



RABSEL: The CERD Educational Journal

ISSN 2957-8019(Online) | ISSN 2077-4966(Print) |26(2) 25-42

Journal homepage: Journal.pce.edu.bt



Assessing the status of ICT integration in Science Education in Secondary Schools

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<http://doi.org/10.17102/rabsel.25.07.1247583>/ Accepted March 2026 | Published June 2026

Abstract

ICT plays an important role in science education by providing real-world experiences and helping students to visualise abstract concepts for better understanding. However, its actual integration in science education remains uncertain, as studies often report of a teacher-centric approach to teaching. This study aimed to assess the status of ICT integration in science education in Bhutanese secondary schools. A concurrent exploratory mixed method design was implemented across 15 secondary schools from four regions of Bhutan, including urban, semi-urban and rural schools. A total of 2,228 students, 63 teachers, and 13 principals participated in the survey, and 12 individual interviews were conducted. The study found that teachers and students hold positive attitudes towards ICT. They demonstrated confidence in using basic tools but showed weak competence with interactive digital tools. While policies exist, the meaningful integration of ICT is constrained by limited availability and access to facilities and resources, minimal teacher preparedness, and insufficient preparation time for teachers. Addressing these limitations and revising policies may help bridge the gap between the current status and the potential of ICT, enabling teachers to implement science curricula more effectively promoting enhanced learning.

Keywords: *Information and Communication Technology, Science education, Facilities and resources, Interactive digital tools, Integration*

Introduction

The integration of Information and Communication Technology (ICT) is increasingly recognised as crucial for enhancing educational outcomes and preparing students for future workplace demands. In secondary schools, particularly in science subjects, ICT has the potential to transform teaching and learning by making abstract and complex concepts easy through use of interactive tools (Dendup et al., 2021; Tenzin et al., 2023).

In Bhutan, the Ministry of Education and Skills Development (MoESD), has been promoting ICT in schools from 2017 onwards through curriculum integration, offering it as a compulsory subject across grade levels and making resources available. As part of a teacher training programme, the teachers are trained in ICT-integrated teaching pedagogies to effectively incorporate ICT tools into their teaching practices. However, the actual integration of ICT in science education is not clear as research reports of teachers' persistent reliance on traditional teaching methods (Tenzin et al., 2023; Utha et al., 2021). This highlights a critical gap in empirical research, hindering informed decision-making. Hence, this study aimed to assess the status of ICT integration in Bhutanese secondary science education, identify existing challenges and gaps, and provide insights to improve integration and enhance science learning outcomes.

Principal question

What is the current status of ICT integration in science education in Bhutan's secondary schools?

Sub questions

1. How well equipped are schools with ICT facilities and resources for effective integration in science education?
2. How accessible are ICT facilities and resources for students and teachers?
3. What are the challenges students and teachers face in integrating ICT into science education?
4. What strategies can be employed to enhance ICT integration in Bhutanese secondary science education?

Literature review

Studies show integration of ICT into teaching and learning has effectively led to student engagement enhancing a student-centered learning environment (Asare et al., 2023; Brophy, 2011). It is also linked to improved learning outcomes (Salas-Pilco & Law, 2018; Tarman & Dev, 2018; Toma et al., 2023), increased success in Physics (Yigit & Akdeniz, 2000), and improved test scores (Weaver, 2000). Especially in science education, the use of simulations has been found to help students understand abstract concepts easily (Sarabando et al., 2016) and

address issues like safety, high costs of materials, and the need for teacher assistants and lab space (Gill et al., 2014; Wieman et al., 2008).

Several countries have made remarkable progress in integrating ICT into their educational systems. The European Union has launched the ‘Digital Education Action Plan,’ which focuses on promoting digital literacy and emphasises the need for tailored strategies that align with local contexts and curriculum goals (European Commission, 2020). The United States’ National Education Technology Plan advocates for using ICT to transform teaching and learning, focusing on personalised learning experiences and making infrastructure available (U.S. Department of Education, 2017).

The effectiveness of ICT integration depends on contextual factors like curriculum alignment, teacher preparedness, and cultural acceptance. Studies emphasise that without adapting ICT initiatives to the local educational context, technology risks being underutilised or misaligned with pedagogical goals (Kozma, 2003; Trucano, 2005). In developing countries, ICT adoption is often influenced by issues of language barriers, relevance of digital content, and the readiness of schools to integrate technology within their existing instructional practices (Kozma & Isaacs, 2011). Moreover, teacher beliefs and attitudes towards ICT play a crucial role in determining the extent to which it is used (Ertmer & Ottenbreit-Leftwich, 2010). Therefore, ICT’s successful integration requires not only infrastructure and policy support but also context-sensitive strategies that address the needs and realities of teachers and students.

There are other challenges with ICT integration in education. A systematic review by Aduwa-Ogiegbaen & Iyamu (2005) identified challenges like limited access, inadequate infrastructure, and teacher resistance to change. Further, the digital divide, remains a critical issue in many developing countries (Pelgrum, 2001), aggravating existing educational inequalities. Teachers are also found to struggle to integrate it effectively. A study shows many educators continue to use traditional teaching methods and adapt technology to fit these methods rather than transforming their approaches (Hernández Camelo et al., 2018). This underlines the need for comprehensive professional development programmes to help teachers utilise ICT in innovative ways to enhance students learning.

Methodology

A concurrent exploratory mixed methods design (Creswell and Creswell, 2018) was implemented using surveys and semi-structured interviews. A total of 15 secondary schools from four regions of Bhutan: East, West, Central, and South participated, including urban, semi-urban

and rural schools to ensure a representative sample. The study deliberately included both boarders and day scholars to ensure a comprehensive understanding of how ICT access and usage may differ across student populations especially outside class hours. A total of 2,228 students from classes VII–XII, 63 teachers, and 13 Principals participated in the survey. Besides, 12 individual interviews were conducted with teachers and students. The survey data were analysed using descriptive statistics including mean and standard deviation (SD). The interviews and survey open-ended questions were analysed using Creswell & Creswell (2018) thematic analysis. Prior approval for the study was sought from all relevant stakeholders. Further, to ensure anonymity, all personal identifiers have been removed. Participant quotations are presented without disclosure of identity, and schools are referred to as S01, S02, etc.

Result

The results consist of the demographic information, followed by the thematic findings. The mean and SD are interpreted using the scale of Zangmo et al. (2016).

Demography

A total of 23.8% of schools were from urban settings, 60.3% from semi-urban, and 15.9% from rural locations. It is worth noting that while some schools are categorised as semi-urban, participants indicated that the environment resembled a more rural setting, suggesting that contextual factors may influence the perception of the setting. Altogether, 1257 students (56.4%) are boarders and 971 (43.6%) are day scholars.

Thematic findings

ICT facilities and resources

The data were analysed on the availability of ICT resources in the schools and in the classrooms and are presented sequentially.

ICT facilities and resources in the schools

The data pertaining to the schools were collected from the principals and is presented in Table 1.

Table 1

ICT facilities and resources available in the school

School	Location	Functional ICT facilities							Internet	
		D	P	STV	SB	Pr	S	Pcr	Connectivity	Speed (Mbps)
S01	Urban	80	19	15	0	5	2	2	Wireless	40
S02	Semi-urban	40	3	3	0	3	2	0	Digital subscriber	7

									line	
S03	Semi-urban	103	10	4	10	5	5	1	Wireless	70
S04	Semi-urban	90	30	0	0	13	0	1	Wireless	49
S05	Rural	58	8	4	3	6	0	5	Wireless	60
S06	Semi-urban	103	10	1	0	6	0	2	Wireless	33
S07	Rural	41	9	0	0	5	0	1	Wireless	72
S08	Semi-urban	78	26	2	0	4	3	3	Wireless	74.8
S09	Rural	31	15	2	0	3	0	2	Wireless	7.8
S10	Urban	113	35	44	5	6	0	1	Wireless	30
S11	Urban	60	15	27	0	4	2	0	Wireless	25
S12	Rural	89	18	0	0	6	5	3	Wireless	89
S13	Semi-urban	30	4	10	0	5	1	2	Wireless	10

Note: D-Desktop; P-Projector; STV-Smart TV; SB-Smart Board; Pr-Printer; S-Scanner; Pcr-Photocopier

Table 1 highlights clear differences in ICT facilities and resources across urban, semi-urban, and rural schools. Urban schools had the highest numbers of devices. But they also reported high student numbers. Semi-urban schools had moderate provision, while rural schools had fewer resources.

Most principals reported that students generally do not have access to printers, photocopiers, or scanners, even when available. Nearly all teachers had personal laptops, ensuring some access for instructional purposes. While all schools reported that electricity and internet were available ‘most of the time’, indicating generally reliable conditions for ICT use, internet speeds varied widely from 7- 89 Mbps. Many students expressed the need to increase the number of computers in the school as well as the internet speed. A student shared:

We have more theory than practical. We don't get any internet facilities to use smartphones in school that's why we fail to develop our mental knowledge. We need our educational system to focus on ICT because we can't lack to fall behind other countries.

Teachers also highlighted shortages of devices. A teacher observed, ‘At least every classroom

from PP–XII should have one projector to make lively teaching and learning in the class without changing or exchanging classes.’

ICT facilities in the classroom

The availability of ICT facilities in the classrooms provides the foundation for ICT-supported teaching and learning. Students’ views on the availability are presented in Table 2.

Table 2

ICT facilities and resources available in the classroom

ICT facilities in the classroom	Yes (%)	No (%)
My classroom has internet connectivity	43.04	56.96
My classroom has smart TV	32.23	67.77
My classroom has a projector	59.43	40.57
My classroom has an interactive board	41.29	58.71

Table 2 shows that ICT facilities in classrooms were unevenly distributed. Projectors were the most widely available, while internet connectivity, smart TVs, and interactive boards were present in fewer classrooms. This indicated that students’ exposure to ICT varied considerably. In the interviews, students reported that when ICT was available, it made science learning more interactive and accessible. They particularly valued simulations, 3D models, virtual labs, and videos to understand abstract or complex concepts in science. A student shared, ‘Doing simulation on every topic helps us visualise concepts we cannot perform physically.’ Another said, ‘ICT integration in learning science subjects is a game-changer... I can explore chemical reactions safely on a screen or understand how the human body works using 3D models.’ At the same time, students highlighted the importance of teacher preparedness for ICT integration. They felt that training and competence were essential to ensure ICT was applied in engaging and meaningful ways. A student said, ‘‘Although ICT is integral for the future, it is not taught in a way that is engaging and fun... Competent teacher training and practical integration would boost its impact.’

Both students and teachers expressed challenges in accessing ICT labs as they were frequently occupied for ICT subject periods. A teacher explained, ‘the major issue with using ICT in schools is the difficulty of accessing the ICT lab since it is mostly used for ICT periods.’ Also, internet connectivity was available in some schools, but students were not permitted to use their devices. Teachers suggested allowing students to bring their own devices.

Access to ICT facilities and support

Access is examined first from students’ perspective during class hours, then after class hours for boarders and day scholars, and finally from teachers’ perspective. Table 3 illustrates students’ access to ICT resources and support during class hours.

Table 3

Students access to ICT facilities and support

Students' access to ICT facilities and support	Never %	Sometimes %	Often %	Always %
I have access to IT lab	1.35	48.56	23.74	26.35
IT lab Assistant guides me when I need help	1.35	23.20	13.20	62.25
I search information in IT lab	1.57	48.65	21.68	21.68
I use mobile phone in the class for learning	68.49	23.65	4.89	2.96
I have access to photocopy and printer	19.88	48.34	18.72	13.06

Table 3 illustrates that during class hours, most students at least have occasional access to ICT labs, though guidance from lab assistants was consistently available. However, fewer students reported using the lab to search for information independently. Also, *access* to personal devices was minimal.

The access of ICT facilities after class hours according to residency is presented in Table 4.

Table 4

Access to ICT facilities by residential status

Access to ICT facilities by residential status	Boarder		Day Scholar	
	Yes %	No %	Yes %	No %
I have access to the internet for learning after class hours	12	88	85.7	14.3
I have access to laptop/computer for learning after class hours	7.4	92.6	40.1	59.9
I have access to smart phone for learning after class hours	11	89	91	9

Day scholars had greater access to ICT facilities outside class (see Table 4). Only a small proportion did not have access to smartphones (9%) and internet (14.3%). In contrast, boarders reported very limited access to devices and internet, highlighting constraints for independent, technology-supported learning outside class. In the interviews, students emphasised the

importance of access to ICT tools and reliable internet for exploration, research, and project work. Boarders particularly expressed the potential benefits of access to ICT facilities outside class. A student shared, ‘boarder students need access to the internet to explore science subjects online... what if especially class 12 students at the hostel could get phones daily to enhance their learning.’ Further, they suggested to keep ICT labs open during weekends and making more devices available in classrooms, to support learning.

Teachers access to ICT facilities in the school is as shown in Table 5.

Table 5

Teachers access to ICT facilities

Teachers access to ICT facilities	Never %	Sometimes %	Often %	Always %
I have access to internet.	0.00	4.76	23.81	71.43
I have easy access to computer lab.	14.29	38.10	23.81	23.81
I have access to photocopy and printer for preparing resource materials.	7.94	41.27	31.75	19.05
I have internet connectivity in the class to support my teaching	41.27	12.70	25.40	20.63
My students have internet connectivity in the class to support their learning	14.29	19.05	11.11	14.29

Table 5 shows that most teachers always had access to the internet, but access to it in class was limited. Use of computer labs and photocopy/printing resources was inconsistent, with many teachers reporting only occasional availability. These limitations make it difficult for teachers to integrate technology effectively. One teacher explained, ‘Overall, while teachers can access some ICT resources outside the classroom, the lack of reliable facilities in-class hinder technology-supported teaching and learning.’

Although curriculum materials include hyperlinks, videos, and interactive worksheets, the lack of well-equipped classrooms with sufficient computers and reliable internet hinders their effective implementation. A teacher stated:

While the national curriculum framework, instructional guides, and all the lesson plans sent by the Ministry have lots of hyperlinks, video lessons, and worksheets which are so interactive and good, we do need a well-furnished classroom full of computers and good internet connectivity. Without such facilities, it hinders the application of such activities.

Teachers’ practices and comfort with ICT in science teaching

Table 6 presents the teachers’ use of ICT in teaching, including their comfort, instructional practices, and its effect on student learning.

Table 6

Teachers’ ICT use and practices in science teaching

Items	Mean	SD	Level of opinion
I use lecture method	3.25	1.02	Moderate
Teaching and learning materials are easily available	3.47	0.95	Moderate
I use videos to teach	4.11	1.04	High
I make my lesson interactive using ICT	4.02	1.14	High
I get time to prepare interactive lesson using ICT	3.25	1.05	Moderate
I am comfortable to use technology to teach	4.13	0.95	High
Students enjoy learning with ICT tools and apps	4.33	0.78	High
Use of online tools enhance students' performance	4.31	0.87	High
Use of ICT helps students understand concept	4.32	0.86	High
I assess students' work using online ICT tools	3.66	1.05	High
Average mean	3.89	0.97	High

Table 6 shows that teachers generally hold positive views on ICT use in science teaching.

Except for items on the availability of sufficient time to prepare ICT integrated lessons, availability of teaching materials, and reliance on the lecture method, which were rated moderate, all the rest were rated high. In the interviews, teachers acknowledged ICT’s potential to improve science teaching through interactive lessons, rapid assessments, and immediate feedback. However, practical constraints, including limited resources and connectivity issues, restricted consistent implementation. For example, a teacher commented, ‘We are instructed to [integrate ICT] but we hardly get the resources.’

Students and teachers’ ICT competencies

The findings on the students ICT competencies are presented in Table 7.

Table 7

Students’ ICT competency

Items	Mean	SD	Level of opinion
I can use Microsoft word competently	2.95	0.51	Moderate
I can use Microsoft Excel competently	2.84	0.58	Moderate
I can use Power Point competently	3.12	0.55	Moderate

I can use Simulation competently	2.53	0.64	Moderate
I can code using coding software (Turtle, Scratch, code monkey) competently	2.99	0.58	Moderate
I can easily search for information on the internet	3.36	0.65	Moderate
Average	2.96	0.58	Moderate

Students demonstrated a moderate level of ICT competency (Table 7) with almost consistent responses. They reported higher proficiency in internet searching and PowerPoint use, while competencies in the use of simulations were on the lower side of moderate. In the interviews also, students expressed the need for more focused training in ICT skills like coding, highlighting the challenges of limited ICT class hours:

Teachers were asked to rate their competence in using devices and applications, assuming that those who are competent would naturally use them in class to support teaching.

Table 8

Teachers' use of ICT devices, features and Apps to support teaching

ICT devices & features teacher use to support teaching	Yes%	No%	Apps teacher use to support teaching	Yes%	No%
Laptop	96.83	3.17	Google classroom	63.49	36.51
Smart TV	53.97	46.03	Google doc	79.37	20.63
Smart board	23.81	76.19	Google drive	82.54	17.46
Projector	85.71	14.29	Google form	79.37	20.63
Desktop	25.40	74.60	Microsoft word	98.41	1.59
Tablet	17.46	82.54	Microsoft excel	90.48	9.52
Printer	79.37	20.63	Geogebra	12.70	87.30
Photocopier]	60.32	39.68	PPT	96.83	3.17
Smartphones]	88.89	11.11	Padlet	26.98	73.02
Audio Player	68.25	31.75	Jamboard	20.63	23.81
Hyperlinks	76.19	23.81	Kahoot	33.33	66.67
Web links	74.60	25.40	Slido	33.33	66.67
Simulation	87.30	12.70	Poll everywhere	38.10	61.90

Table 8 shows high use of laptops, projectors, smartphones, printers, and photocopiers, while smart boards, desktops, and tablets were less common. Basic tools such as Microsoft Word, Excel, PowerPoint, and Google Docs/Drive/Forms were widely used, whereas interactive applications like Padlet, Jamboard, Kahoot, Slido, Poll Everywhere, and GeoGebra saw limited

uptake. This indicates a reliance on conventional ICT tools for lesson delivery. In the interviews, teachers reported limitations in access and infrastructure as barriers to effective ICT use. A teacher shared, ‘Although the teachers may be very familiar with the ICT knowledge and implementation process, the main drawback is seen in the limited availability of resources which somehow cripples the result halfway.’ Some teachers reported acquiring ICT skills through self-directed learning, noting confidence in using devices and applications. A teacher shared, “I mostly learned about ICT through YouTube and have not received any formal training in the field yet.”

Professional development for teachers

Table 9 illustrate the number of teachers trained to integrate ICT pedagogy in each school.

Table 9

Teachers trained to integrate ICT pedagogy

School	Total number of science teachers	No. of science teachers trained to integrate ICT pedagogy
S01	14	10
S02	3	2
S03	3	0
S04	9	1
S05	5	5
S06	12	0
S07	4	1
S08	6	1
S09	3	0
S10	9	2
S11	11	0
S12	6	1
S13	3	2

Table 9 shows that the number of teachers trained to integrate ICT pedagogy is generally low and unevenly distributed. This indicates that, overall, formal ICT training among science teachers remains limited.

Teachers’ participation in ICT-focused professional development (PD) in terms of number and hours attended across 2022 and 2023 is presented in Table 10.

Table 10

ICT focused professional development

No. of ICT focused PDs attended	In 2022 (%)	In 2023 (%)	Hours of focused attended	ICT PDs In 2022 (%)	In 2023 (%)
1	73	73	1 to 10	87.3	93.7
2	14.3	11.1	11 to 20	7.9	4.8
3	7.9	9.5	21 to 30	3.2	0
4	1.6	1.6	31 to 40	0	0
5	1.6	3.2	41 to 50	0	0
6-8	0	0	51 to 60	1.6	0
9	0	0	61 to 70	0	0
10	1.6	1.6	71 to 80	0	0
> 10	0	0	> 80	0	1.6

In 2022 and 2023, the majority of teachers attended only a single ICT-focused PD session, with participation dropping sharply after two sessions. The duration of PDs was also predominantly short, with most teachers engaging in sessions lasting only 1–10 hours. Only a very small proportion (1.6%) reported completing more than 80 hours of PD in 2023. These findings are consistent with teachers’ own reflections. While acknowledging the value of ICT-related training, they emphasised the need for sustained and unbiased programmes. One teacher noted, ‘Good idea, if there is a PD programme to enhance and update the teachers on ICT it will be better.’ Another added, ‘More PD is needed in this area, without biases.’ Such views highlight that although teachers are motivated, the lack of systematic and comprehensive PD opportunities continues to limit effective ICT integration.

Policy Support for ICT Integration

Except for S06 and S11, other principals reported the existence of MoESD policies regarding the use of ICT resources and the teaching of ICT as a compulsory subject. These policies provide a framework to support the integration of ICT in teaching and learning, including in science subjects. Most schools reportedly follow the Ministry’s guidelines for ICT implementation, and ICT teachers are generally aware of the policies. These suggest that formal policy frameworks for ICT integration exist in nearly all schools and are generally known to relevant staff, providing a structural basis to support ICT in science instruction.

Teachers’ survey responses further reflect these findings (Table 11).

Table 11

Teachers’ views on the existence and awareness of ICT policies

Items	Mean	SD	Level of opinion
There is a school policy to monitor and evaluate students and teachers use of ICT in Curriculum implementation	2.68	0.78	Moderate
There is a policy issued by the MoESD on the use of ICT resources in the school	2.86	0.64	Moderate
There is a policy issued by the MoESD to teach ICT as a subject to the students	3.19	0.69	Moderate
The school follows guidelines issued by MoESD to implement ICT	3.19	0.53	Moderate
The ICT teachers are aware of the policy on ICT implementation	3.25	0.54	Moderate
Average mean	3.03	0.64	Moderate

Table 11 shows a moderate perception of the presence and implementation of ICT policies and guidelines among teachers. The lowest mean was for the presence of a school policy to monitor and evaluate ICT use, suggesting this area is the least effectively implemented. Conversely, the highest mean (3.25) reflects that ICT teachers are relatively aware of the policies governing ICT implementation. Teachers also highlighted policy-related barriers to ICT integration in science teaching. Many felt that current policies are unrealistic without adequate resources. A recurring concern was the need to permit student devices or the Ministry to provide enough computers and internet connectivity in schools. Teachers further called for clearer guidelines and stronger infrastructure to support ICT-based instructional materials, particularly in science lessons where practical and interactive tools are needed.

Discussion

The themes presented in this section correspond with those presented in the result section.

ICT facilities in schools and classrooms: The study highlights clear disparities in ICT facilities and resources across urban, semi-urban, and rural schools. While all schools reported having IT labs, urban schools were comparatively better resourced whereas semi-urban and rural schools had fewer facilities highlighting unequal provision of ICT infrastructure.

At the classroom level, projectors were relatively common, but internet connectivity, smart TVs, and interactive boards remained scarce, particularly in rural schools. Most teachers had personal laptops, but they had limited access to other devices, restricting opportunities for ICT-based tasks and resource preparation. Large class sizes in urban schools further reduced per-student

access and limited the benefits of available resources. Despite these challenges, both teachers and students acknowledged the value of ICT in enhancing science learning. This is in line with other literatures (Sarabando et al., 2016; Yigit & Akdeniz, 2000).

Access to ICT facilities and support: During class hours, most students reported at least occasional access to ICT labs, with guidance from lab assistants consistently available. However, independent use for searching information was limited, and mobile phone use in class was almost non-existent due to school restrictions. Access to supplementary resources such as printing and photocopying was available but uneven. These findings illustrate that access alone does not guarantee meaningful engagement with ICT, even when infrastructure exists (Aduwa-Ogiegbaen & Iyamu, 2005; Selwyn, 2011). The study also shows that ICT labs were often difficult to access outside ICT-specific periods further constraining students' opportunities for independent learning.

Access to ICT outside class hours differed notably by residential status. Day scholars generally had better access but boarders experienced significant limitations, which constrained their ability to engage in independent, technology-supported learning. Students across both groups emphasised that reliable ICT access is essential for exploration, research, and project-based work. Boarders, in particular, highlighted the benefits of access to devices and suggested measures such as keeping ICT labs open during weekends and increasing the number of devices in classrooms to support learning which corroborates with other studies (Salas-Pilco & Law, 2018; Tarman & Dev, 2018).

Almost all the teachers had access to laptops and reliable internet connectivity in classrooms but students' limited access constrained the full integration of technology into lessons. Even though the curriculum materials included interactive content such as hyperlinks, videos, and worksheets, these resources were underutilised due to limitations in facilities and resources.

Teachers' practices and comfort with ICT in science teaching: Teachers are generally confident in using ICT and recognised its potential to enhance student engagement, understanding, and performance aligning with prior research showing that ICT can improve comprehension of complex scientific concepts (Asare et al., 2023; Sarabando et al., 2016). However, the actual integration varied across teachers. This was attributed mainly to several practical constraints such as limited lesson preparation time, insufficient access to devices, and unreliable internet connectivity which ultimately made teachers to rely on lecture methods. These findings highlight that for effective ICT integration in science lessons, teachers' knowledge and confidence in using ICT alone is not sufficient. It must be supported by adequate infrastructure, access to devices, and adequate time for preparation to transform confidence into

meaningful, student-centred science education (Hernández Camelo et al., 2018; Salas-Pilco & Law, 2018; Wieman et al., 2008). Supporting teachers in overcoming these limitations is essential for maximising the benefits of ICT use in science education.

Students and teachers' ICT competencies: Students possess moderate ICT competencies with the ability to manage general ICT tasks. However, their ability to use interactive digital tools relevant for science learning is limited, reflecting restricted hands-on exposure in classrooms and ICT lessons. This aligns with other studies where students often demonstrated confidence in basic applications but struggled with domain-specific technologies essential for science education (Sarabando et al., 2016). The results suggest that targeted support and practice in simulations, coding, and other interactive tools are necessary to enhance students' capacity for ICT-supported learning. Teachers also demonstrated confidence in using conventional ICT tools and common software applications, but the use of interactive digital tools was limited. This suggests that technical competence alone does not ensure effective ICT integration, particularly when exposure to interactive tools is constrained (European Commission, 2020; Hernández Camelo et al., 2018). Limited adoption of interactive tools may also contribute to gaps in students' ICT skills, highlighting the importance of teacher preparedness.

Professional development for teachers: Teachers received limited PD to support the integration of ICT into teaching, which constrains their ability to create interactive and student-centred learning experiences. This finding is consistent with prior research (Aduwa-Ogiegbaen & Iyamu, 2005; Hernández Camelo et al., 2018; Tshewang, 2019), where inadequate PD is found to prevent teachers from translating ICT competence into effective classroom practice. Without adequate PD, disparities in teacher preparedness may reinforce uneven ICT integration and limit the potential of technology to enhance science education (Asare et al., 2023). Further, it may lead to even available ICT resources to being underutilised, limiting the potential of technology to enhance science learning.

Policy support for ICT integration: While ICT policies exist in almost all schools, their implementation is uneven, particularly regarding school-level monitoring and resource provision. Teachers' and students concern about limited ICT facilities and resources, and restrictive guidelines on use of mobile phones by students in class, suggest that policies and school regulations may have to be revisited for effective ICT integration in science classrooms where practical and interactive tools are essential. The Bhutan Education Blueprint 2014-2024 (MoE, 2014), also emphasises teachers to use ICT in teaching, highlighting a gap between policy directives and practical support. Literature shows that supportive policy frameworks, combined

with infrastructure and teacher training, are critical for realizing ICT's potential to enhance engagement and learning outcomes (Asare et al., 2023; Brophy, 2011; Tarman & Dev, 2018).

Conclusion

Teachers and students hold positive attitudes towards the use of ICT to enhance science education. They display a good level of competence in basic applications but show weaker competencies in the use of interactive digital tools that are critical for enhancing science education. The meaningful integration of ICT into science education is constrained by limited availability and access to facilities and resources, minimal teacher preparedness, insufficient preparation time and policies that are not aligned such as students access to devices. These findings reveal that while policies and general competencies exist, the current status of ICT integration in science education is shaped by both infrastructural and resource limitations. Addressing these limitations through alignment of resources, teacher capacity building, and policy revision may bridge the gap between the current status and the potential of ICT, enabling teachers to implement science curricula more effectively and enhance students learning. This study recommends education systems to prioritise availability and access to ICT facilities and resources for science learning. The study also urges sustained teacher PD programmes focusing on both technical competencies and pedagogical strategies to enable innovative and interactive teaching practices. Future research could explore the long-term impact of interactive digital tools on students' conceptual understanding and inquiry skills in science education.

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