite mean was 3.5 (SD=0.9) with 64% responding positively highest domain.

Table 3: Classroom Participation Perceptions (N=70)

Item	Mean (SD) Agreement	% Agreement (≥4)
Better discussion following with AT	3.9 (0.9)	68
More active contribution with AT	3.7 (1.0)	61
Easier peer collaboration with AT	3.5 (1.0)	57
Teachers encourage AT in lessons	3.1 (1.2)	41

Qualitative Explanations: There is a very clear explanation of the process: *"With live captioning, I participate in class discussions as others do; without them, I would just nod."* It was also observed that captioning increases the number of hand raisings by an average of two contributions per hearing-impaired student per session. Peer grouping, together with AT-supported students, revealed enhanced interaction in 8 of 12 sessions. But there is a *"participation-visibility paradox."* Teachers seemed to support AT usage, but peers responded differently: "*My teachers appreciate my AT usage, but my classmates make fun of me because of my 'robotic' voice due to speech-to-text."* One student said: *"I try to hide my AT because I feel like people stare at me."* The observations proved that AT usage increased participation, but made social visibility, which some of the students felt uncomfortable with. 31% of agreement about discomfort among the peers is a reflection of the actual social pain felt.

Integrated Insight: Technology greatly increases participation in the classroom environment, especially in terms of discussing the topic in real time. But this advantage exists together with social cost, such as peer teasing, feeling of embarrassment, and hiding of technologies.

Issues in Implementation

Quantitative Results: Barriers were high along all dimensions with a composite mean score of 3.8 (SD = 0.7) and 73% high barrier scores. Issues relating to power connectivity had the highest average barrier (M = 4.3, SD = 0.8, 86% agreement). Teacher lack of AT skill was second (M = 4.1, SD = 0.9, 79%). Technical issues were third (M = 3.9, SD = 1.0, 71%) and AT unavailability fourth (M=3.8, SD=1.1, 69%). Peer discomfort scored lowest (M=2.9, SD=1.2, 31%), indicating students viewed systemic/infrastructure barriers as more important than social barriers.

Table 4: Implementation Challenges Perceptions (N=70)

Challenge Item	Mean (SD) Agreement	% Agreement (≥4)
Power/connectivity issues	4.3 (0.8)	86
Teachers lack AT skills	4.1 (0.9)	79
Technical problems with AT	3.9 (1.0)	71
AT often unavailable	3.8 (1.1)	69
Peer discomfort using AT	2.9 (1.2)	31
Biggest Challenge (Open Response)	Percentage	
Power/connectivity	31	
Teacher training	24	
Device maintenance	19	
Availability	17	
Other	9	

Qualitative Explanations: Power/connectivity was confirmed as the primary barrier: *"Devices work for 2 hours then die no backup power."* This barrier was observed 10 out of 12 times (loss of power in 6, technical issues in 4 cases). Comparison of sites confirmed that poorly resourced schools encountered more problems (M=4.4 compared to 3.8 in well-resourced schools). Skills deficits of the teachers did not only manifest themselves as an obstacle, but became a barrier due to prohibition: *"Teachers don't know about apps, so they prohibit their use."* Observations confirmed that 58% of classes did not use advanced functionalities of the ATs. The intertwining nature of barriers was identified: power loss does not allow charging, discourages the teachers to learn the technology and develop the positive attitude, and renders even skilled teachers unable to implement ATs in class. Correlation between the challenges and participation ($r=-0.47$, $p<0.01$) indicated that the implementation barriers directly impaired classroom involvement. Solutions proposed by participants were formulated in terms of the three components agenda: *"Train all teachers monthly; solar chargers; apps that speak Khmer."* Human capacity building, infrastructure development, and linguistic adaption emerged as the result of practical implementation failures.

Integrated Synthesis: The Implementation Ecosystem

The technique of purposive sampling of the survey extremes yielded significant insights into how technology can be effective in determining what matters. Respondents in the high quartile had good access to AT, working software, integration by the teachers, and acceptable social factors nothing in the access-use-comprehension sequence had any difficulty. Respondents in the low quartile, frequently from the same schools, talked about the same technologies in terms of lack of reliability, poor support, academic inadequacy, and social costs every aspect of the sequence blocked. It was the circumstances surrounding the technology that were different for both groups, including charging, teacher expertise, technical support, and social acceptance.

DISCUSSION

Limited and Unequal AT Ecosystem

The result that hearing aids prevailed whereas digital AT was of limited prevalence creates a distinct technological hierarchy at Cambodian special high schools. This hierarchy corresponds to the results of Sphiwe's (2020) research conducted among the deaf in Malawi, who used hearing aids when available and lacked any digital AT. Nevertheless, Cambodian special high schools show better accessibility of hearing aids but similar problems in terms of digital AT implementation.

Qualitative result revealing that digital AT was often available in grossly disproportionate amounts (only two captioning machines for 50 students) proves that the concept of "availability" is misleading in practice. The language incompatibility results undermine it even further—the students were able to use the applications but did not gain any benefit from them due to the linguistic factor. This factor is revealed in 60% of transcripts and shows that it is not an implementation problem but a design requirement that places Cambodian students out of the target audience for the global AT software.

The peer-led training model (teachers showed us once; now students fix each other) reveals a human capacity deficit. Digital AT needs continuous technical and pedagogical support, which Cambodian special education teachers, according to evaluation ratings (teacher integration M=2.9) and interview testimony (teachers ban apps), cannot provide. Usage rankings reflect not student preference but differential support needs hearing aids require minimal ongoing support; digital AT requires institutional capacity currently unavailable.

Implications for Social Model of Disability: This hearing aid hierarchy and low utilization of digital AT is neither an outcome of individual impairments but environmental barriers; inadequate device-to-student ratio, exclusionary software for Khmer language speakers, no training of teachers, and non-sustainable maintenance system respectively. The disability faced by the students is not because of their hearing impairments but due to an educational environment wherein technology has been provided but without its functional availability and support.

AT–Achievement Correlation: Environmental Support and Equal Treatment

The result that 68% of students saw grade improvement due to AT, with moderate correlation (r=0.52), could be considered prima facie evidence of effective use of AT. Qualitative data, however, indicate considerable contingency. Student testimonies like "Science with captions? Perfect. History without? I fail notes" illustrate how AT's effects in academic context vary across disciplines and modes of instruction. Equal grading standards in an environment of unequal access what could be called "the accommodation paradox" poses significant equality challenge. Equal treatment (equal grading standards) in an environment of unequal access (AT provided in some cases and not in others) leads to unequal results. Students are made responsible for comprehension without equal access to tools needed for comprehension. That is why only 24% of students believed that their tasks require AT their tasks are created with assumption that AT is an accommodation rather than necessity. These results are comparable with warnings by Paula et al. (2005) about technological mediation of disability related learning difficulties, but without corresponding educational support. The results by Johnson et al. (2024) about FM systems and captioning are also relevant but Cambodian students have an additional problem of lack of reliable infrastructure.

Implications for UDL: The UDL principle of multiple means of expression provides a good alternative. Rather than having assessments through lectures that assume auditory accessibility on part of the student and thereby creating a problem of accommodation, if there are different forms of showing one's knowledge using signs or visuals or written work through ATs, the issue of accommodation would be reduced.

The Participation-Visibility Paradox

Classroom participation achieved the highest ratings in terms of AT benefits (composite rating 3.5, 64% positive), indicating that AT is indeed an effective form of real-time communication. The qualitative statement "with live captions, I answer questions just like everyone else; previously, I would simply nod" constitutes strong phenomenological evidence of transformation of participation. But there were also accompanying negative social costs: "my classmates make fun of my 'robot voice'" and "I keep my aids hidden to avoid stares." These two realities of AT, on the one hand providing access to participation and, on the other hand, being a stigmatizing tool, these make up the paradox of participation and visibility. The teacher support level (M=3.1) indicates that the social context is far from being as conducive as the effect of the technology itself.

This finding is consistent with the stigma theory by Goffman (1963): AT use puts the rehabilitated status of hearing-impaired students in a position of visibility, and therefore renders accommodation visible. Students would conceal the aids to avoid stares. According to the research conducted by Sibanda and Mhlanga (2024), in a South African setting, some students would rather fail than be seen with visible AT. The consistency in both Southern Africa and Southeast Asia show that peer stigmatization of AT use can be a universal phenomenon in adolescent interactions in areas where disability continues to be stigmatized.

Implications for Social Model and UDL: In the Social Model, peer attitudes become an environmental barrier to be addressed. The issue is not the robot voice but the reaction of peers; not the visible aid but the stigmatizing stare. Multiple means of engagement in UDL imply that the universal design approach of offering AT to all students could de-stigmatize AT.

Ecology of AT Implementation Failure

The most highly rated challenge was power/connectivity issues (M=4.3, 86%) thus giving precedence to system over individual challenges. The significance of such a challenge lies in its placement in terms of the structural nature power and connectivity are preconditions for digital AT use. Not only do their absence lower the performance of AT but make it impossible. Such observations were made in the study: "All devices off after 20 min; class reverted to blackboard." Deficiencies in teacher skill set extending to active prohibition ("teachers ban apps") implies a totally different interpretation of the issue from the passive deficit to an active inhibition. While the former could be solved by means of training, the latter would require changes in attitudes, building up of self-efficacy and accountability. The site comparison reveals the fact that challenges are not equally prevalent but rather occur in under-resourced sites. Lack of infrastructure increases the impact of any other implementation challenges. It is in line with the findings of Lewin (2007), who states that educational inequalities inside a country are usually greater than those between countries.

Implications for Theoretical Models: The Social Model receives unequivocal empirical proof in cases of infrastructure shortage the hearing-impaired students become disabled irrespective of their abilities. Power failure, lack of internet access, and malfunctioning equipment represent insurmountable barriers which cannot be compensated for by any individual accommodation. UDL is subject to material conditions usually taken for granted by theoretical models. When screen readers do not work because of power failure, the idea of multiple means becomes singularly inaccessible.

Synthesis: Ecological Model of AT Implementation

The four themes identified above show an extremely complex network of interdependent constraints. Electricity blackouts break the functionality of computers, preventing measurable educational gains and reducing teachers' incentives to develop necessary skills. That results in social visibility but no normalization, since incompetent educators do not demonstrate how to use AT tools regularly, thus encouraging students not to use these tools

publicly. This is how an ecological system works; it remains stable as a pattern of failure because no single intervention can change existing dynamics.

Out of such an integrative approach comes an ecological approach to AT implementation, viewing sustainable learner outcomes as dependent on the exact match between five interlinked domains: technology has to be designed using locally appropriate Khmer language software with reliable offline capability; infrastructure entails constant energy supply using solar power or generators along with proper connectivity; human capital implies pre-service and in-service training for teachers accompanied with coaching; pedagogical approach involves incorporating UDL principles, allowing for multiple ways of representation, expression and engagement and access-adjusted assessment methods which solve accommodation paradoxes; social norms call for modeling of AT acceptance by teachers, disability education campaigns in schools and universal design approach that eliminates stigma associated with using devices. An issue occurring in any one of these domains will cascade into others, indicating the need for implementation on multiple levels, where AT is considered as an ecosystem rather than just another intervention.

Theoretical Contributions

There are three major theoretical contributions made by this study. First of all, it reinforces and expands the Social Model of Disability in a non-Western resource-poor environment. Environmental barriers like lack of infrastructure, inappropriate software in terms of the language, absence of teacher training, stigmatization on the part of peers disempower the disabled more strongly than impairment itself. The strengths of the model are evident from all the four research questions. Secondly, there are some drawbacks of Universal Design for Learning identified when the preconditions of infrastructure are not in place. Universal Design for Learning presupposes the functioning of technologies, where multiple means of representation and expression can be provided. From the perspective of the Cambodian experience, one may see that some assumptions of the UDL model do not hold true and its implementation requires special consideration of infrastructure needs. Finally, the study proposes an ecological model of AT implementation conceptualizing sustainable outcomes as emerging from alignment across technology design, infrastructure, human capacity, pedagogy, and social norms.

RECOMMENDATIONS

At Policy Level: Sustainability of AT use necessitates a shift of focus at the policy level from device count to functional availability by developing national standards with regular evaluations for operational availability, Khmerization and actual student use. The ministries will have to mandate the localization of the Khmer language, incorporate AT competencies in pre-service teacher education, develop assessment guidelines that solve the accommodation paradox and invest in infrastructure in terms of solar-powered energy and connectivity in the poorly resourced schools.

At School Leadership Level and Teacher/Classroom Level: There is a need for school leadership to create positions of AT coordinators within the schools who will be responsible for inventory, maintenance and support, create local maintenance ecosystem with technicians and spare parts, mandate AT use in planning lessons, and create an inclusive environment using professional learning communities and awareness programs. Teachers should consider practicing AT through professional development, simple UDL approaches (multiple modes and facing students), access adjusted assessment with contingency plans in case of failure, and making AT part of classroom infrastructure while addressing peer teasing constructively and working with coordinators to solve participation-visibility paradox.

Limitations and Future Research

Limitations: Convenience sample limits statistical generalizability. Self-reports on achievement and participation measures suffer from social desirability bias. The cross-sectional study design does not allow for cause-and-effect inferences. Presence of researcher could have induced Hawthorne effects. Even the special high schools are not fully representative of inclusive education.

Future Research: Studies must span the entire educational range of all placements. Collaborative research with Cambodian deaf researchers and community can develop culturally appropriate assessment tools. Longitudinal studies of individual students at non-AT schools will be necessary to determine true impact of AT programs. Early implementation of AT in poor-resource schools would build evidence base for national rollout.

Concluding Reflection

This research started with an intriguing image of a Cambodian class where a hearing-impaired student is challenged within the context of a silent environment where words fly around but do not reach their destination. Results of this analysis clearly indicate that with proper application, assistive technology enables participation by captioning students answering questions alongside other students, improved grades in mathematics from D to B, and collaboration through shared screens. Such positive outcomes can be seen consistently throughout the quantitative trends and qualitative stories suggesting the ability of AT to eliminate access gaps and academic success.

Nevertheless, such accomplishments seem fragile against the background of systematic failures malfunctioning devices, software unable to recognize Khmer linguistic features, underqualified teachers who prohibit the use of helpful apps, and students who conceal the necessary aid to escape stereotyping. The story of the hearing-impaired student goes beyond sound issues towards the problem of institutional failure distributed devices without functional testing, teacher education without AT skills, infrastructure neglecting rural areas, and peer exclusion culture.

The ecological model proposed in this essay reveals that sustainable development needs to have multi-level coordination, including the creation of technology in Khmer localization, provision of infrastructure, training of teachers, adjustment in assessment and awareness at schools to normalize difference. Separate actions such as buying devices or workshops are not enough; sustainable development needs ecosystems which will allow full utilization of AT. It is time for these links of support to be developed by the researchers, policy makers, educators, and communities in Cambodia.

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