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WORLD GREEN SCIENCE DAY 超选 Fine Selected AROST Andean Road Countries for Science & Technology unesco International Green Science Academy Network 2024 • 2033 International Decade of Sciences for Sustainable Development UNIVERSIDAD PRIVADA DEL VALLE BOLIVIA

Journal of Latin American Sciences and Culture (JLASC)

JLASC promotes the Science Culture Construction (SCC), and the exchange of knowledge. It fosters the sharing of information that echoes on the construction of a community of shared future for mankind.

JLASC is open to the world. It crosses the geographic, cultural and linguistic barriers. Popularizing science can contribute to the development of society and improve the well-being and well living of people in harmony with nature.

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Journal of Latin American Sciences and Culture (JLASC)

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Aims and Scope

Introduction

The Journal of Latin American Sciences and Culture (JLASC) is an international journal seeking to promote the scientific landscape in Latin America by pushing conventional boundaries to include issues, perspectives, and methods relevant to education, science, technology, and culture. JLASC thus intends to truly internationalize these areas through the journal's attention globally.

JLASC seeks to explore not only the diversity and richness of Latin American scientific issues, but perspectives, research methods, and evidence of the many creative flows of influence that exist between Latin America, Sino-American cultures, and other peripheries, therefore, education, science, technology can be powered by wide-ranging ideas from many cultures and research areas.

JLASC welcomes submissions that focus on empirical research, theoretical analyses, or literature and book reviews. Proposals for special issues are actively encouraged and should be discussed with the Editor-in-Chief or a member of the Senior Editorial Team of the journal.

The JLASC promotes scientific literacy, the popularization of science, science popularization, media and information literacy (MIL) following the guidelines UNESCO. The JLASC also promotes the exchange of knowledge and the dissemination of information for the development of society in science, technology, innovation, education, culture. Special attention is given to the use promotion of Spanish for these purposes, as the Cervantes Institute is one of our collaborators. We also count on the support of Chaoxuan Intelligent Research Institute and Elektro High Tech Co. Ltd for the promotion of Science and Technology advances that can be beneficial for the world.

Editorial Policies (Part One)

JLASC is a peer-reviewed journal published in English, Spanish and Chinese by Universidad Privada del Valle (UNIVALLE), Bolivia. The journal only publishes manuscripts that meet the world class-standards of global academic publications. These must follow the guidelines provided on the website in the instructions for authors.

Those submissions deemed by the Editor-in-Chief and the Senior Editorial Team to be of the world-class will be published regardless of authors' ability to pay the Article Publication Charges (APCs), which are US$600/£460/€530. Waivers for APCs can be requested by all authors regardless of background and will be appraised by the Publisher and the Editors based on individual circumstances and the ability to pay. Those who are truly unable to afford the APCs will receive full waivers. This includes many Latin Americans, as well as graduate students, independent researchers, and researchers from around the globe who do not have grants or other funds to cover publication costs.

Authors submit their manuscripts through the UNIVALLE website, Website Customization by: OpenJournalSystems.com (journal homepage: www.journalasc.org and submission site: www.revistas.univalle.edu), and receive an acknowledgment

of submission. The Editorial Team assesses the manuscript and the author is notified that the manuscript has either been rejected or that it is to be sent out for double blind external review.

Peer Review Policy

All submitted manuscripts are subject to initial appraisal by the Editors, and if found suitable for further consideration, to peer review by independent, anonymous expert referees. The Editors are supported by an active Editorial Board and an International Advisory Board. All refereeing is double blind. Submissions can be made online at: editorial@journalsac.org

Publishing Ethics

The Journal adheres to the world class standards of publishing ethics, with rigorous

processes in place to ensure this is achieved. Our publisher, Universidad Privada del Valle utilizes CrossCheck for all Journals. More information on our ethical standards and policies can be found in www.journalasc.org.

Read the Instructions for Authors for information on how to submit your article in https://journalsac.org/author-instructions/

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- Scopus
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Editorial Policy's (Part Two)

About this topic

The following policies apply to the Journal of Latin American Sciences and Culture (JLASC). Where the journal is hosted at Universidad Privada del Valle (UNIVALLE) on behalf the Andean Road Countries for Sciences and Technology. Please read these policies in full before submitting your article, to ensure you've correctly followed all the requirements.

Affiliations

You and your co-authors must list all relevant affiliations to attribute where the research or scholarly work was approved and/or supported and/or conducted. For non-research articles, you must list your current institutional affiliation. If you have moved to a different institution before the article has been published, you should list the affiliation where the work was conducted, and include a note to state your current affiliation. If you do not have a current relevant institutional affiliation, you should state your independent status.

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The Journal of Latin American Sciences and Culture follows the Committee on

Publication Ethics (COPE) guidelines on appeals to journal editor decisions and complaints about a journal's editorial management of the peer-review process. We welcome genuine appeals to editor decisions. However, you will need to provide strong evidence or new data/information in response to the editor's and reviewers' comments. Where you, as an author, wish to comment on aspects of the journal's editorial management please contact us at: editorial@journalasc.org

Authorship

Listing authors' names on an article is an important mechanism to give credit to those who have significantly contributed to the work. It also ensures transparency for those who are responsible for the integrity of the content. Authors listed on an article must meet all of the following criteria:

- Made a significant contribution to the work reported, whether that's in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas.
- Have drafted or written, or substantially revised or critically reviewed the article.
- Have agreed on the journal to which the article will be submitted.
- Reviewed and agreed on all versions of the article before submission, during revision, the final version accepted for publication, and any significant changes introduced at the proofing stage.
- Agree to take responsibility and be accountable for the contents of the article and to share responsibility to resolve any questions raised about the accuracy or integrity of the published work.

The journal editor will not decide on order of authorship and cannot arbitrate authorship disputes. Where unresolved disputes between the authors arise, the institution(s) where the work was performed will be asked to investigate. Consider details such as:

- Corresponding authors
- Changes in authorship
- Assistance from scientific, medical, technical writers or translators
- Assistance with experiments and data analysis
- Acknowledgments
- Author name change policy

Citations

Research and non-research articles must cite relevant, timely, and verified literature (peer-reviewed, where appropriate) to support any claims made in the article. You must avoid excessive and inappropriate self-citation or prearrangements among author groups to inappropriately cite each other's work, as this can be considered a form of misconduct called citation manipulation. If you're the author of a non-research article (e.g. a Review, Opinion, etc) you should ensure the references you cite are relevant and provide a fair and balanced overview of the current state of research or scholarly work on the topic. Your references should not be unfairly biased towards a particular research group, organization or journal. If you are unsure about whether to cite a source you should contact the journal editorial office for advice.

Competing interests

You and all of your co-authors must declare any competing interests relevant to, or which can be perceived to be relevant to the article. A competing interest can occur where you (or your employer, sponsor or family/friends) have a financial, commercial, legal, or professional relationship with other organizations, or with the people working with them which could influence the research or interpretation of the results. Competing interests can be financial or non-financial in nature. To ensure transparency, you must also declare any associations which can be perceived by others as a competing interest.

Corrections, expressions of concern, and retractions

Sometimes after an article has been published it may be necessary to make a change to the Version of Record (VoR). This will be done after careful consideration by the Editor who is also supported by Universidad Privada del Valle

(UNIVALLE) and the Andean Road Countries for Science and Technology to ensure any necessary changes are done in accordance with guidance from the Committee on Publication Ethics (COPE). Any necessary changes will be accompanied with a post-publication notice which will be permanently linked to the original article. This can be in the form of a Correction notice, an Expression of Concern, a Retraction and in rare circumstances a Removal. The purpose of this mechanism of making changes which are permanent and transparent is to ensure the integrity of the scholarly record. Read our full policy on corrections, retractions, and updates to published articles.

Data availability and deposition

Universidad Privada del Valle (UNIVALLE) supports a number of open data initiatives and offers a suite of data-sharing policies. Contact us at: editorial@journalasc.org

Data Repositories

A data repository is a storage space for researchers to deposit data sets associated with their research. And if you're an author seeking to comply with a journal data sharing policy, you'll need to identify a suitable repository for your data. Read our guide to choosing a data repository which includes some generalist repositories you may wish to consider.

Community-endorsed public repositories

Where community-endorsed mandates exist for submission of data to public repositories, authors should submit the datasets to the appropriate repositories and provide the accession numbers (where available) in the paper. Examples of repositories community-endorsed public repositories include:

Data Type	Suggested Repositories
DNA and RNA sequences	GenBank
	EMBL Nucleotide Sequence Database (ENA)
Gene expression	Gene Expression Omnibus (GEO)
	ArrayExpress
Genetic polymorphisms	dbSNP (NCBI)
	dbVar (NCBI)
	European Variation Archive (EVA)
Linked genotype and phenotype data	dbGaP (NCBI)
	European Genome-Phenome Archive (EGA)
Protein sequences	UniProt
Proteomics data	PRIDE
	PeptideAtlas
Metabolomics data	Metabolomics Workbench
3-D printable models	NIH 3D Print Exchange
Neuroimaging data	OpenNeuro
	NeuroVault
Macromolecular structures	Biological Magnetic Resonance Data Bank (BMRB)
	Electron Microscopy Data Resource (EMDB)
	Worldwide Protein Data Bank (wwPDB)
	RCSB Protein Data Bank (PDB)
Crystallographic data	Cambridge Crystallographic Data Centre (CCDC)
	Crystallography Open Database (COD)
Earth and environmental science data	PANGAEA
	NERC Data Centres
	World Data Center for Climate (WDCC)
	Knowledge Network for Biocomplexity (KNB)
	EarthChem
High Energy Physics Data	HEPData
Archaeology Data	Archaeology Data Service (ADS)
Paleontology Data	Paleobiology Database
Humanities outputs	CORE (Humanities Commons)

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To enable full assessment of submissions, you must make available on request to Editors and/or reviewers any custom computer codes, software tools, or algorithms which have been used to generate the results and conclusions that are reported in your manuscript.

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Editor Code of Conduct

Universidad Privada del Valle (UNIVALLE) group's journal program provides a home for validated, trusted research from the world's brightest and best minds. The editor of a journal plays a vital role in advancing knowledge within fields of research. They do this by:

- Maintaining and improving the quality of work the journal publishes and the integrity of its peer review process,
- Supporting the journal's authors and reviewers,
- Maintaining and improving the journal's reputation in collaboration with the journal's wider editorial team and Universidad Privada del Valle (UNIVALLE).

To support this role, our Editor Code of Conduct sets out the minimum standards for all editors who have responsibility for decisions on journal content to help ensure our journals publish quality, trustworthy content.

Harassment

Universidad Privada del Valle (UNIVALLE) will not tolerate any kind of harassment of our authors, editors, reviewers, staff, or vendors. We expect to work in an environment of mutual respect and will work with the Universidad Privada del Valle (UNIVALLE) ethics team and legal team to deal with any cases of harassment. Advice for researchers experiencing harassment: As a researcher, you should expect your work to be scrutinized by the public, policy makers, and campaigners. However, some researchers working on high-profile subjects that attract controversy have also found themselves targeted with online harassment. To help researchers dealing with these issues, Universidad Privada del Valle (UNIVALLE) has supported the Science Media Centre in producing an updated guide, including tips on how to deal with social media harassment.

Images and figures

Authors should only use images and figures in your article if they are relevant and valuable to the work reported. Please refrain from adding content of this type which is purely illustrative and does not add value to the scholarly work.

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As a warranty in the Journal Author Publishing Agreement you make with us, you must obtain the necessary written permission to include material in your article that is owned and held in copyright by a third party, including – but not limited to – any proprietary text, illustration, table, or other material, including data, audio, video, film stills, screenshots, musical notation, and any supplemental material.

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Content (e.g. photographs, video or audio recordings, 3D models, illustrations, etc) which can reveal the identity of patients, study participants or study subjects can only be

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Misconduct

Universidad Privada del Valle (UNIVALLE) takes all forms of misconduct seriously and will take all necessary action, in accordance with COPE guidelines, to protect the integrity of the scholarly record. Examples of misconduct include (but are not limited to):

- Affiliation misrepresentation
- Breaches in copyright/use of third-party material without appropriate permissions
- Citation manipulation
- Duplicate submission/publication
- "Ethics dumping"
- Image or data manipulation/fabrication
- Peer review manipulation
- Plagiarism
- Text-recycling/self-plagiarism
- Undisclosed competing interests
- Unethical research

Peer review

Articles published in Universidad Privada del Valle (UNIVALLE) journals (including its imprints) undergo thorough peer review and the *Journal of Latin American Sciences and Culture* (JLASC) endorses COPE guidelines for reviewers. Journals may operate different peer review processes. Our guide to understanding peer review outlines several different peer review models, including:

- Single-anonymous peer review (also called 'single-blind peer review')
- Double-anonymous peer review (also called 'double-blind peer review')
- Open peer review

Registered Reports

Every Universidad Privada del Valle (UNIVALLE) journal publishes a statement describing the model of peer review used by the journal within the journal homepage. Generally, comments from a minimum of two independent experts are required to ensure complete assessment of the article. The details of the comments as well as the overall recommendations by peer reviewers will be considered by the Editor when making a decision, but ultimate responsibility for acceptance or rejection lies with the Editor. In accordance with COPE recommendations on ethical editing for new Editors, Editors will assign any submissions they cannot handle (e.g. if they are the author of an article submitted to their own journal) to a member of the Editorial Board or a guest editor. The majority of journals at Universidad Privada del Valle (UNIVALLE) do not permit you to recommend peer reviewers. If you wish to suggest potential reviewers this information can be included in the covering letter, but it is at the discretion of the Editors to consider these reviewers or not. Providing any false information about potential reviewers may lead to rejection of the article.

Confidentiality of peer review

It is a requirement to maintain confidentiality and integrity of the peer review and editorial decision-making process at all stages, complying with data protection regulations (including GDPR). The invited reviewer should declare any competing interest before submitting their report to the journal. If they wish to involve a colleague as a co-reviewer for an article, they should ask the journal editorial office before sharing the manuscript and include

their names, affiliation and any relevant competing interests in the comments for Editors when they return their report. In the process of investigating an ethical query, the submitted manuscript, author, reviewer, and any other person (including whistleblowers) involved will be treated in confidence. During an investigation it may be necessary for the Editor to share information with third parties, such as the ethics committee and/or the authors' institution.

Plagiarism

Trust and integrity are among what readers value the most in scholarly peer-reviewed journal content. That's why the Journal of Latin American Sciences and Culture takes the issue of plagiarism very seriously. The Committee on Publication Ethics (COPE) defines plagiarism as: "When somebody presents the work of others (data, words or theories) as if they were his/her own and without proper acknowledgment." For Universidad Privada del Valle (UNIVALLE), this applies to data, images, words or ideas taken from any materials in electronic or print formats without sufficient attribution. The use of any such material either directly or indirectly should be properly acknowledged in all instances. You should always cite your source.

Preprints, preprint servers, and early reporting of scholarly work

We support the need for authors to share early versions of their work before peer-review publication. There are also a number of options for Universidad Privada del Valle (UNIVALLE) authors to share the final Version of Record of their published article.

Preprints and preprint servers

A preprint, also known as the Author's Original Manuscript (AOM), is your article before you have submitted it to a journal for peer review. Preprint servers are online repositories that enable you to post this early version of your research paper online. If you upload your AOM to a non-commercial preprint server, you can subsequently submit the manuscript to a University Privada del Valle (UNIVALLE) journal. We do not consider posting on a preprint server to be duplicate publication and this will not jeopardize consideration for publication. If you've posted your AOM to a preprint server, we ask that, upon acceptance, you acknowledge that the article has been accepted for publication as follows: "This article has been accepted for publication in [JOURNAL TITLE], published by Universidad Privada del Valle (UNIVALLE)."

After publication, please update your preprint, adding the following text to encourage others to read and cite the final published version of your article (the "Version of Record"): "This is an original manuscript of an article published by Universidad Privada del Valle (UNIVALLE) in [JOURNAL TITLE] on [date of publication], available online: http://xxx[Article DOI]."

Sharing your published article

If you've published in Universidad Privada del Valle (UNIVALLE) journal, there are many ways you can share different versions of your article with colleagues and peers.

Research ethics and consent

All research published in Universidad Privada del Valle (UNIVALLE) journals must have been conducted according to international and local guidelines ensuring ethically conducted research.

Research involving humans

All research studies on humans (individuals, samples or data) must have been performed in accordance with the principles stated in the Declaration of Helsinki. Prior to starting the study, ethical approval must have been obtained for all protocols from the local institutional review board (IRB) or other appropriate ethics committee to confirm the study meets national and international guidelines for research on humans. A statement to confirm this must be included within the manuscript, which must provide details of the name of the ethics committee and reference/permit numbers where available. This includes:

- Prospective studies on humans
- Clinical trials
- Clinical Case reports
- Organ or tissue transplants
- Human embryos and human stem cells
- Consent for research involving children, adolescents, and vulnerable or incapacitated study participants
- Retrospective studies
- Survey studies
- Covert observational research
- Research on indigenous communities
- Communication research
- Social media research

Participant/patient privacy and informed consent

Universidad Privada del Valle (UNIVALLE) endorses the recommendations of the International Committee of Medical Journal Editors (ICMJE), which emphasizes that patients and study participants have a right to privacy that should not be infringed without informed consent. In accordance with the principles outlined in the Nuremberg Code, the Belmont Report, and the American Anthropological Association, informed consent must be voluntarily obtained from the participant who should be fully informed of the study including any of the benefits and risks involved.

Research involving animals, plants, and heritage sites

Studies involving vertebrates or regulated invertebrates (e.g. cephalopods), field studies and other non-experimental research on animals must have been carried out after obtaining approval from the relevant institutional ethics committee or the institutional animal use and care committee. Research procedures must be carried out in accordance with applicable national or international guidelines. In field studies, authors must have also obtained any necessary permits for access to lands. Authors must include a statement within the manuscript to provide details of the name of the ethics committee(s) which approved the study and include the permit or animal license numbers where available.

Biosafety, biosecurity, and emerging biotechnology

Universidad Privada del Valle (UNIVALLE) journals will only consider research which has been carried out in compliance with institutional biosafety and biosecurity policies, which in turn should be informed by national or international recommendations.

Standards of reporting

Research should be communicated in a way that supports verification and reproducibility, and as such we encourage authors to provide comprehensive descriptions of their research rationale, protocol, methodology, and analysis. To aid authors in this, a number of study-design-specific consensus-based reporting guidelines have been developed, and we recommend you use these as guidance prior to submitting your manuscript. A comprehensive list of reporting guidelines for medicine and health research can be accessed via the EQUATOR network website, and for biosciences research via the MIBBI Foundry portal.

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You must obtain the necessary permission to reuse third-party material in your article. These materials may include – but are not limited to – text, illustration, photographs, tables, data, audio, video, film stills, screenshots, or musical notation. The use of short extracts of text and some other types of material is usually permitted, on a limited basis, for the purposes of criticism and review without securing formal permission. If you wish to include any material in your paper for which you do not hold copyright, and which is not covered by this informal agreement, you will need to obtain written permission from the copyright owner prior to submission.

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Collaborators

Cervantes Institute, Chaoxuan Intelligent Technology Research Institute, Media and Information Literacy (MIL) UNESCO and the International Green Science Center for Latin America and the Caribbean.

Affiliated and supported by:

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About our Supporting Organizations

1. **Andean Road Countries for Science and Technology (ARCST)**

Mission: ARCST is an international scientific organization founded in 2018 based on the general principles of "joint consultation, joint effort and joint sharing" and the promotion of shared development and achievement of the UN SDGs. ARCST members include national academies of sciences, universities, research institutes, and international organizations. ARCST is committed to playing an effective role in catalyzing and implementing innovative international science initiatives to build a community of the whole humankind with a shared future. Science, Technology, Innovation, and Capacity building (STIC) is essential to the progress and welfare of human societies and ARCST is particularly keen to cooperate and partner with those who want to collaborate in these endeavors. Promoting the popularization of Science, the exchange of knowledge, the diffusion of information, mutual learning, and collaboration.

Vision: To become an international science organization of global impact in catalyzing and implementing concrete innovative programs, initiatives and actions in Science, Technology, Innovation, and Capacity Building (STIC) for the promotion of shared development and the advancement of the UN Sustainable Development Goals (SDGs). We welcome you to join ARCST!

2. Elektro High Tech Co. Ltd.

Mission: To improve people's lives through meaningful innovation.

Vision: To inspire the world with innovative technologies, products, and design that enrich people's lives and contribute to social prosperity by creating a new future.

3. Universidad Privada del Valle (UNIVALLE)

Founded on October 4, 1988 by Dr. Gonzalo Ruiz Martinez; Univalle has been projected as a synonym for academic excellence in Latin America with more than 32 undergraduate degree programs. Currently, about 14,000 national and foreign students carry out their higher studies in the university infrastructure with the greatest technological advance in Bolivia. In these 33 years of academic trajectory, Univalle has trained more than 16,000 professionals at the undergraduate and postgraduate levels in its four locations, which are located in Cochabamba, La Paz, Sucre and Trinidad. And soon in the new headquarters located in Santa Cruz. Our

history reflects the fact that ... "We are the Scientific Answer to the Future".

4. International Green Science Center for Latin America and the Caribbean (IGSCLAC)

The **International Green Science Center for Latin America and the Caribbean (IGSCLAC)**, established in 2023 in Colombia, is a key institution driving scientific innovation and sustainability in the region. Founded through a collaboration between the Andean Road Countries of Science and Technology (ARCST) and Unidad Central del Valle del Cauca (UCEVA), its mission is to address environmental challenges through a new paradigm of development known as **Science Culture Construction (SCC)**. IGSCLAC's prominence aligns with a significant moment for Colombia, which has officially assumed the presidency of **COP16** (the UN Convention on Biological Diversity). This positions the Center as a core player in the region's efforts to achieve global biodiversity goals under Colombia's environmental leadership. To mark this historic moment, IGSCLAC has unveiled its official logo. The emblem features a symbolic bird native to Colombia, representing the nation's rich biodiversity. This bird embodies the Center's core values of **resilience, adaptability, and a harmonious balance between nature and scientific progress**, visually defining IGSCLAC's vision for a greener future.

Chaoxuan Intelligent Research Institute

Research Institute is a leading technology and mode research and development institution set up by Chaoxuan Group. The Institute brings together academicians and experts in various fields, and has an academic committee and some expert committees. Focusing on the industry's pain points and social development needs, the Institute carries out theoretical research, industry research, model design, technology application, standard compilation and international exchanges, providing strong support for economic and social development.

Chaoxuan is a group enterprise integrating research, operation and service, includes research institute, intelligent technology, vocational education, human resource service, industrial operation, financial capital and other business segments, and is committed to the top-level construction and systematic service of ecological scene. Focusing on the strategic deployment of the State, Chaoxuan adheres to the concept of selecting the better of the best and open interconnection, gathers expert resources and leading enterprises, takes research as the lead, takes Digital Twin and other IOT as the support, takes vocational education and human resources services as the core, collaborates with ecological platform, helps with capital and together with public welfare. Chaoxuan has taken the lead in the construction industry and rural revitalization and achieved remarkable results, promoting the transformation and upgrading of traditional industries and promoting sound economic and social development. Chaoxuan has national high-tech, Zhongguancun High-tech, vocational education, labor dispatch, human resources

service licensing, radio and TV program production and more than 200 intellectual property rights such as patents, Copyrights, trademarks and so on.

6. UNESCO Media and Information Literacy (MIL) Alliance

Our brains depend on information to work optimally. The quality of information we engage with largely determines our perceptions, beliefs and attitudes. It could be information from other persons, the media, libraries, archives, museums, publishers, or other information providers including those on the Internet. People across the world are witnessing a dramatic increase in access to information and communication. While some people are starved for information, others are flooded with print, broadcast and digital content. Media and Information Literacy (MIL) provides answers to the questions that we all ask ourselves at some point. How can we access, search, critically assess, use and contribute content wisely, both online and offline? What are our rights online and offline? What are the ethical issues surrounding the access and use of information? How can we engage with media and ICTs to promote equality, intercultural and interreligious dialogue, peace, freedom of expression and access to information? Through capacity-building resources, such as curricula development, policy guidelines and articulation, and assessment framework, UNESCO supports the development of MIL competencies among people. Free and open online courses are available for self-paced learning about MIL. Through media and information technologies, the Organization facilitates networking and research through the Global Alliance for Partnerships on MIL (GAPMIL) and MIL University Network. The recently-launched MIL CLICKS social media initiative is also part of UNESCO's strategy to enable media and information literate societies.

7. Mega Science

Science popularization means to bring science to the general public, to disseminate knowledge and to foster a scientific way of thinking among people. In particular, science popularization refers to the understanding of science and public engagement. In this way science popularization is a powerful tool and a strategic measure to build a modern society, not only disseminating useful knowledge and skills but spreading a general approach and a common culture.

In general, conflicts between science community and public opinion are connected to people's distrust but also to scientists' prejudice. In some cases, science is not correctly understood by non-scientist due to the use of technical jargon and wrong communication. We believe that every topic can be the object of science popularization; it only depends on the communication skills of who is in charge of the dissemination and the way to disseminate it. That is why we are glad to cooperate with Mega Science, the first platform of science popularization that creates and shares content in three languages and in diverse areas of science. Scan the following QR code to know more about it.

Our framework

Science as a Human Right: Building a New Culture of Inclusive Knowledge for Latin America and the Caribbean
By: Advisory Board JLASC

Fig. 1.- Official logo of the Science Culture Construction (SCC)

A foundational, yet often overlooked, article of the Universal Declaration of Human Rights proclaims that “everyone has the right freely to… share in scientific advancement and its benefits.” For decades, this powerful statement remained a largely aspirational ideal. Today, a dynamic movement across Latin America and the Caribbean, spearheaded by the Andean Road Countries for Science and Technology (ARCST) and its collaborators, is working to make this right a tangible reality. This movement is the Science Culture Construction (SCC), a paradigm that redefines science not as a privilege for the few, but as a fundamental human right and a shared cultural heritage for all. The SCC paradigm is built on the conviction that access to science is a multifaceted right. It is not merely the right to consume pre-packaged scientific facts. It is the right to participate in the scientific process, to contribute to the creation of knowledge, and to have that knowledge equitably address the needs of one's community. It is about shifting science where diverse voices and forms of knowledge are not only welcomed but are seen as essential.

The Journal of Latin American Sciences and Culture (JLASC) stands as a direct embodiment of this commitment. Its very existence is a collaborative effort, made possible by the visionary framework of ARCST, the academic dedication of institutions like the International Green Science Center for Latin America and the Caribbean (IGSCLAC), Universidad Privada del Valle (Univalle), Unidad Central del Valle del Cauca (UCEVA), and the private and public contributions of researchers and institutions across the world. By providing a platform for science communication, we are actively fulfilling the "right to share in scientific advancement." We are ensuring that the groundbreaking work conducted here is visible, accessible, and integrated into the global scientific conversation.

This approach is particularly transformative for a region endowed with immense biodiversity and cultural wealth. The SCC paradigm actively dismantles the outdated model where the Global South is a passive subject of study. Instead, it positions our nations as vibrant generators of knowledge. It shows the idea that the path to sustainable development is paved with scientific innovation that is culturally resonant and locally relevant. The establishment of the International Green Science Center for Latin America and the Caribbean (IGSCLAC) is a flagship initiative in this regard. It serves as a hub where the right to science is operationalized, fostering research that directly addresses regional environmental challenges while empowering a new generation of scientists.

As we move forward the connection between the human right to science and the preservation of biodiversity becomes ever clearer. We cannot protect our natural heritage without a scientifically literate and engaged citizens. The SCC is our strategic pathway to build this engagement from the ground up. It is an invitation to every citizen to claim their right to be a part of the scientific solution. By constructing a robust scientific culture, we are not just advancing knowledge; we are upholding a fundamental human right and building a more just, informed, and sustainable future for all.

Our ambassador

Biopochito's Journey: Spreading the Seeds of Green Science Across a Continent

Fig. 2.- Cover of the presentation of Biopochito utilized during the workshops and capacity building activities with Biopochito and Biopochito AI

In the realm of science diplomacy, we often speak in terms of treaties, joint declarations, and high-level conferences. These are essential, yet the most profound diplomatic victories often begin in the wide-eyed wonder of a child. This is the story of **Biopochito**, a humble yet powerful ambassador of green science, whose journey across more than 12 countries is quietly forging a generation of environmental stewards and bringing the vision of Science Culture Construction to life.

Developed by the International Green Science Center for Latin America and the Caribbean (IGSCLAC) in collaboration with the Andean Road Countries for Science and Technology (ARCST), Biopochito is far more than an educational kit; it is a portable ecosystem of inspiration. At its heart, it is a simple, accessible tool, often a small biosphere or a seed-growing kit featuring native plants, designed to fit in a child's hands. But within its unassuming frame lies a profound mission: to inspire a tangible, emotional love for green science and to plant the seeds of a lasting scientific culture in the minds of our youth.

The genius of Biopochito, a name which evokes a small, living treasure (*bio-* meaning life, *-pochito* suggesting something small and cherished), is its experiential nature. Children are not just told about photosynthesis or biodiversity; they witness it. They care for it. They are entrusted with the miracle of a sprouting seed, a microcosm of the very ecosystems we are striving to protect. This direct engagement fosters a sense of connection and responsibility that no textbook alone can ever achieve. It transforms abstract concepts like "sustainability" and "biodiversity" into a personal, cherished relationship with a living thing.

Biopochito has travelled across nine countries, from the Andes to Asia, Europe, central America and Africa, is a masterclass in grassroots diplomacy. In each nation, the program is adapted in coordination with local educators and communities, incorporating cultural elements and connecting to local environmental contexts. This respect for local knowledge is a cornerstone of the Science Culture Construction paradigm; it is not an imposition of knowledge, but a sharing and co-creation of it.

The impact is palpable. Biopochito has become a catalyst for excitement. It has sparked school-wide gardening projects, inspired science fair entries, and ignited dinner-table conversations about nature. It is building a transnational community of young learners who share a common language: the language of curiosity, care, and green science. They are not just learning biology; they are living the principles of resilience, interdependence, and sustainable growth.

Biopochito's voyage is a powerful testament to IGSCLAC's and ARCST. Biopochito is ensuring the foundation for those agreements remains strong for decades to come by cultivating the values in the next generation. It is a vivid demonstration that the future of our planet depends not only on the policies we enact today but on the love for nature we nurture in the children of today. This little ambassador is proving that the most sustainable resource we have is the inspired curiosity of a child, and it is diligently sowing that resource across the continent, one seed at a time.

Editorial Note

The *Journal of Latin American Sciences and Culture* is a critical, interdisciplinary platform dedicated to exploring the rich interface between scientific endeavors and cultural expression in a global context. We operate from the conviction that science is profoundly shaped by, and in turn shapes, the historical, social, and epistemic landscapes from which it emerges.

This current volume exemplifies our mission, featuring insights from leading experts across both the natural and social sciences. Their discussions engage with some of the most pressing topics of our time, with a special focus on **AI technologies, green science, education, and the Sustainable Development Goals (SDGs)**. By intentionally convening voices from a diverse, global community of scholars, this issue serves as a powerful reminder that science has **no frontiers and no edges**; it is a fundamentally collaborative and transnational pursuit of knowledge.

Our ongoing mission is to publish high-quality research that examines how scientific knowledge is produced, negotiated, and represented worldwide. We welcome submissions from all fields that:

- Contextualize science within specific regional, national, or cultural frameworks.
- Foster dialogue across disciplinary boundaries.
- Engage with local, Indigenous, and plural knowledge systems.
- Challenge hegemonic narratives by centering underrepresented perspectives in the history and philosophy of science.
- Examine cultural and artistic representations of science and technology.

We invite scholars, researchers, and cultural analysts from around the world to contribute to this vital conversation. **We welcome your submissions** to our journal as we continue to build an essential forum for rethinking the global geography of knowledge.

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Nota Editorial

La *Revista de Ciencias y Cultura* es una plataforma crítica e interdisciplinaria dedicada a explorar la rica interfaz entre los quehaceres científicos y la expresión cultural en un contexto global. Partimos de la convicción de que la ciencia se moldea profundamente por—y a su vez moldea—los paisajes históricos, sociales y epistémicos de los que emerge.

El presente volumen ejemplifica nuestra misión, presentando perspectivas de expertos líderes tanto de las ciencias naturales como de las sociales. Sus análisis abordan algunos de los temas más urgentes de nuestro tiempo, con un **énfasis especial en las tecnologías de IA, la ciencia verde, la educación y los Objetivos de Desarrollo Sostenible (ODS)**. Al convocar intencionalmente voces de una comunidad global y diversa de académicos, este número sirve como un recordatorio poderoso de que la ciencia **no tiene fronteras ni límites**; es una búsqueda fundamentalmente colaborativa y transnacional de conocimiento.

Nuestra misión permanente es publicar investigación de alta calidad que examine cómo se produce, negocia y representa el conocimiento científico a escala mundial. Recibimos contribuciones de todos los campos que:

- Contextualicen la ciencia dentro de marcos regionales, nacionales o culturales específicos.
- Fomenten el diálogo a través de las fronteras disciplinarias.
- Dialoguen con sistemas de conocimiento locales, indígenas y plurales.
- Cuestionen narrativas hegemónicas situando en el centro perspectivas subrepresentadas en la historia y filosofía de la ciencia.
- Examinen las representaciones culturales y artísticas de la ciencia y la tecnología.

Invitamos a académicos, investigadores y analistas culturales de todo el mundo a contribuir a esta conversación vital. **Agradecemos y damos la bienvenida a sus envíos** a nuestra revista, mientras continuamos construyendo un foro esencial para repensar la geografía global del saber.

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Journal of Latin American Sciences and Culture

Article

Strengthening Local Climate Leadership: Evaluating a Community-Based Empowerment Initiative

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Abstract: Women and youth play a vital role in strengthening climate resilience, particularly in vulnerable regions such as Sindh, Pakistan. This study evaluates the Green Earth Action Day Foundation (GEAF) one-day climate leadership intervention aimed at improving climate literacy, encouraging community participation, and empowering young people and women. The event was conducted in a rural community where 420 participants including 320 youth and 100 women aged 15 to 35, took part in climate awareness sessions, a simple knowledge quiz, tree-planting activities, and discussions on green entrepreneurship. A brief pre- and post-questionnaire assessed changes in basic climate knowledge and perceptions. Findings showed noticeable improvement in understanding climate change, water challenges, waste management, and sustainable practices. The event also included the distribution of practical livelihood resources, such as sewing machines for five women and green materials to support small-scale environmental initiatives. Overall, the GEAF intervention demonstrated that a short, community-based program can effectively enhance climate awareness and empower women and youth in resource-constrained settings.

Keywords: climate leadership; women empowerment; youth engagement; green entrepreneurship; sustainable development; plantation; environmental education

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1. Introduction

The world is experiencing an unprecedented environmental crisis that threatens the wellbeing of both present and future generations. Climate change, in particular, has emerged as one of the most pressing global concerns, manifested through rising temperatures, extreme weather patterns, loss of biodiversity, and the steady deterioration of ecosystems. These impacts continue to intensify despite growing international efforts, highlighting an urgent need for broader societal participation and stronger local leadership. As emphasized by Abdul Qayyum Gondal (2025), addressing the climate emergency requires deliberate, inclusive engagement of all segments of society, especially women and youth, who collectively represent over half of the global population yet remain among the most vulnerable to climate risks.

Women and young people possess unique local knowledge, lived experiences, and innovation-driven perspectives that position them as powerful agents of change in the pursuit of environmental resilience. However, their leadership potential often goes unrealized due to deep-rooted structural inequalities, restrictive social norms, unequal access to resources, and limited representation in decision-making spaces. (Kakade et al. 2024) The women, particularly in rural settings, have historically faced disproportionate burdens related to water scarcity, food insecurity, limited energy access, and environmental degradation. These challenges heighten their vulnerability while

simultaneously limiting opportunities to lead climate solutions. Empowering women to take active roles in environmental governance enables more comprehensive, socially responsive, and sustainable climate strategies. (Goryunova & Madsen, 2024)

The exclusion of these groups from climate leadership also diminishes the overall effectiveness of climate policies. When women, youth, low-income communities, and other marginalized populations are sidelined, climate actions fail to address intersecting inequalities and therefore lack long-term impact. More inclusive governance frameworks are needed to ensure that climate solutions are just, participatory, and reflective of the diverse experiences of those most affected. (Memon, 2020)

Global institutions have begun to acknowledge this gap. Under the United Nations Framework Convention on Climate Change (UNFCCC), mechanisms such as the Gender Action Plan (GAP) and the Youth Constituency (YOUNGO) aim to enhance the participation of women and youth in climate governance. However, translating these commitments into meaningful, community-level action remains a significant challenge. Localized, practical initiatives are urgently required to bridge global ambitions with grassroots realities. (Lecoutere et al., 2024)

Across different regions, inspiring examples demonstrate the transformative impact of women and youth in advancing climate resilience. Community cooperatives in multiple countries have successfully led sustainable agriculture, forest conservation, and renewable energy projects, benefiting both the environment and local economies. Youth-led networks continue to mobilize large-scale climate awareness campaigns, reforestation drives, and policy advocacy efforts, illustrating the power of collective action.

Despite these successes, women and youth often operate at the intersection of multiple forms of marginalization including gender inequality, economic exclusion, and social discrimination which further limits their ability to influence climate agendas. Advancing climate justice requires centering the voices of those who experience the harshest impacts of environmental degradation. Climate leadership, therefore, cannot be separated from broader struggles for equity, social protection, and human rights. (Lammers et al. 2024)

Climate change remains one of the most urgent crises facing humanity, with disproportionate impacts on women and youth, particularly in low-resource areas that lack formal climate education and leadership opportunities. Globally, community-based climate leadership programs are recognized for enhancing knowledge, inspiring action, and building localized resilience, yet systematic evaluations of short, one-day interventions are limited in the literature. Previous research indicates that extended youth climate programs improve content knowledge, civic engagement, and self-efficacy over time through sustained engagement and curriculum design. (Wellman et al., 2025)

In this context, community-based interventions that build climate knowledge, enhance local leadership capacity, and provide practical empowerment opportunities hold immense value. The Green Earth Action Day Foundation (GEAF) initiative evaluated in this study was designed with this principle in mind. Through a one-day engagement that brought together women and youth from diverse bakground for climate awareness sessions, a simple knowledge quiz, tree-planting activities, and the distribution of livelihood-support resources including sewing machines for women and green materials for community initiatives the program sought to foster environmental responsibility and empower emerging grassroots leaders. By assessing immediate knowledge gains and shifts in perceptions, this study contributes to growing evidence that accessible, localized

programs can strengthen climate literacy and catalyze meaningful community-driven action.

Figure 1: Youth and Women from diverse background present on the day of GEAF

2. Materials and Methods

This study employed a mixed-method, single-day quasi-experimental design to evaluate the effectiveness of the Green Earth Action Day Foundation (GEAF) climate leadership intervention. The event was developed to simultaneously enhance climate literacy, promote participatory environmental action, and strengthen livelihood-oriented empowerment among youth and women. Because the intervention was delivered in a single day, the design prioritized tools that could capture immediate, measurable learning gains while also documenting behavioral and motivational changes observable during the program. This approach is consistent with established models of short-duration community climate education programs conducted in resource-limited settings (Monroe et al., 2019).

The study followed a pre and post assessment strategy in which all participants completed a brief knowledge-based quiz before and after the intervention. Alongside this structured quantitative component, qualitative observations, participant discussions, and interactional patterns during activities provided important contextual insight into empowerment, motivation, and engagement.

2.1 Study Setting and Participant Recruitment

The intervention took place in a rural community characterized by limited access to formal climate education, gender-restrictive social norms, and high exposure to environmental risks such as water scarcity and extreme heat. These conditions mirror many climate-vulnerable rural environments globally, where socio-economic constraints reduce the ability of residents particularly youth and women to actively participate in climate resilience initiatives (Aguilar, 2012).

A total of 420 participants took part in the event. These included 320 youth and 100 women, all within the age range of 15-35 years, reflecting the demographics of local schools and surrounding communities. Recruitment occurred through school announcements, community leaders, women's groups, and GEAF outreach volunteers.

This method ensured broad participation among individuals with an existing interest in environmental issues, while also including participants with low baseline climate knowledge, aligning with participatory rural appraisal principles that prioritize inclusivity, trust, and community relevance over purely random sampling (Chambers, 1994).

Table 1. Participant Demographics (N = 420)

Category	Number	Percentage
Youth	320	76.2%
Women	100	23.8%
Age 15–20	210	50.0%
Age 21–25	130	31.0%
Age 26–35	80	19.0%

2.2 Intervention Components

The intervention consisted of four main components: structured climate awareness sessions, a pre- and post-knowledge quiz, a youth-led tree-planting activity, and a women-focused livelihood empowerment session featuring the distribution of sewing machines and green materials. The combination of educational, practical, and economic empowerment elements was designed to simultaneously target knowledge, behaviour, and agency, consistent with empowerment theory and community-based climate education best practices (Kabeer, 1999; Chawla & Cushing, 2007).

2.3 Climate Awareness and Educational Sessions

The core of the intervention was a 90-120 minute climate awareness session, facilitated by trained climate educators. Content included fundamental climate science, local environmental challenges, observed impacts of extreme weather events, the ecological importance of trees and water conservation, and sustainable household practices. Participants were also introduced to the potential roles of youth and women in driving community-level climate resilience.

Figure 2: During the GEAF day women and youth attending sessions

To accommodate participants with diverse literacy levels, educators employed visual aids, flip charts, participatory Q&A, storytelling, drawings, short videos, and real-life examples. Interactive discussions encouraged participants to relate climate concepts to their personal experiences, including local heatwaves, water shortages, and waste management challenges. Women were engaged in household-level adaptation strategies, composting, kitchen gardening, and low-resource entrepreneurship opportunities. This approach draws on research emphasizing the effectiveness of contextualized and participatory learning for improving climate understanding and retention.

2.4 Pre- and Post-Intervention Quiz

A 10-item quiz was used to measure climate knowledge before and after the intervention. The quiz was designed for simplicity, cultural relevance, and accessibility for participants with varying literacy levels. The instrument included multiple-choice, true/false, and yes/no questions for the one who can't write or and still be part of event. Example items include:

- "Climate change mainly refers to long-term changes in _____."
- "Planting trees helps reduce the effects of climate change. True/False."
- "Which of the following is a major source of waste pollution in rural communities?"
- "Water scarcity is caused by: (a) Overuse (b) Climate change (c) Poor storage (d) All of the above."

Facilitators read questions aloud for participants with lower literacy, following recommendations for inclusive assessment in community education programs (Monroe et al., 2019). Scores ranged from 0–10. All responses were recorded by GEAF data collectors and later tabulated for analysis. Descriptive results are presented in Table 2.

Table 2. Pre- and Post-Quiz Average Scores

Assessment	Mean Score (0–10)	SD
Pre-Test	4.1	1.8
Post-Test	8.3	1.4

2.5 Youth-Led Tree-Planting Activity

Following the awareness session, youth participants engaged in a structured tree-planting exercise designed to promote practical climate action and leadership. Participants planted 150 native, drought-resistant saplings in school and community areas. GEAF volunteers demonstrated techniques for soil preparation, planting depth, mulching, and watering. Youth were encouraged to monitor the saplings' growth, fostering ownership and long-term stewardship.

Active youth participants were recognized as Youth Climate Representatives for their schools, providing them with informal leadership roles and responsibilities to advocate for environmental initiatives. This approach aligns with youth-centered

environmental education strategies that link knowledge acquisition to practical action and responsibility.

2.6 Women's Livelihood Empowerment

The intervention integrated a livelihood component to empower women economically while reinforcing climate leadership. Five women received sewing machines based on their active participation, engagement during discussions, and expressed interest in skill-building and home-based income generation. Recipients were provided with starter kits, including needles, threads, and fabric pieces, and were offered guidance on sustainable micro-enterprises such as stitching school uniforms, reusable bags, and upcycled crafts. The selection process was transparent and conducted in the presence of all participants, emphasizing fairness and accountability. Integration of climate literacy with economic empowerment has been shown to increase both sustainability and impact of community-based interventions (Kabeer, 1999).

Table 3. Sewing Machine Distribution Criteria

Criteria	Description
Participation	Involvement in sessions
Engagement	Asking questions, contributing
Skill Interest	Expressed motivation to sew
Leadership	Helping others during activities

2.7 Qualitative Observation and Data Collection

Throughout the intervention, facilitators documented participant engagement, enthusiasm, and behavioral indications of empowerment. Observational notes included questions asked, level of interaction during activities, leadership during group tasks, and responsiveness to practical exercises. These qualitative insights were analyzed thematically to identify trends in motivation, knowledge application, and confidence building, complementing the quantitative findings from the pre- and post-quiz.

3. Discussion

The findings from this study indicate that even a short, one-day climate leadership intervention can produce meaningful gains in climate knowledge, motivation, and empowerment among youth and women in resource-constrained rural communities. The pre- and post-quiz results clearly demonstrate significant improvements in understanding climate change, water challenges, waste management, and sustainable practices. These findings align with prior studies indicating that brief, focused educational interventions can positively impact climate literacy and self-efficacy, particularly when participants are engaged through interactive and contextualized learning strategies (Monroe et al., 2019; Fatima, 2025).

Importantly, this intervention extended beyond cognitive learning by integrating practical, empowerment-focused activities. The youth-led tree-planting exercise provided hands-on experience in ecological restoration and nurtured leadership, responsibility, and ownership over local environmental resources. Similarly, the distribution of sewing machines to five highly engaged women participants exemplifies the strategic integration of livelihood support with climate education, reinforcing the link between environmental knowledge, personal agency, and economic empowerment (Kabeer, 1999). By rewarding active participation and commitment, these practical components fostered intrinsic motivation, ensuring that participants viewed themselves not merely as learners but as agents capable of initiating local environmental action.

The differential focus on youth and women highlights the importance of gender- and age-sensitive programming in climate interventions. Women were engaged in household-level adaptation strategies, low-resource entrepreneurship, and discussions on sustainable practices, which can enhance resilience at both family and community levels. Youth were encouraged to adopt school- and community-based leadership roles, such as acting as Youth Climate Representatives, planting saplings, and monitoring local environmental projects. Such dual-targeted approaches are consistent with empowerment theory, which emphasizes the interconnection between resources, agency, and achievements, particularly for historically marginalized populations (Kabeer, 1999; Chawla & Cushing, 2007).

Moreover, the integration of simple pre- and post-assessments allowed for an immediate and measurable evaluation of knowledge acquisition. This method, combined with qualitative observation of engagement, discussions, and behavior during activities, offered a holistic understanding of both cognitive and affective changes. The use of culturally appropriate, low-literacy-friendly questionnaires ensured that all participants, regardless of educational background, could meaningfully engage in the evaluation process, reflecting best practices in inclusive community education programs (Monroe et al., 2019).

While these results are promising, they should be interpreted in the context of certain limitations. The absence of a control group restricts the ability to formally attribute observed outcomes solely to the intervention. Additionally, the reliance on self-reported data and immediate post-event measurement limits insights into long-term retention of knowledge or sustained behavioral change. Despite these constraints, the study provides compelling evidence for the efficacy of short, practical, and participatory community-based climate leadership programs, particularly when combined with livelihood empowerment initiatives.

Overall, the GEAF intervention exemplifies how community-based, single-day programs can address structural barriers to climate engagement among youth and women, cultivate local leadership capacity, and stimulate action-oriented learning. These findings resonate with global evidence emphasizing the importance of localized,

participatory approaches in climate education, highlighting that small-scale, contextually tailored interventions can meaningfully contribute to climate resilience and social empowerment (Huq, 2023).

3.1 Limitations

Reliance on self-reported data immediately post-event limits long-term interpretation of knowledge retention or behavior change. Absence of a control group restricts formal attribution of outcomes entirely to the intervention.

4. Conclusion

This study demonstrates that a community-based, one-day climate leadership intervention can effectively enhance climate awareness, foster environmental motivation, and promote empowerment among women and youth in resource-limited settings. By combining structured educational sessions, interactive knowledge assessments, hands-on environmental action, and practical livelihood support, the GEAF program strengthened participants' capacity to act as local climate leaders.

The results suggest that short, inclusive, and contextually appropriate interventions can complement larger climate governance frameworks by cultivating grassroots leadership, building community ownership, and linking climate literacy with practical skills and income-generating opportunities. Integrating gender- and youth-sensitive approaches ensures that interventions address systemic inequalities while fostering resilience and agency among the most vulnerable populations.

Future research should incorporate longitudinal follow-ups to assess knowledge retention, behavioral outcomes, and the sustained impact of livelihood support on climate leadership. Expanding such interventions across diverse rural settings could inform scalable and inclusive models of climate education, demonstrating that even brief, well-designed programs can catalyze meaningful local action and contribute to broader environmental sustainability and social empowerment goals.

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Data, Materials, and Code Availability
The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' Contributions
All authors contributed equally to the conception, design, data collection, analysis, and writing of this manuscript. All authors have read and approved the final version for submission.

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Article

Rapid Development of Molecularly Imprinted Polymers for Efficient Removal of Cadmium Ions from Water

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Abstract: Molecularly imprinted polymers (MIPs) are specialized cross-linked polymer networks designed to show strong affinity for specific target molecules, ions, or metallic species with remarkable selectivity for structurally related compounds. This study reports the development of a cadmium (II) ion-imprinted polymer (Cd-IIP) designed for the selective extraction of Cd^{2+} ions from aqueous solutions. The polymer was synthesized via bulk polymerization using 4-vinylpyridine as the functional monomer, and its structure and composition were thoroughly characterized using TGA, SEM, and CHNS elemental analysis. Adsorption experiments confirmed that the material exhibits high affinity for Cd^{2+}, with kinetic data following a pseudo-first-order model and thermodynamic results indicating an exothermic adsorption process. When evaluated in binary metal-ion systems, the polymer demonstrated excellent selectivity. Additionally, throughout several adsorption-desorption cycles, the material demonstrated outstanding regeneration capability

Keywords: Molecularly imprinted polymers; metals; adsorption, Selectivity

1. Introduction

The rational design of polymer architectures that can precisely identify and bind target species is made possible by molecular imprinting technology. Cross-linked polymer matrices with a strong affinity for specific target molecules, ions, or metallic elements are known as molecularly imprinted polymers (MIPs) (Priyadarshanee & Das, 2021). MIPs have been widely used in many different scientific fields because of their distinct molecular recognition capabilities and predictable structural features (Liu et al., 2024, Ndunda, 2020). One particularly promising method for improving MIPs' recognition abilities is metal ion imprinting (Ansari et al., 2017). Through bioaccumulation in food chains, cadmium (Cd) is a highly toxic heavy metal

that poses significant risks to biological systems and environmental health even at trace concentrations. Cadmium is one of the thirteen most hazardous metals listed by the EPA as a non-essential element (Cui et al., 2022). It has been shown to have detrimental effects on a number of physiological systems, including the cardiovascular, renal, neurological, gastrointestinal, reproductive, and respiratory systems (Kumar & Kumar, 2019, Wang et al., 2010). It is also a confirmed human carcinogen (Ahmed et al., 2025, Haddad et al., 2025). In order to assess the usefulness of MIPs for the selective identification and removal of cadmium ions from aqueous environments, the current study focuses on creating a Cd (II) ion-imprinted polymer. The produced MIPs demonstrated strong selectivity for the target metallic ion along with a significant binding capacity.

2. Research Methodology

2.1 Materials

4-vinyl pyridine (4-VP) was purchased from ACROS Organics, New Jersey USA. Ethyleneglycol dimethacrylate (EGDMA), Benzoyl peroxide (BPO) was purchased from (Trade TCI mart) TCI-EP Tokyo Kasei Kogyo Co. Ltd, Japan. All other chemicals were reagent grade and purchased from ACROS Organics, New Jersey USA.

2.2 Synthesis of Cd (II) Ion Imprinted Polymer (IIP):

The fabrication of Cd (II) ion imprinted polymer was done by radical polymerization by dissolving (4 mmol) of Cd $(NO_3)_2$ $2H_2O$ in a (3:1) mixture of ethanol: water followed by addition of (12 mmol) of 4-vinyl pyridine (VP), (60 mmol) of ethyleneglycol dimethacrylate acid (EGDMA) and10 mg of benzoyl peroxide (BPO). The reaction mixture was further exposed to sonication for 1 hour. After purging with N_2 for 10 min polymerization reaction was initiated by placing reaction tube in oven at 70 °C for 24 hours. Finally, the prepared polymer was removed from reaction tube and washed with ethanol and deionized water to eradicate, unreacted monomer. The crushed and sieved polymeric product was treated with 0.5 M hydrochloric acid to eliminate the template ion. The same step was repeated frequent times till the template ion was hundred percent removed followed by washing with methanol to remove extra amount of HCl. After removal of template a cavity is produced in polymer matrix that is responsible for adsorption of Cd ions from aqueous solution The fabricated MIP product was employed to eliminate Cd (II) ions from aqueous solution. The mechanism of MIP synthesis is given in Fig. 1. The non-imprinted polymer (NIP) was also prepared by similar procedure in the absence of template Cd ion.

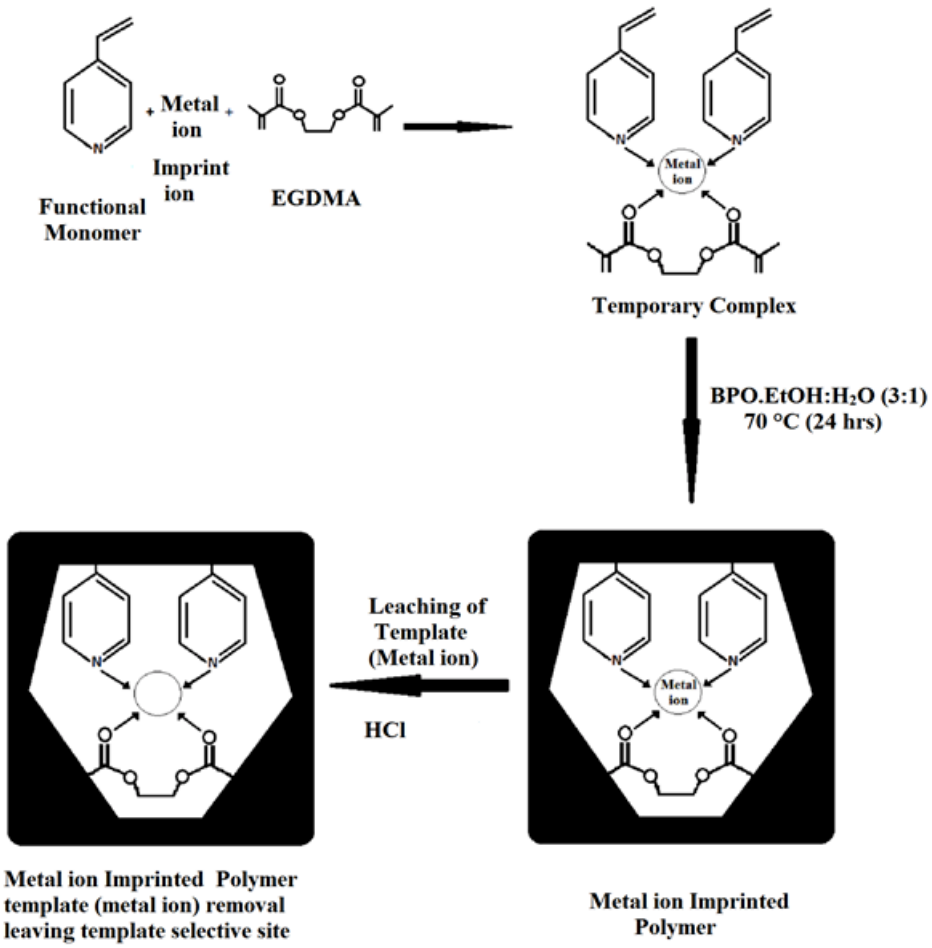


Figure 1: Schematic representation of synthesized Cd (III) ion Imprinted Polymers

2.3 Batch Adsorption Experiment

To explore the adsorption performance of Cd (II) ions, the batch mode of adsorption was applied by optimizing pH, the dose of adsorbent, rpm, concentration and shaking time. The % Adsorption Capability was calculated using this formula:

$$\%Adsorption = Ci - Ce/Ci \ldots\ldots\ldots (1)$$

Where Ci is the initial concentration & Ce is the concentration at equilibrium in (mol/dm3), The initial and equilibrium concentrations were determined by atomic absorption spectroscopy.

3. Results

3.1 Characterization of Cd (III) ion imprinted polymer

3.1.1 CHNS Analysis:

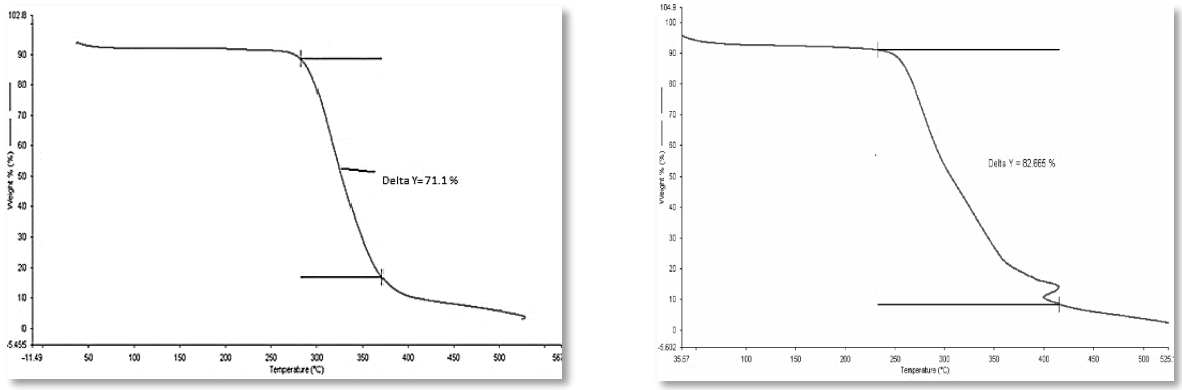
The CHNS elemental analysis of prepared molecularly imprinted polymer (MIP) was done by using CHNS Analyser FLASH THERMO EA. 1112 series and outcomes of examination are presented in table 1.

Table 1. CHNS analysis of synthesized ion imprinted polymer (IIP).

Sample	C	H	N	S
IIP-Cd (II)	60.95 %	5.99 %	9.48 %	0
NIP	61.29 %	6.71 %	9.37 %	0

3.1.2 Thermogravimetry (TG)

Thermal stability of the Cd (II) ion imprinted polymer (IIP) was checked by Perkin Elmer's Diamond TG Thermal Analyzer through Pyris Manager Software by performing thermo gravimetric analysis (TGA) as shown in figure 2 (a) for NIP & (b) for Cd (II)IP. The thermo gravimetric examination (TGA) exhibited complete great stability of fabricated MIPs and results are exhibited in table 2.



(a) (b)

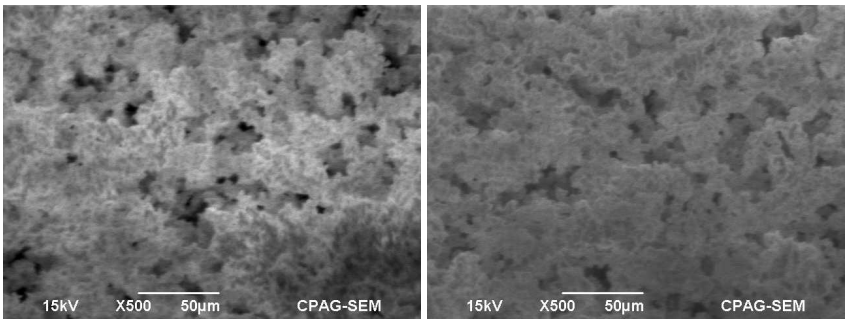
Figure 2: Thermo Gravimetric Analysis of NIP & Cd (II) Ion Imprinted Polymer

Table 2. Thermo gravimetric analysis of synthesized ion imprinted polymer

Sample	TGA Characteristics			Possible Molecular Involvement
	1st Stage Weight Loss	**2nd Stage Weight Loss**	**3rd Stage Weight Loss**	
IIP-Cd (II)	36-225 °C (9 %)	225-420 °C (82.665 %)	400-525 °C (10 %)	**1st** weight loss indicates the removal of solvent. **2nd** weight loss is due to organic part of polymer. **3rd** weight loss is owing to metal oxide residue.
NIP	40-260 °C (10 %)	260-365 °C (71.1 %)	365-540 °C	**1st** weight loss is due to solvent interaction. **2nd** weight loss represents organic part of polymer.

3.1.3 SEM Analysis:

The (SEM) analysis is used to approve structural reliability of fabricated ion imprinted polymers (Cormack & Elorza, 2024). In current study, the scanning electron microscopic images were done using JEOL/EOJSM-6490 scanning electron microscope and the results are shown in figure 3(a) & 3(b). The surface morphology of Cd (II)-IIP & NIP evidently revealed the synthesize polymers having high roughness and porosity.



(a) **(b)**

Figure 3: SEM image of (a) Cd (II)-IIP & (b) NIP

3.2 Equilibrium Studies

In adsorption studies the adsorption isotherms have a significant role in predicting demonstrating of adsorption systems. Freundlich adsorption isotherm is used to describe the exponential distribution of sites, heterogeneity of the surfaces and their energies. Freundlich (Eq. No.2) and Langmuir (Eq. No. 3) isotherms have been used to analyse the equilibrium experimental data.

$$log\ C_{ads} = K_F + \frac{1}{n} log\ C_e \quad \ldots\ldots\ldots (2)$$

$$\frac{C_e}{C_{ads}} = \frac{1}{K_L} b + \frac{C_e}{K_L} \quad \ldots\ldots (3)$$

3.3 Kinetic Studies

The kinetic study of the adsorption is calculated by using the pseudo first- order equation as

$$ln\ (q_e - q_t) = lnq_e - kt \ldots\ldots (4)$$

3.4 Thermodynamic Studies

In thermodynamic studies following equations is used to calculate the activation parameters like ΔH, ΔS and ΔG.

$$lnKc = \frac{-\Delta H}{RT} + \frac{\Delta S}{R} \ldots\ldots (5)$$

$$\Delta G = \Delta H - T\Delta S \ldots\ldots (6)$$

4. Discussions

4.1 Removal of Cd (II) by Ion Imprinted Polymer (IIP)

The synthesized Cd (II) - (IIP) was utilized to remove imprinted metal ions from aqueous media by optimizing diverse experimental environments.

4.1.1 Effect of pH

The pH of medium has an imperative role during adsorption studies. The adsorption examination for Cd (II) was done over the range of pH 2-10 by taking 5 mg of polymer with 10 ml of 5 ppm salt solution at shaking speed of 100 rpm for 30 min at room temperature. It was perceived that with the rise of pH the % adsorption was increased as visible in figure 4,

the maximum efficiency was observed at 9 pH. At lower limits of pH, the binding groups present in template specific sites were protonated as a result of increase in hydrogen ion concentration increase in H+ ion concentration. In acidic pH, the lower extent of adsorption rate confirmed that the hydrogen ions are the competitor ions of imprinted ions and nitrogen of pyridine groups on polymer surface is accountable for the attachment of Cd (II) (Luo et al., 2011, Guo et al., 2014).

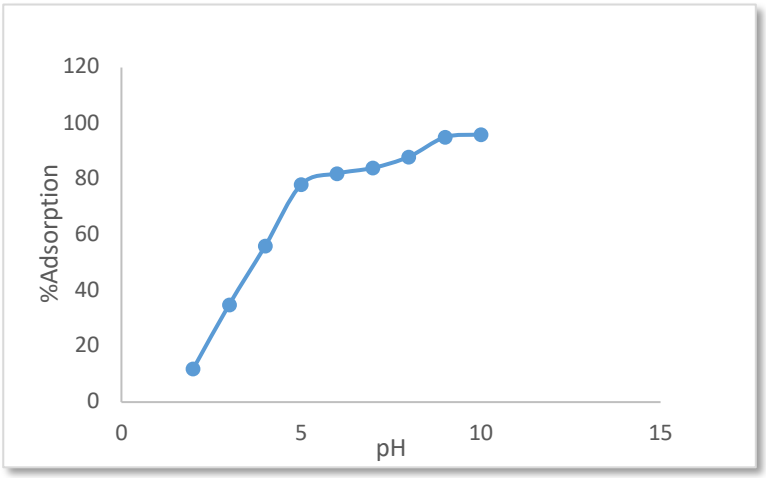


Figure 4. pH effect on adsorption of Cd (II) onto an ion imprinted polymer

4.1.1 Effect of Adsorbent Amount

Another topmost major factor accountable for adsorption competence is amount of MIP for adsorption of Cd ions at a given initial concentration (Memon et al., 2007& 2009). Studies on effect of adsorbent amount for the elimination of Cd (II) ion was done by changing the amount of adsorbent from 0.001-0.01 g per 10 ml of 5 ppm salt solution. As presented in figure. 5 the % adsorption increases till 0.005 g, and after that there is no significant change was observed. This shows that at certain concentration of adsorbent % adsorption increases and after that it shows no major change due to saturation of vacant sites and fixed amount of adsorbate. After 0.007 g of adsorbent no significant increase was observed in % adsorption

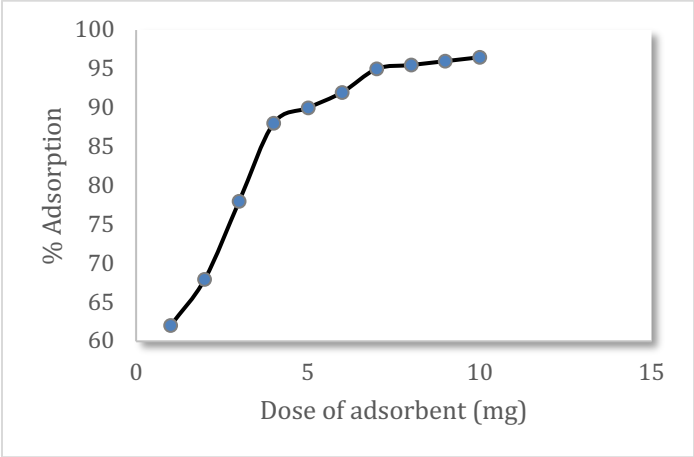


Figure 5: Adsorbent Amount effects on adsorption of Cd (II) onto ion imprinted polymer (II)

4.1.3 Effect of Shaking Speed

The adsorption capability is depending on another important parameter i.e., shaking speed for the adsorption of metal ions (Zhang et al., 2012). On the adsorption of Cd (II) the influence of shaking speed was observed from 25-150 rpm. As revealed in figure. 6 it was observed that with increase in shaking speed the % adsorption increases till 100 rpm after that a decrease was seen with increasing shaking speed. So, the 100-rpm shaking speed was used for more studies on individual metal ions.

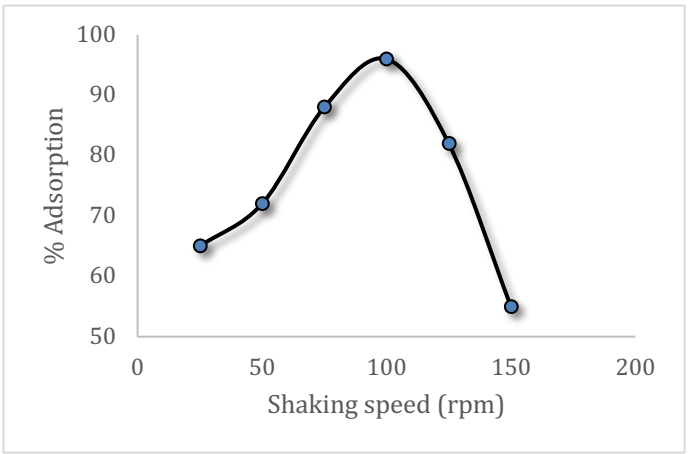


Figure 6: shaking speed effect on adsorption of Cd (II) onto an ion imprinted polymer

4.2. Kinetics of Adsorption

The time for completion of adsorption reaction was determined in a batch experiment by shaking 5 mg of adsorbent in metal salt solution of preferred concentration for 5-100 minutes at previously optimized adsorption parameters i.e. 9 pH, 30 0C temperature etc. It was observed that % adsorption increases till 30 min and after that there is no major change was observed (Qiu et al., 2009). The adsorption process followed pseudo 1st order rate equation as shown in Fig. 7. The rate constant was calculated as 0.011min-1 with R2 0.932 using Lagergren equation.

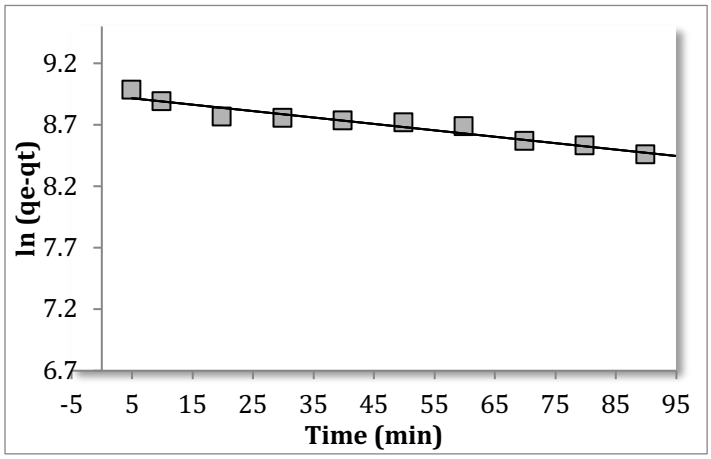


Figure 7: Kinetic studies for the adsorption of Cd (II) onto an ion imprinted polymer (IIP)

4.3 Thermodynamic studies

For studying consequence of temperature on Cd (II) ions adsorption by an ion imprinted polymer was carried out in the temperature range of 283-363 K, at 9 pH, for 30 min of shaking time. The maximum efficiency was observed at low temperature and was decreased at high temperature this reveals exothermic and spontaneous nature of adsorption process with ΔH -20.9 kJmol-1, ΔS -5.3 kJmol-1, ΔS -0.054 kJmol-1K-1and R2 0.93, shown in figure 8.

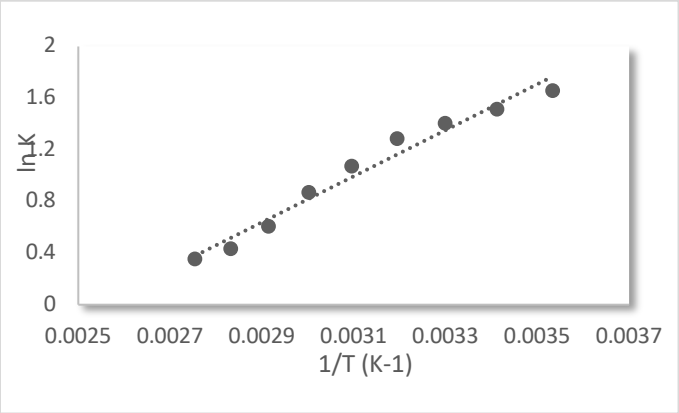


Figure 8: Thermodynamic studies for the adsorption of Cd (II) onto an ion imprinted polymer (IIP)

4.4 Equilibrium Studies:

Adsorption studies were performed by applying Langmuir and Freundlich model. The adsorption data is well fitted to both Langmuir and Freundlich models as shown in 9 and 10. The monolayer and multilayer adsorption capacities along with R2 and other constant parameters are mentioned in Table 3.

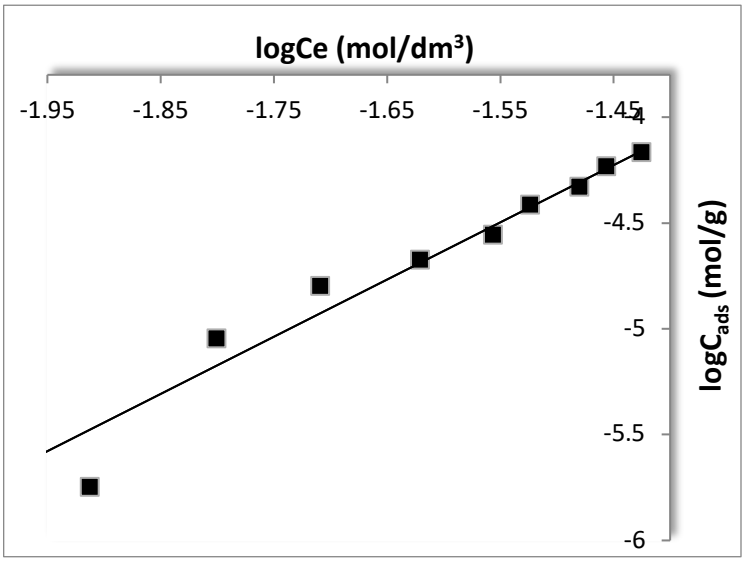


Figure 9: Freundlich adsorption isotherm for removal of Cd ions from aqueous solution

Table 3. Adsorption isotherm parameters for Zn (II) & Cd (II) Ion Imprinted Polymers

Adsorption isotherms	Isotherm parameters	Cd (II)
Freundlich isotherm constants	1/n	0.359 ± 0.02
	K_F (mmol/g)	1.158 ± 0.12
	R^2	0.971 ± 0.003
Langmuir isotherm constants	K_L (mmol/g)	0.040 ± 0.005
	b (dm^3/mol)	8173 ± 2.9
	R_L	0.430 - 0.070
	R^2	0.960 ± 0.003

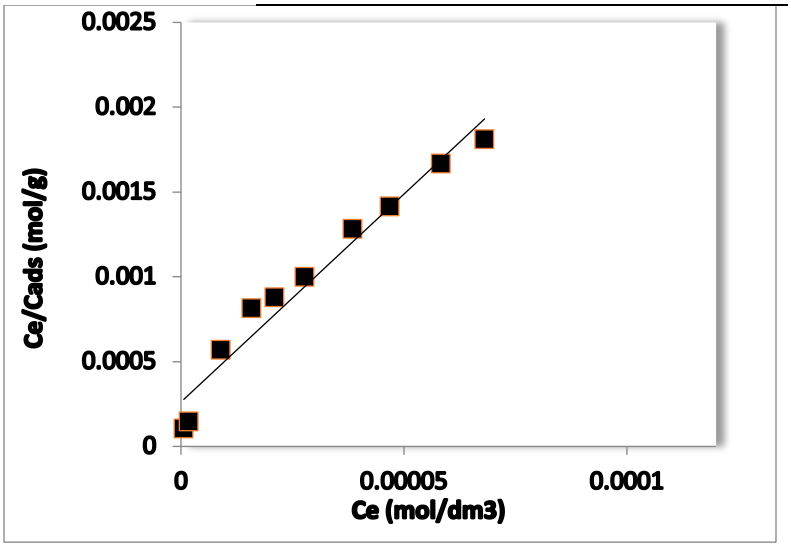


Figure 10: Langmuir adsorption isotherm for removal of Cd ions from aqueous solutions

4.5. Selectivity Studies:

In order to examine the specificity of both synthesized Cd (II) ion imprinted polymer for their respective metal ions competitive adsorption of other similar metal ions were studied. The comparative study for Pb (II) & Al (III) was done via preparing Cd (II)/ Pb (II) & Cd (II)/Al (III) binary mixed solutions of similar concentration for both metal ions. Adsorption study was done by using this mixed solution in batch method. The selectivity of metal ion depends on the ionic radius and oxidation state of comparative metals. The ionic radius of imprinted metal ion Cd (II) = 95 pm smaller then Pb (II) = 119 pm , and Al has larger oxidation state with smaller ionic radius of 53.5 pm. The distribution coefficients (Kd), and selectivity coefficient k (k= Kd of template ion/kd of comparative ion) of comparative selectivity study are summarized in Table 4 which revealed that selective adsorption potential for imprinted metal ion Cd (II) by Cd (II) – IIP confirmed by decrease in Kd & k values of comparative metal.

Table 4. Parameters of selectivity studies for Cd (II) Ion Imprinted polymer

Metal ion	Kd	K
Cd (II)	3.8	--
Pb (II)	1.12	3.39
Al (III)	1.26	2.9

4.6. Desorption and Regeneration Studies

The economic achievement of adsorption evolution be liable upon adsorbent reusability, consequently desorption and regeneration study is very significant (Fan et al., 2012). In present study the reusability of synthesized Cd (II) – IIP was tested by repeating adsorption- desorption cycles for seven times by using same adsorbent. The effect of reusability as shown in figure 11 displayed minor decrease of almost 15 % for Cd (II) – IIP in adsorption capability of adsorbent after seven repeated cycles. The results revealed that the synthesized ion imprinted polymers can successfully be reutilized for further applications.

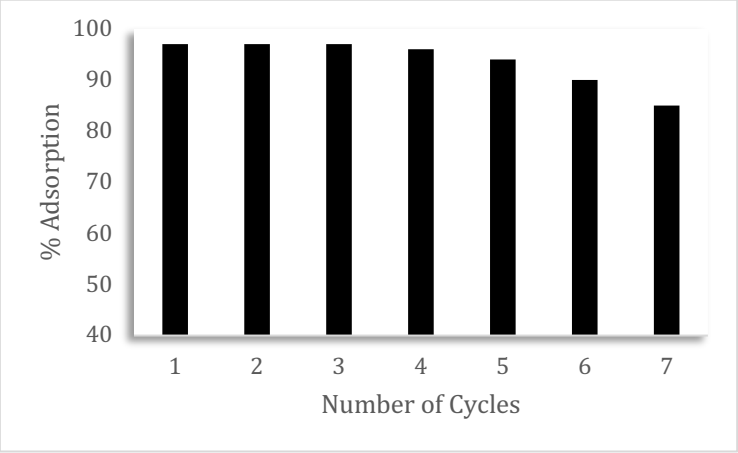


Figure 11: The effect of reusability of Cd (II) Ion imprinted polymer for adsorption of Cd (II) ions

4.7 Analytical applications to water samples

The synthesized ion imprinted polymers (IIP's) was used to remove Cd ions from environmental water samples. Water samples were taken from industrial areas of district Sadiqabad & Rahim Yar Khan. Total number of six samples was collected of which three of ground water and three of surface water. The collected samples were filtered to remove particulars. The adsorption study of metal ions was done by spiking procedure by preparing 10 ppm Cd (II) solution in real water samples and

in deionized water. The atomic absorption absorbance measurements were done for spiking samples and for metal ion solution in deionized water and the amount of metal ion in real sample were estimated as (table 5).

Table 5 Removal of Cd ions from environmental water samples using Cd (II) ion imprinted polymer

Samples	Determined Amount of metal ion in (µg /L)		Adsorption (%)
Abbasia town (RYK)	Cd (II)	2.45	90.0 ± 1.0
Gulshan-e-Arjumand (RYK)	Cd (II)	2.11	89.0 ± 1.2
Canal road (RYK)	Cd (II)	1.85	98.0 ± 0.7
Link road (SDK)	Cd (II)	2.90	90.0 ± 1.2
Mantaqabad (SDK)	Cd (II)	1.99	91.0 ± 0.5
Mukhtargarh (SDK)	Cd (II)	2.81	88.0 ± 1.4

5. Conclusions

Molecularly imprinted polymers (MIP's) are exceptionally crossed linked and extremely specific in nature for binding certain marks. The current work explored the fabrication of ion imprinted polymers (IIP) with efficient removal capability for targeted metal ions from aqueous solutions and environmental samples. The removal parameters were standardized in 30 min as the adsorption was equally fast due to geometric desirability between metal ions and template hollows in the polymer matrix. The selectivity and reusability study for fabricated ion imprinted polymers (IIP's) demonstrates great selectivity to template metal ions in presence of other competitor metal ions and can be reusable without misplacing adsorption ability.

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Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

Data, Materials, and Code Availability

The datasets generated and/or analysed during this study are available from the corresponding author upon reasonable request.

Authors' Contributions

All authors contributed equally to the conception, development, and writing of this manuscript and have approved the final version for submission.

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Article

Current Status and Countermeasures of Water and Soil Resources in the Syr Darya River Basin of Kazakhstan

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Abstract: Climate change and anthropogenic activities pose significant challenges to agricultural sustaina-bility in the Syr Darya River Basin. This study investigates the spatial distribution of land use and assesses the current state of water resource development and utilization in the basin. Furthermore, it analyzes trends in temperature and precipitation from 1950 to 2021. Our findings reveal that between 2000 and 2015, the areas of cultivated land, forest land, grassland, construction land, and bare land increased overall. During 1950–2021, the basin experienced a temperature increase of 0.323°C per decade and a precipitation increase of 1.393 mm per decade. The accurate classifi-cation and monitoring of land use and cropping systems are crucial for clarifying the spatial dis-tribution and utilization patterns of land and water resources in the Syr Darya region. Such analysis is pivotal for diagnosing the driving mechanisms behind soil salinization and ecological degradation. Consequently, this study provides a robust data foundation for formulating integrated management strategies, including the optimization of agricultural practices and the implementation of precision water allocation. Ultimately, this research establishes a scientific basis for evidence-based decision-making in regional salinization control and ecological rehabilitation.

Keywords: Syr Darya River Basin; Spatial distribution of land Use; Water resources

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1. Introduction

Since the Industrial Revolution, global warming has become an indisputable fact. The Intergovernmental Panel on Climate Change (IPCC) stated in its Sixth Assessment Report (2023) that human activities are the primary driver of this warming. The report indicates that the global surface temperature in 2020 was 1.1°C higher than the aver-age for the period 1850–1900 (Jiang et al., 2023). Climate change and human activities have also profoundly impacted agricultural development in the Syr Darya River Basin. For decades, the high-intensity exploitation of soil and water resources has disrupted the basin's ecological balance, triggering a series of environmental issues such as soil pollution, salinization, erosion, and desertification (Duan et al., 2022).

Human activities, particularly irrigation, have profoundly influenced agricultural development in the Syr Darya River Basin. Since the 1960s, the former Soviet Union initiated extensive agricultural development in the region (Zhang et al., 2019), which was accompanied by the construction of irrigation canals. However, outdated irriga-tion

techniques and aging drainage infrastructure have led to widespread salinization in these irrigated areas (Liu et al., 2022). The Soviet era saw the construction of nu-merous large-scale water conservancy projects and reservoirs in the basin. Addition-ally, the intensive reclamation of land resources in the Fergana Basin and the mid-dle-lower reaches degraded the local soil ecological environment. Moreover, inefficient irrigation practices and the cultivation of water-intensive crops, such as cotton, have caused crop yields to decline or even fail, resulting in a continuous deterioration of farmland soil quality (Bissenbayeva et al., 2021).

Climate change and human activities have emerged as the primary challenges to agricultural sustainability in the region. Therefore, it is crucial to conduct a compre-hensive survey on agricultural resources in the Syr Darya River Basin. Based on land use data and global climate data from the middle and lower reaches of the basin, this study investigates the land use patterns and the trends in temperature and precipita-tion. The findings are intended to provide a scientific reference for managing water and land resources within the basin.

2. Methodology

2.1 The Study Area

The Syr Darya River Basin is situated in the hinterland of the Eurasian continent, within the coordinates 61°6′–78°24′ E and 39°23′–46°6′ N. The river originates in the Middle Tien Shan Mountains north of the Pamir Plateau. It then flows through the Fergana Valley and the Golodnaya Steppe, crosses the Kyzylkum Desert, and traverses four countries from east to west—Kyrgyzstan, Uzbekistan, Tajikistan, and Kazakh-stan—before finally drain-ing into the North Aral Sea. Topographically, the terrain of the basin slopes from the southeast to the northwest. Hydrologically, the Syr Darya is the longest river in Central Asia, stretching 2,219 kilometers from the confluence of its headstreams, the Naryn and Karadarya Rivers. Climatically, the region is strongly influenced by altitudinal variations, resulting in a wetter climate at higher elevations and a drier climate at lower elevations.

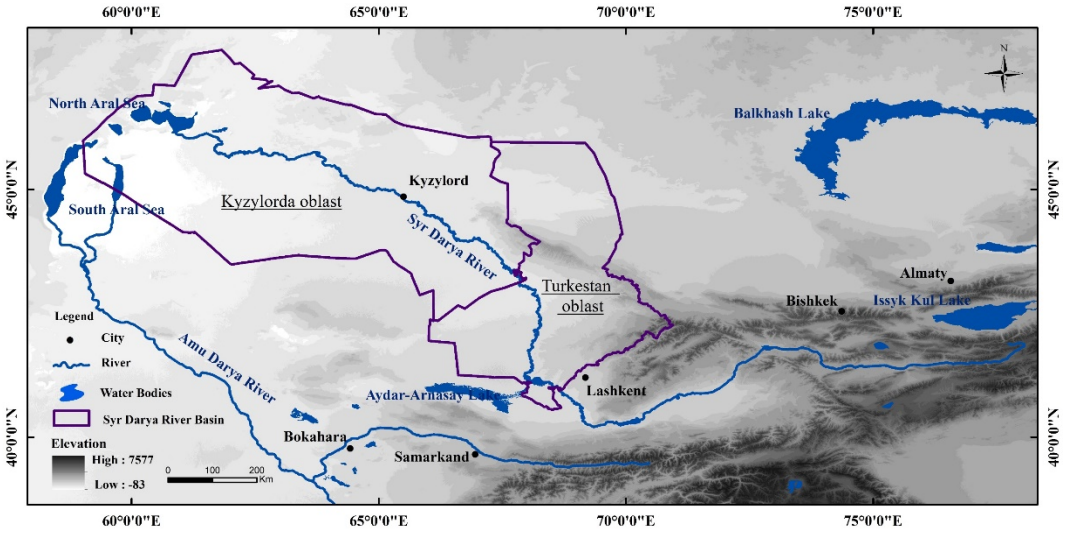

Figure 1. The location of the study area.

2.2 Data source

The Landsat 8 satellite is equipped with a multispectral imager that captures data across eight distinct spectral bands, covering the visible, near-infrared, and short-wave infrared regions. This multi-band observation capability enables the derivation of rich spectral information from the Earth's surface, significantly enhancing the potential for accurate land cover classification.

In this study, Landsat-8 imagery was acquired through the Google Earth Engine (GEE) platform. The dataset underwent preprocessing steps, including radiometric calibration and geometric correction, to mitigate atmospheric effects and normalize surface reflectance values, thereby improving data quality and usability. Subsequently, a suite of image processing functions and statistical tools available in GEE were employed to extract features relevant to land use and land cover classification. These features encompass spectral indices, textural characteristics, and morphological at-tributes. Finally, a supervised classification approach was implemented utilizing training samples defined via GEE's annotation tools, in conjunction with a feature ex-traction algorithm, to assign a specific land use category to each pixel in the imagery. This study utilized data from four years: 2000, 2005, 2010, and 2015.

Temperature and precipitation data were sourced from the Global Climate Dataset (CRU TS), produced by the U.K.'s National Centre for Atmospheric Science. This dataset has a spatial resolution of 0.5 degrees and a monthly temporal resolution. The CRU data used in this paper cover the period from 1950 to 2020 (Harris et al., 2017).

2.3 Research Methods

Long-term trends of temperature and precipitation in the study area were analyzed using the rank-based Mann-Kendall nonparametric statistical test, which is commonly used to test the significance of trends and has been widely used in hydro-meteorological trend tests and analyses. The methodology of the M-K statistical test is as follows (Zou et al., 2019), For a given time series $Xi\{Xi, i=1,2, \ldots, n\}$, the Mann–Kendall S Statistics could be calculated.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\,(T_J - T_I)$$

$$sign\,(T_j - T_i) = \begin{cases} 1 \ if \ T_j - T_I > 0 \\ 0 \ if \ T_J - T_i = 0 \\ -1 \ if \ T_j - T_i < 0 \end{cases}$$

This test is particularly well-suited for trend detection in non-normally distributed data, such as hydro-meteorological variables, as it does not require the data to follow a specific distribution and is robust against outliers.

For series with n≥10, the statistic S is approximately normally distributed. The standardized test statistic Z is then computed and compared against the critical values $Z_{1-\alpha/2}$ from

the standard normal distribution to determine the trend's significance. At a given significance level α (typically $\alpha = 0.05$), if $|Z| > Z1 - \alpha/2$ (e.g., Z0.975=1.96), the null hypothesis is rejected, indicating a statistically significant trend in the series; a positive Z signifies an upward trend, while a negative Z indicates a downward trend.

In summary, the combined use of the M-K test and Sen's Slope estimator offers a robust and effective methodology. It not only detects long-term trends and rates of change in temperature and precipitation but also provides reliable evidence for assessing hydrological responses to climate change.

3. Results

3.1 Current status of land use in the Syr Darya River Basin

This study employed a Random Forest classifier to perform land cover classification based on the multi-band spectral characteristics and derived indices from Landsat 8 imagery. Areas with annual maximum NDVI values consistently below 0.15, and from which water bodies, cloud shadows, and built-up structures were excluded through visual interpretation, were defined as 'bare land'. In terms of the spatial distribution pattern of land use, arable land is mainly concentrated in the areas along the Syr Darya River and its tributaries in a belt-shaped distribution, which is due to the fact that the areas on both sides of the Syr Darya River are relatively rich in water re-sources due to the relatively fertile soils, which gives them a unique advantage in agricultural development.

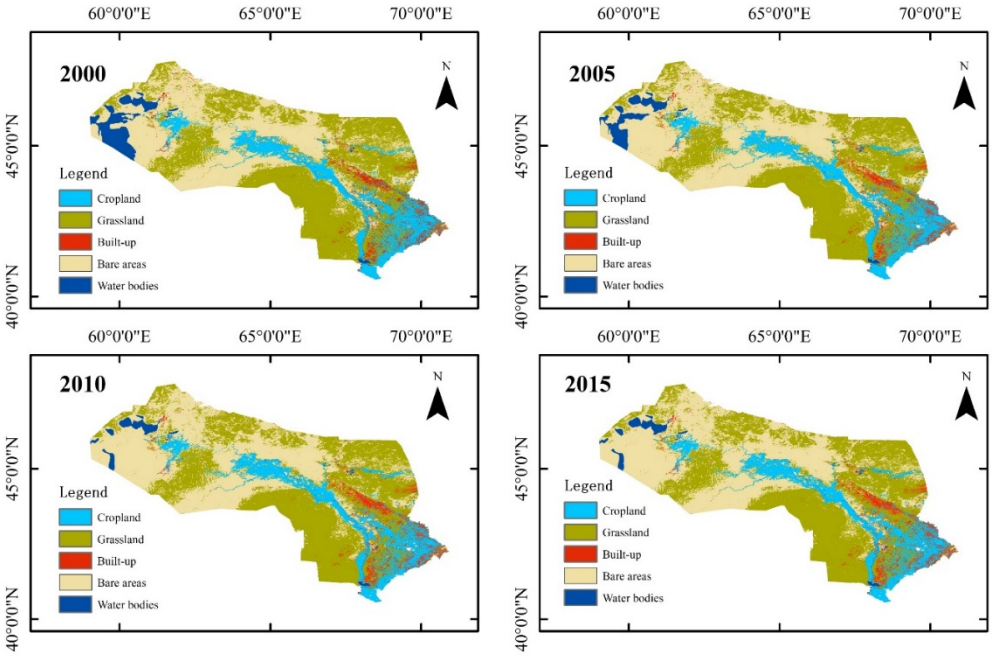

Figure 2. Land use types of study area

In terms of the spatial distribution pattern of land use, arable land is mainly concentrated in the areas along the Syr Darya River and its tributaries in a belt-shaped distribution, which is due to the fact that the areas on both sides of the Syr Darya River are relatively

rich in water resources due to the relatively fertile soils, which gives them a unique advantage in agricultural development. The areas of arable land, forest land, grassland, construction land and bare land all show an increasing trend on the whole, with the greatest increase in the area of bare land, where deserts, the Gobi and bare soil occupy more than half of the area in Turkestan Oblast, and in Kyzylorda Ob-last, where bare land accounts for 75.7% of the total area of the Oblast, and where arable land's share of the Oblast's area has remained basically stable at between 1.5% and 1.6%. Bare land is the largest land type in Kyzylorda and Turkestan oblasts. The size of the area of the other five land-use types is: forest land > cropland > water bodies > grassland > construction land.

A stratified random sampling method was employed to select 1000 validation points across the study area. These points were visually interpreted with reference to high-resolution imagery available in Google Earth Engine. Subsequently, a confusion matrix was generated, which yielded an overall accuracy of 89%.

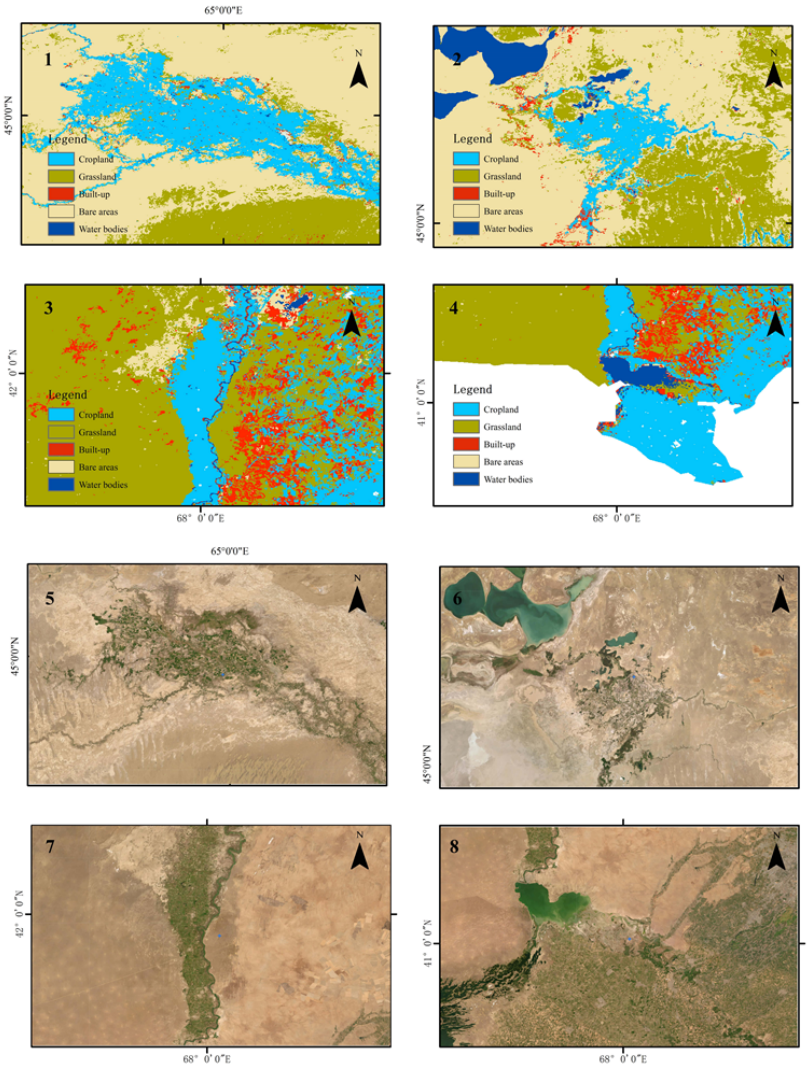

Figure 3. The comparative Analysis of the Land Cover Classification Results against the Land-sat 8 Remote Sensing Image

Table 1. The Classification Accuracy Assessment Results

Type	Overall Accuracy	Kappa Coefficient	User's Accuracy	Producer's Accuracy
cropland			0.89	0.86
grassland			0.80	0.82
Built-up	0.89	0.85	0.83	0.89
Bare areas			0.85	0.82
Water bodies			0.89	0.86

There has been a marked change in the cropping structure of crops in the riverine irrigation areas of the Syr Darya basin, with a shift from water-intensive cotton to less-demanding wheat and other cereals. This transformation is due to two main fac-tors, the shortage of irrigation water and changes in domestic politics on the supply and demand for food. Cotton is the second largest agricultural export category in Kazakhstan after grain, and Turkestan Oblast is the only cotton-producing region in Ka-zakhstan, with the planting area mainly concentrated in the Chardara and Makhtaral regions. As of 2018, the area under cotton cultivation in Turkestan Oblast has reached 227,000 hectares, with an average annual cotton planting area of 180,000-200,000 hectares. Rice is the main crop grown in Kyzylorda oblast with a long history of cultivation, and the oblast accounts for 85-88% of the country's rice production. As of 2018, the area under rice cultivation has reached 103,000 hectares, and rice production in the region has declined sharply in recent years due to degradation of irrigation and drainage facilities.

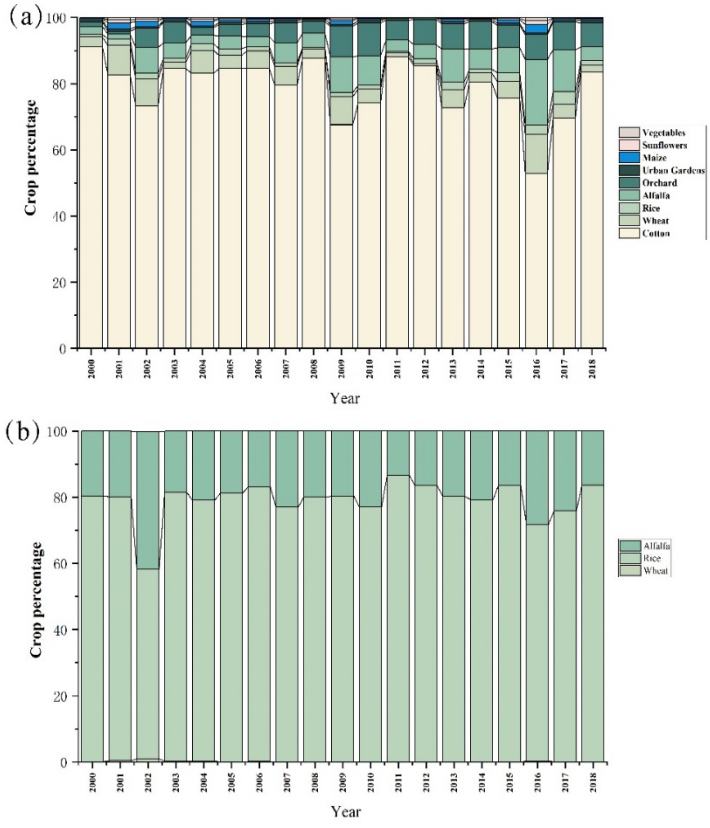

Figure 4. The Planting structure of the study area. (a) Kyzylord Oblast; (b) Turkestan Oblast.

3.2 Trend analysis of temperature and precipitation in the Syr Darya River Basin

Over the past 70 years, the Syr Darya River Basin has experienced a clear warming trend. The annual mean temperature for the basin, along with its 5-year moving aver-age, is shown in the figure. The temperature increased at a rate of 0.323°C per decade, a trend slightly more pronounced than the 0.16°C per decade observed in the broader arid zone of Central Asia. The lowest annual mean temperature of 7.05°C was record-ed in 1972, while the highest, 10.73°C, occurred in 2016.The average annual precipitation in the basin is 357.4 mm, with substantial interannual variability. The maximum precipitation of 594.9 mm was recorded in 1969, contrasting with the minimum of 231.7 mm in 1995, resulting in a difference of 363.2 mm. Figure 3 illustrates the year-to-year changes in annual precipitation and the corresponding 5-year moving average. A linear regression analysis indicates a slight upward trend in annual precipitation from 1950 to 2020, with an increase of 1.393 mm per decade. The precipitation variability in the basin exhibits a relatively regular pattern of fluctuation.

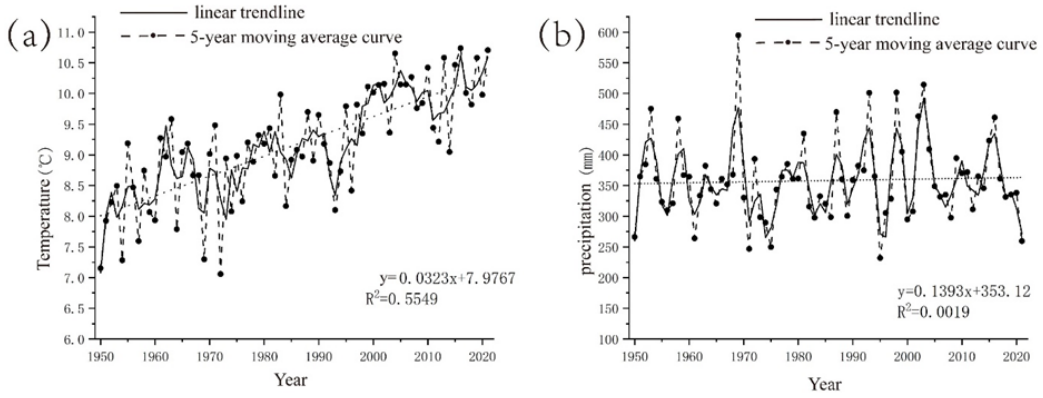

Figure 5. Average annual trends in the Syr Darya basin, 1950-2021 (a) Temperature (b) Precipitation

4. Discussion

4.1 Impact of climate change on agricultural development in the Syr Darya River

The Mann-Kendall trend analysis for the Syr Darya River Basin reveals a distinct upward trend in temperature since 1950, with a rate of increase of 0.323°C per decade. This warming trend became particularly pronounced and statistically significant from the 1980s onward (passing the significance test at the 95% confidence level). The analysis identified an intersection point between the forward and backward sequences in 1991. However, as this point falls outside the confidence interval, it does not indicate a statistically significant abrupt change in temperature. This significant temperature rise promotes increased evaporation from lakes and watersheds, thereby exacerbating cropland salinization (Shi et al., 2020).Regarding precipitation, the Mann-Kendall results indicate a slight increase over the past 70 years. Multiple intersections between the sequences occur within the confidence interval, suggesting that precipitation varies in a fluctuating manner without a distinct abrupt change.

The linear regression analysis indicates a slight increasing trend in annual precipitation from 1950 to 2020, at a rate of approximately 1.393 mm per decade. However, the coefficient of determination (R^2) for this linear model is only 0.05, suggesting that the time variable explains a very limited portion of the variation in precipitation. This result is consistent with the conclusion drawn from the Mann-Kendall test: the M-K test shows multiple crossing points within the confidence interval and detects no significant monotonic trend ($p > 0.05$). In summary, the long-term variation of annual precipitation in the study area is characterized by strong interannual fluctuations, rather than a clear and stable linear increasing trend.

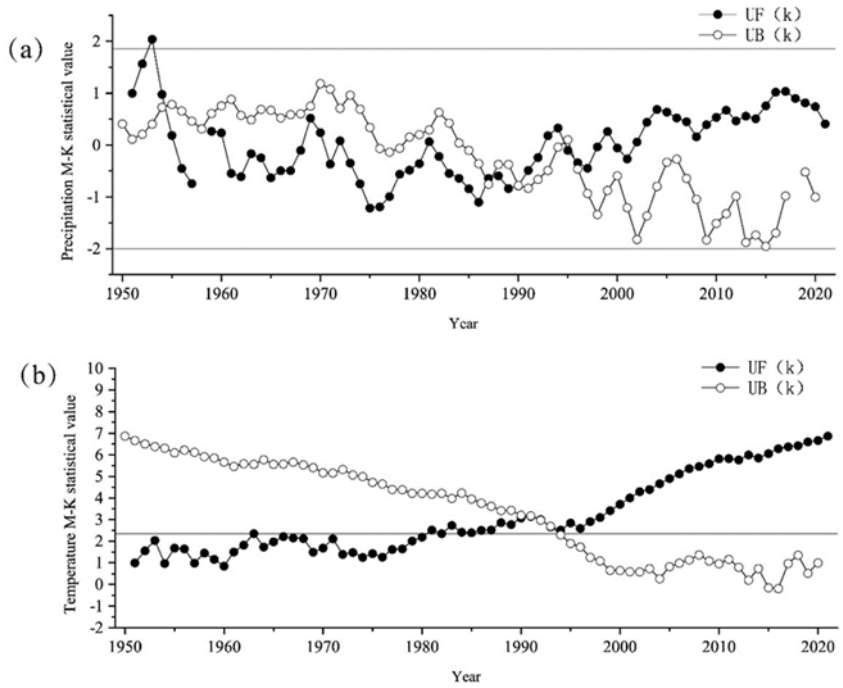

Figure 6. Mann-Kendall mutation test of temperature and precipitation in the Syr Darya River Basin from 1950 to 2021

4.2 Impact of human activities on the agricultural development of the Syr Darya River

In recent years, the cropping structure in the riverine irrigation areas of the Syr Darya Basin has undergone a marked shift. There has been a transition from water-intensive cotton cultivation to less demanding crops such as wheat and other cereals (Leng et al., 2021). This shift is primarily driven by two factors: irrigation water scarcity and changes in domestic policies affecting grain supply and demand.

Human activities have profoundly impacted the basin's ecology. The population is predominantly rural, with agriculture serving as the main economic activity. From the 1960s to the 1980s, the population grew rapidly from 1.337 million to 2.754 million, an increase of 105.9%, fueled by the expansion of agriculture and other economic sectors. The water resource development system in the Syr Darya Basin is among the most complex in the world. To meet irrigation and energy needs, a series of large and small reservoirs were constructed between 1940 and 1983, including major ones such as the Chardara, Andijan, and Tortkul reservoirs, with a total capacity of 35 km^3. A network of major canals, ranging

in length from 25 to 344 kilometers, distributes the water. These reservoirs intercept and store water resources, which are then conveyed through an extensive canal network to support irrigated agriculture.

Table 2. The land use types in the Syr Darya River Basin.

Canal name	Capacity（m^3/s）	Length（km）
Great Namangan	61	162
Northern Fergana	110	165
Great Fergana	270	344
Great Andijan	200	110
Southern Fergana	130	103
Akhunbabaeva	60	50
Upper Dalverzin	40	30
Lower Dalverzin	78	25
South Golodnaya Steppe	300	127
Kirov	260	120
Kyzylkum	200	115

5. Conclusion and Recommendations

Based on the findings regarding land use and climate trends, this study proposes an integrated remediation framework to address the interconnected challenges of soil salinization and irrigation inefficiency in the Syr Darya region. The strategy centers on a systematic combination of engineering and biological interventions.

The installation of a subsurface drainage system in Yangiyer District is designed to directly combat secondary salinization by lowering the water table and leaching dissolved salts from the root zone. Concurrently, modernizing key irrigation canals near Kyzylorda City with concrete lining and automated gates is crucial for water conservation. This intervention is projected to be the primary driver for increasing irrigation efficiency from 45% to 85%, by minimizing conveyance losses and enabling precise, demand-based water allocation.

Complementing these engineering solutions, the introduction of salt-tolerant specie, *Suaeda salsa* (seepweed) and wolfberry, represents a shift toward sustainable land use. Cultivating *Suaeda salsa* on unproductive salt-alkaline wasteland facilitates the phytoremediation of degraded soils while generating economic returns through a market-oriented biomass offtake model. Similarly, promoting wolfberry agroforestry on marginal land diversifies farmers' income sources by utilizing abandoned plots (Xu et al., 2024).

The synergy of these measures—where engineering controls water and salt dynamics, and biological strategies stabilize and monetize reclaimed land—is projected to create a virtuous cycle. This integrated system is expected to reduce overall irrigation water consumption by 30% while increasing crop yields by an estimated 15%, offering a viable pathway for enhancing agricultural resilience in arid, salinity-prone regions (Chen et al., 2024).

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Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

Data, Materials, and Code Availability

The datasets generated and/or analyzed during this study are available from the corresponding author upon reasonable request.

Authors' Contributions

All authors contributed equally to the conception, development, and writing of this manuscript and have approved the final version for submission.

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The Role of AI Tools In Shaping Teaching Practices for Design and Communication Skills: A Study in Ghana

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Abstract: The integration of Artificial Intelligence (AI) into education offers transformative possibilities for enhancing design and communication pedagogies, particularly in resource-constrained settings. This study examines the adoption, impact, and barriers to AI use in Ghanaian secondary and technical education, with a focus on design-related subjects. Using a quantitative cross-sectional design, data were collected through structured questionnaires administered to 108 teachers. Findings highlight a pronounced disparity between teachers' recognition of AI's pedagogical potential and its actual implementation. Respondents widely acknowledged AI's capacity to support student-centered learning, enrich teaching strategies, and improve outcomes (all $p < 0.001$). However, adoption remains limited. Reported barriers include inadequate ICT infrastructure (62%), lack of formal training (only 23.1% had received any), ethical concerns, and poor alignment with existing curricula. Logistic regression further identified postgraduate qualification, AI-specific training, adequate ICT resources, and engagement with technical subjects as significant predictors of adoption. The results underscore a systemic digital divide that continues to constrain the pedagogical use of AI in Ghana. While its value for fostering innovation in design and communication education is evident, sustained progress requires coordinated policy and institutional support. A multi-pronged strategy is essential prioritizing investment in digital infrastructure, comprehensive and discipline-specific teacher training, ethical frameworks, and curricular reforms tailored to local contexts. Addressing these gaps will enable more equitable and effective AI integration, advancing both educational quality and technological capacity within resource-limited environments.

Keywords: Artificial Intelligence; Design; Education; SDG 4: Quality Education; Technical and Vocational Education and Training

1. Introduction

The integration of Artificial Intelligence (AI) into education is reshaping teaching practices, curriculum delivery, and skills development worldwide. AI is increasingly recognised not merely as a supportive technological tool but as a catalyst for pedagogical innovation with significant implications for knowledge transfer, employability, and creativity. Disciplines that prioritise design and communication skills particularly benefit from AI's adaptive and interactive capabilities, making them fertile ground for experimentation and reform.

In Ghana, persistent systemic challenges such as large class sizes, limited resources, and the need for contextually relevant teaching approaches have amplified interest in AI's potential. Emerging evidence suggests that AI can foster creativity, collaboration, and critical communication skills within these constraints (Osondu, Francois, & Strycker, 2024; Liekum, 2025). At the same time, however, ethical, pedagogical, and infrastructural considerations continue to shape both global and local debates. This study situates Ghana within these broader conversations, while identifying nationally specific opportunities and barriers to AI adoption in design and communication education. It further addresses a critical gap in scholarship by exploring how AI can both mitigate structural inequities and enrich creative teaching practices in this context.

2. Literature Review

2.1 Global Perspectives on AI in Education

The adoption of AI in education has become a global phenomenon, largely driven by its capacity to personalise learning, improve efficiency, and prepare students for evolving labour markets. Applications such as adaptive learning platforms, intelligent tutoring systems, and automated assessment tools have redefined individualised and collaborative learning (Labadze, Grigolia, & Machaidze, 2023). In higher education, generative tools such as ChatGPT are influencing knowledge creation, assessment, and dissemination practices (Borger et al., 2023).

Nonetheless, global scholarship highlights ethical, social, and governance challenges. Concerns about academic integrity, equity, and student agency remain central (Al-Zahrani & Alasmari, 2024), while Dwivedi et al. (2019; 2023) emphasise the complexities of integrating generative AI into educational policy, pedagogy, and professional practice. In creative fields, where originality and critical thinking are paramount, educators' experiences with AI reveal a mixture of enthusiasm and caution (Kruk & Kałużna, 2024). Collectively, these perspectives underscore the dual promise and risk of AI in transforming pedagogy, necessitating careful governance and context-sensitive integration.

2.2 AI and 21st-century skills

Artificial intelligence (AI) is reshaping education by transforming how students acquire design and communication skills competencies vital for employability and civic engagement in the twenty-first century. Globally, AI is viewed both as an enabler of personalisation, feedback, and creativity, and as a source of ethical, equity, and assessment concerns (Dwivedi et al., 2019; Dwivedi et al., 2023; Al-Zahrani & Alasmari, 2024). Tools such as

chatbots, large language models, and generative media are increasingly embedded into curricula. In Ghana, these developments align with national priorities to enhance educational quality, relevance, and labour market alignment.

2.3 AI in Ghanaian Education

In Ghana, AI adoption is increasingly framed as a strategy to address enduring educational challenges, including resource shortages and misalignment between curricula and labour market demands (Gyamfi, Dayie, & Asiedu, 2022). Policy-oriented research highlights AI's role in improving instructional quality and expanding access to innovative teaching tools (Osondu et al., 2024). Studies further show that Ghanaian educators perceive AI as capable of enhancing teaching effectiveness and fostering student engagement, particularly in higher education and teacher training (Liekum, 2025; Adobea, Nyantakyi, Fosu, & Tuffour, 2024).

However, teacher preparedness remains uneven. Research on AI literacy reveals that while some educators, particularly at the basic school level, are beginning to acquire relevant knowledge, sustained capacity-building is essential for meaningful integration (Arkorful et al., 2025). These findings suggest that beyond technical support, AI must be embedded as a pedagogical tool to cultivate creativity, critical communication, and collaborative design practices.

2.4 Educator Readiness and Teacher Training

Teacher readiness is central to AI adoption. Studies show limited AI literacy among Ghanaian teachers, underscoring the need for professional development (Arkorful et al., 2025). Evidence from language teaching demonstrates improved learning outcomes through AI use, though gaps in digital competence remain (Adobea et al., 2024). International findings also show chatbots providing systematic learning support (Labadze, Grigolia, & Machaidze, 2023), while applications in second language learning enhance motivation and translation skills (Kruk & Kałużna, 2024). For preservice teachers, AI-based training fosters digital literacy and 21st-century skills (Bircan, Şeref, & Nacaroğlu, 2025), reinforcing the need to embed AI training in Ghana's Colleges of Education (Liekum, 2025).

2.5 Challenges and Emerging Concerns

Despite its promise, AI adoption in Ghana faces significant hurdles. Ethical and governance challenges particularly around data privacy, academic integrity, and equitable access persist (Dwivedi et al., 2019; 2023). Teachers' perceptions also strongly influence adoption, with studies in early childhood education showing cautious openness, tempered by concerns over depersonalisation and sustainability (Mohammed, 2023).

At the tertiary level, debates increasingly link AI to employability, as universities explore how it can foster competencies such as problem-solving, digital communication, and teamwork (Segbenya et al., 2023). Yet infrastructural constraints, inconsistent access to digital tools, and the absence of a national AI framework continue to limit progress. Moreover, pedagogical concerns remain: while AI can streamline instruction and support personalised learning, over-reliance risks undermining human-centred teaching approaches

that are vital for developing creativity and communicative competence (Shum & Luckin, 2019).

3. Research Gap

Although existing studies connect AI adoption to innovation in teaching and employability skills, limited attention has been paid to its role in design and communication education in Ghana. Prior research has primarily focused on technical disciplines, literacy, and general higher education contexts (Arkorful et al., 2025; Adobea et al., 2024), overlooking the unique demands of design pedagogy, which emphasises creativity, collaboration, and iterative communication.

Equity and educator experience also remain underexplored, particularly regarding how disparities between rural and urban institutions affect AI adoption. This study addresses these gaps by examining how AI tools are integrated into teaching practices for design and communication skills in Ghana, offering insights into the opportunities and constraints that shape transformative pedagogy in this field.

The study addresses the following research questions:

- ***RQ1:*** What are the Types of AI Tools Teachers Use to Support the Teaching of Design and Communication Skills in Selected Schools in Ghana?

- ***RQ2:*** How does the Use of AI tools influence teaching methodologies and instructional strategies in the Delivery of Design and Communication-Related Subjects in Selected Schools in Ghana?

- ***RQ3:*** How Effective are AI Tools in Enhancing Student Learning Outcomes in Design and Communication Skills Subjects in Selected Schools in Ghana?

- ***RQ4:*** What are the Challenges Faced by Teachers in Integrating AI Tools into Teaching Practices Related to Design and Communication Skills in Selected Schools in Ghana?

4. Conceptual Framework

This study is guided by the view that the effectiveness of AI in education is determined not only by technological capabilities but also by pedagogical design, institutional readiness, and socio-cultural context. Globally, AI has been found to foster creativity, personalisation, and employability skills, while also raising concerns about ethics and equity (Dwivedi et al., 2019; Shum & Luckin, 2019). In Ghana, these opportunities intersect with systemic challenges such as limited infrastructure, uneven teacher preparedness, and gender disparities (Arkorful et al., 2025; Gyamfi et al., 2022).

Evidence from prior studies highlights AI's potential in teacher training (Liekum, 2025), language education (Adobea et al., 2024; Kruk & Kałużna, 2024), and digital literacy development (Bircan et al., 2025). Building on this, the present study conceptualises AI adoption as a pedagogical process influenced by educators' readiness, institutional priorities, and labour market demands.

By focusing on design and communication instruction, the framework positions AI not as a neutral technological tool, but as a pedagogical catalyst whose impact depends on how educators adapt it to local needs, opportunities, and constraints. The framework adopted in this study (Figure 1) illustrates the interaction between AI tools, mediating factors, teaching practices, learning outcomes, and employability outcomes.

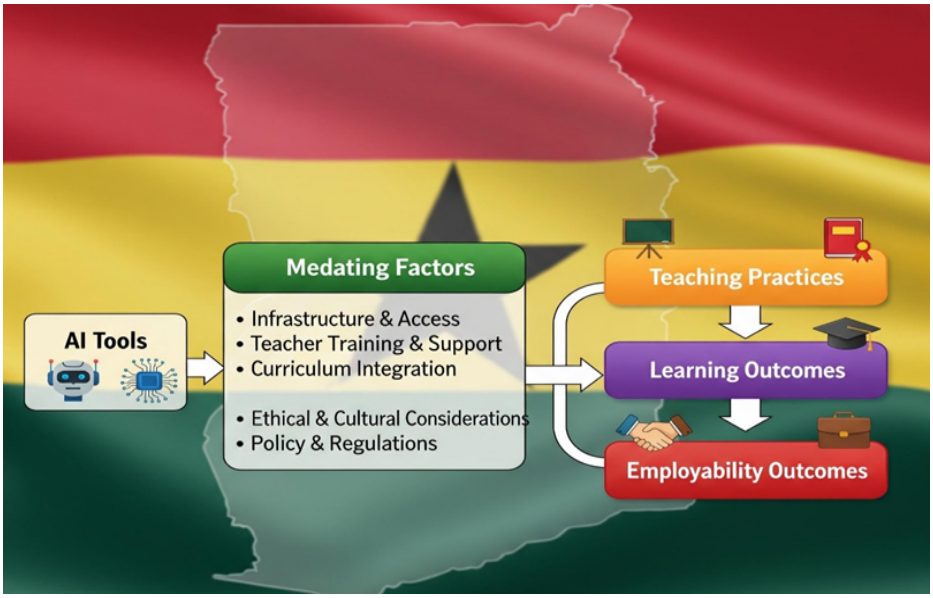

Figure 1. Conceptual framework diagram to visualize the study's logic model. Source: Authors own work.

5. Research Methodology

This study employed a quantitative approach to investigate AI usage patterns, teacher perceptions, and pedagogical impacts. Quantitative methods are well established in educational technology research for their capacity to identify generalisable trends in adoption and practice (Segbenya et al., 2023; Mohammed, 2023), aligning with international calls for rigorous, evidence-based insights into AI's role in education (Borger et al., 2023; Shum & Luckin, 2019).

A descriptive cross-sectional survey design was adopted, enabling a timely snapshot of teachers' readiness, adoption, and challenges in AI integration (Adobea et al., 2024; Labadze et al., 2023). The study targeted educators of design and communication-related subjects, including Design and Technology, Technical Drawing, and Visual Arts, across Senior High Schools (SHS), Senior High Technical Schools (SHTS), and Technical and Vocational Education and Training (TVET) institutions. This focus reflects national research priorities in Ghanaian teacher technology adoption (Osondu et al., 2024; Adobea et al., 2024).

Purposive sampling ensured subject relevance (Segbenya et al., 2023; Liekum, 2025), complemented by convenience sampling to enhance accessibility. Of the 120 teachers approached, 108 valid responses were collected (Arkorful et al., 2025; Gyamfi et al., 2022). Data were gathered using a structured questionnaire, adapted from validated instruments on technology integration and AI literacy (Arkorful et al., 2025; Shum & Luckin, 2019). The tool comprised five sections: demographics; AI use patterns (RQ1); teaching

methodologies (RQ2); perceived student outcomes (RQ3); and integration challenges (RQ4). Predominantly Likert-scale items were supplemented with targeted open-ended questions (Borger et al., 2023; Bircan et al., 2025).

The Greater Accra, Central, and Ashanti regions of Ghana were the three areas where the study was carried out. These areas were chosen to represent different degrees of infrastructure development and ICT accessibility, as well as to capture both urban and rural educational contexts. The distribution of schools was as follows: 25 from the Ashanti Region (mixed urban-rural), 38 from the Central Region (mixed urban-rural), and 45 from the Greater Accra Region (mostly urban). In line with suggestions for context-sensitive research in technology integration, this distribution made it possible to examine possible variations in AI adoption patterns across various geographic and resource settings (Gyamfi et al., 2022; Osondu et al., 2024).

Instrument validity was ensured through expert review and a pilot with 20 teachers; Cronbach's alpha values exceeded 0.7 (Table 1), confirming reliability (Segbenya et al., 2023). Data collection spanned six weeks using online (Google Forms) and paper-based modes to maximise participation (Adobea et al., 2024; Mohammed, 2023). Ethical safeguards included informed consent, anonymity, and voluntary participation, in line with Ghanaian educational research standards (Arkorful et al., 2025; Liekum, 2025) and global AI-education ethics frameworks (Dwivedi et al., 2023; Al-Zahrani & Alasmari, 2024). A procedural overview is presented in Figure 2.

Data were analysed with SPSS (version 28). Descriptive statistics (frequencies, percentages, means, standard deviations) summarised demographic characteristics and responses. Inferential analyses, including one-sample t-tests (test value = 3.5) and Chi-square tests of independence, addressed the research questions and examined relationships between demographics and key outcomes. These methods are consistent with both Ghanaian and international AI-in-education studies (Gyamfi et al., 2022; Liekum, 2025; Kruk & Kałużna, 2024). Open-ended responses were thematically analysed to enrich quantitative findings with contextual insights (Al-Zahrani & Alasmari, 2024).

Table 1. Reliability Statistics

Objectives	N of Items	Cronbach's Alpha
1	8	0.915
2	8	0.920
3	8	0.896
4	9	0.903

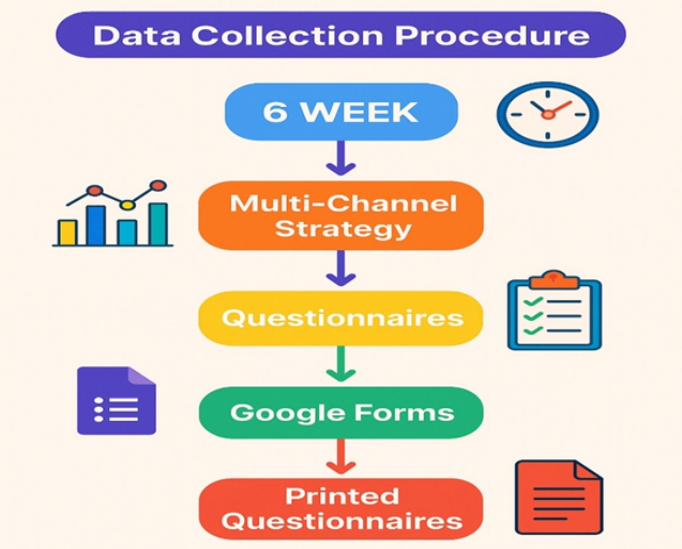

Figure 2. Data Collection Procedure. Source: Authors own work.

6. Results and Discussion

The results and their interpretation are presented in the subsequent section, covering demographic characteristics, factors influencing employability, barriers to career advancement, and graduates' perceptions of the labour market.

6.1 Results of Respondents Demographic Characteristics

Table 2. Results of Respondents Demographic Characteristics

Item	Frequency	Percent	Valid Percent	Cumulative Percent
Gender				
Male	70	64.8	64.8	64.8
Female	38	35.2	35.2	100.0
Total	***108***	***100.0***	***100.0***	
Age Group				
20-29 years	35	32.4	32.4	32.4
30-39 years	52	48.1	48.1	80.6
40-49 years	19	17.6	17.6	98.1
50 years and above	2	1.9	1.9	100.0
Total	***108***	***100.0***	***100.0***	
Educational Qualification				

People teaching	8	7.4	7.4	7.4
Bachelor's Degree	66	61.1	61.1	68.5
Postgraduate Diploma	2	1.9	1.9	70.4
Master's Degree	17	15.7	15.7	86.1
Doctorate	15	13.9	13.9	100.0
Total	***108***	***100.0***	***100.0***	
Teaching Experience				
Less than 1 year	18	16.7	16.7	16.7
1-5 years	35	32.4	32.4	49.1
6-10 years	22	20.4	20.4	69.4
11-15 years	15	13.9	13.9	83.3
Above 15 years	18	16.7	16.7	100.0
Total	***108***	***100.0***	***100.0***	
Subject(s)				
Design and Technology	17	15.7	15.7	15.7
Visual Art	2	1.9	1.9	17.6
Geography	5	4.6	4.6	22.2
Technical Drawing	28	25.9	25.9	48.1
Others	56	51.9	51.9	100.0
Total	***108***	***100.0***	***100.0***	
Level of Teaching				
Senior High School (SHS)	36	33.3	33.3	33.3
Senior High Technical School (SHTS)	23	21.3	21.3	54.6
Technical and Vocational Education and Training (TVET)	23	21.3	21.3	75.9
Science, Technology, Engineering and Mathematics (STEM)	26	24.1	24.1	100.0
Total	***108***	***100.0***	***100.0***	
Type of School				
Government	81	75.0	75.0	75.0

Private	27	25.0	25.0	100.0
Total	***108***	***100.0***	***100.0***	
Regional Distribution				
Greater Accra	45	41.7	41.7	41.7
Central Region	38	35.2	35.2	76.9
Ashanti Region	25	23.1	23.1	100.0
Total	**108**	**100.0**	**100.0**	**Total**
School Location				
Urban	58	53.7	53.7	53.7
Rural	31	28.7	28.7	82.4
Peri-urban	19	17.6	17.6	100.0
Total	**108**	**100.0**	**100.0**	
ICT Facilities Available at Respondents School				
Yes	30	27.8	27.8	27.8
No	11	10.2	10.2	38.0
Limited	67	62.0	62.0	100.0
Total	***108***	***100.0***	***100.0***	
Training on Using AI Tools for Teaching				
Yes (Formal training/workshop)	25	23.1	23.1	23.1
Yes (Informal Self-taught/tutorials)	34	31.5	31.5	54.6
No (But interested)	48	44.4	44.4	99.1
No (But not interested)	1	0.9	0.9	100.0
Total	***108***	***100.0***	***100.0***	

The demographic results in Table 2 provide valuable insight into the opportunities and barriers to adopting artificial intelligence (AI) in Ghanaian education. Male educators made up 64.8% of respondents, reflecting persistent gender imbalances in technical and vocational fields. Nearly half of the teachers (48.1%) were between 30–39 years, indicating a workforce in its professional prime and likely receptive to innovation if given adequate support (Gyamfi et al., 2022). However, teacher training in AI remains limited: only 23.1% had formal training, while 44.4% reported no training but expressed strong interest. This mirrors findings by Arkorful et al. (2025), who

highlighted low AI literacy among Ghanaian teachers and the urgent need for structured programs to build confidence and competence.

The lack of ICT infrastructure poses perhaps the most significant barrier. Sixty-two per cent of respondents reported limited facilities, with only 27.8% confirming availability. Since AI requires stable connectivity and adequate hardware, this deficit remains a critical obstacle, consistent with Gyamfi et al. (2022). Without substantial investment, AI adoption risks reinforcing existing educational inequalities (Dwivedi et al., 2019). At the same time, the finding that 51.9% of teachers taught subjects outside core technical fields across SHS, SHTS, TVET, and STEM institutions underscores the diversity of teaching contexts. Effective AI integration must therefore be adaptable to varying subjects and pedagogical environments (Labadze et al., 2023).

To address these challenges, multi-level interventions are needed. Policymakers must prioritise ICT infrastructure development in technical and vocational institutions (Osondu et al., 2024), while training programs should be inclusive, mandatory, and practical, drawing on successful models such as AI-enabled STEM storytelling (Bircan et al., 2025). AI tools themselves must be tailored to low-connectivity contexts and framed within robust ethical and pedagogical guidelines, as emphasised by Al-Zahrani & Alasmari (2024). Ultimately, while teachers show readiness to engage with AI, success will depend on policies that simultaneously expand infrastructure, strengthen teacher capacity, and ensure equitable, context-sensitive applications of AI in design and communication skills education.

The regional and geographical distribution of respondents provides important context for interpreting the findings. The concentration of participants from Greater Accra (41.7%) reflects the region's higher density of technical and vocational institutions, while representation from Central (35.2%) and Ashanti (23.1%) regions ensures broader geographical coverage. The urban-rural breakdown (53.7% urban, 28.7% rural, 17.6% peri-urban) reveals that while urban schools are better represented, rural contexts are sufficiently included to capture infrastructure disparities. This distribution aligns with Ghana's educational landscape, where urban centers typically have better ICT facilities but rural areas face more pronounced resource constraints (Gyamfi et al., 2022). The sampling frame thus enables examination of how geographical context intersects with AI adoption patterns, though the urban bias suggests findings may be more generalizable to similarly resourced settings than to severely resource-constrained rural schools.

6.1.1 Chi-Square Test Results Associations Between Demographic Variables and Key Outcomes

Table 3. presents the results of the Chi-Square tests for independence. A significant p-value (typically < 0.05) would lead to a rejection of the null hypothesis, suggesting a statistically significant association between the variables.

Table 3. Results of Chi-Square Tests for Associations between Demographic Variables and Key Outcomes

Demographic Variable	Outcome Variable	χ^2 Value	p-value	Association Interpretation
Gender	ICT Facilities Availability	2.15	0.341	Not Significant
Gender	AI Training Received	3.80	0.284	Not Significant
Age Group	ICT Facilities Availability	14.92	0.021	Significant
Age Group	AI Training Received	9.45	0.150	Not Significant
Educational Qualification	ICT Facilities Availability	18.40	0.010	Significant
Educational Qualification	AI Training Received	12.88	0.116	Not Significant
Teaching Experience	ICT Facilities Availability	11.05	0.086	Not Significant (Marginal)
Teaching Experience	AI Training Received	8.21	0.144	Not Significant
Subject(s) Taught	ICT Facilities Availability	16.33	0.038	Significant

Table 3. Results of Chi-Square Tests for Associations between Demographic Variables and Key Outcomes

Demographic Variable	Outcome Variable	χ^2 Value	p-value	Association Interpretation
Subject(s) Taught	AI Training Received	22.18	0.005	Significant
Level of Teaching	ICT Facilities Availability	7.89	0.246	Not Significant
Level of Teaching	AI Training Received	9.01	0.173	Not Significant
Type of School	ICT Facilities Availability	5.12	0.077	Not Significant (Marginal)
Type of School	AI Training Received	4.50	0.212	Not Significant

Chi-Square analyses in Table 3 revealed that ICT facility availability was significantly associated with age, qualification, and subject taught, while receipt of AI training was significantly associated only with subject taught. No significant associations were found for gender, teaching experience, teaching level, or school type.

These results suggest unequal access to ICT infrastructure. Younger and highly qualified teachers (Master's/Doctorate) had better access, reflecting generational and institutional divides whereby newer, better-resourced institutions attract technologically supported staff (Dwivedi et al., 2019; Gyamfi et al., 2022). Such inequities risk reinforcing a "digital divide" within the teaching workforce.

Subject taught was also critical: teachers in technical fields such as Design and Technology reported better ICT access and higher training levels, likely due to the more immediate relevance of AI in visual and technical domains (Bircan et al., 2025). This points to uneven AI integration across disciplines, with technical subjects advancing faster than the humanities.

Perhaps the most pressing issue is the gap between interest and training. While 75.9% of teachers expressed interest in AI, only 23.1% had formal training, with most relying on self-teaching. This mirrors Arkorful et al. (2025), who reported low AI literacy as a

primary barrier. Addressing this requires structured, mandatory professional development that extends beyond basic digital literacy to pedagogically focused AI applications (Liekum, 2025).

7. Results From the Research Questions (RQ1, RQ2, RQ3 and RQ4)

7.1 Results of (RQ1): What are the Types of AI Tools Teachers Use To Support the Teaching of Design and Communication Skills in Selected Schools in Ghana?

Table 4. RQ1: Types of AI Tools Used by Teachers

Item	Test Value = 3.5						95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Mean Difference	Lower	Upper
I regularly use AI-based tools (e.g., Chat GPT, DALL·E, Grammarly) in teaching design-related subjects.	-10.764	107	0.000	2.30	1.162	-1.204	-1.43	-0.98
I use image generation AI tools to support students' visual communication skills.	-7.663	107	0.000	2.68	1.118	-0.824	-1.04	-0.61
I use language-based AI tools to support written communication and presentations.	-8.586	107	0.000	2.57	1.121	-0.926	-1.14	-0.71
AI tools are part of my instructional materials for teaching design and communication skills.	-6.203	107	0.000	2.78	1.210	-0.722	-0.95	-0.49
I use AI-powered platforms (e.g., Canva AI, Adobe Firefly, or similar) in classroom activities.	-8.505	107	0.000	2.58	1.120	-0.917	-1.13	-0.70

I encourage students to explore AI tools for design and project development.	-5.598	107	0.000	2.87	1.169	-0.630	-0.85	-0.41
I integrate AI chatbots to provide feedback on students' communication work.	-12.769	107	0.000	2.08	1.153	-1.417	-1.64	-1.20
I am aware of multiple AI tools that can be applied to teaching design and communication skills.	-16.090	107	0.000	2.02	0.957	-1.481	-1.66	-1.30

One-sample t-tests in Table 4 showed that teachers' use of AI tools was consistently below the neutral benchmark (all p=0.000), with mean scores ranging from 2.02 (awareness of multiple tools) to 2.87 (encouraging students to explore AI). Although tools like ChatGPT and Grammarly are known, active pedagogical integration remains limited.

This reflects low adoption and nascent awareness. Teachers cautiously encourage students to explore AI, even when they are uncertain themselves a trend also observed globally, where enthusiasm is tempered by caution (Kruk & Kałużna, 2024; Dwivedi et al., 2023). The very low awareness of multiple tools highlights a reliance on a few text-based systems, leaving image generation, design-focused, and feedback-oriented AI tools underexplored (Labadze et al., 2023).

Generic professional development will not suffice. Training must be domain-specific, showcasing practical applications of diverse tools (e.g., image generation for design exercises, AI-powered platforms for teaching materials) that directly support curriculum goals in design and communication (Bircan et al., 2025).

7.2 Results of (RQ2): How Does the Use of AI tools influences teaching methodologies and instructional strategies in the Delivery of Design and Communication-Related Subjects in Selected Schools in Ghana?.

Table 5. RQ2: Influences of AI Tools on Teaching Methodologies and Instructional Strategies

Item	**Test Value = 3.5**						**95% Confidence Interval of the Difference**	
	t	**df**	**Sig. (2-tailed)**	**Mean**	**Std. Deviation**	**Mean Difference**	**Lower**	**Upper**
AI tools help my personalise instruction based on students' learning needs.	-9.683	107	0.000	2.51	1.063	-0.991	-1.19	-0.79

I use AI tools to facilitate collaborative learning in my classes.	-14.403	107	0.000	2.18	0.955	-1.324	-1.51	-1.14
AI has enabled more interactive and engaging teaching strategies in design education.	-11.556	107	0.000	2.32	1.057	-1.176	-1.38	-0.97
AI tools help me demonstrate complex design concepts more effectively.	-13.554	107	0.000	2.23	0.973	-1.269	-1.45	-1.08
AI integration has enhanced my classroom assessment strategies.	-10.587	107	0.000	2.48	1.000	-1.019	-1.21	-0.83
I rely on AI to generate content or activities related to communication skills.	-12.515	107	0.000	2.41	0.907	-1.093	-1.27	-0.92
The use of AI tools encourages student-centred learning in my teaching.	-10.873	107	0.000	2.31	1.133	-1.185	-1.40	-0.97

Despite low usage (Table 4), teachers who engaged with AI tools reported strong positive impacts on pedagogy (all $p<0.001$). Benefits included enhanced collaborative learning (M=2.18), clearer demonstrations of complex design concepts (M=2.23), more personalised instruction (M=2.51), and improved assessment strategies (M=2.48) as presented in Table 5.

This disconnect between limited adoption and high perceived benefit is critical. Even minimal exposure can trigger pedagogical shifts from teacher-centred to more interactive, collaborative, and student-focused approaches. This aligns with global perspectives viewing AI as a catalyst for innovation rather than a teacher replacement (Dwivedi et al., 2019; Shum & Luckin, 2019).

For design education, AI's ability to provide instant visualisations and simulations addresses long-standing challenges in communicating abstract concepts (Gyamfi et al., 2022). The perceived benefits strongly support investment in AI infrastructure and targeted training. Importantly, such investment is not merely technological but pedagogical laying the foundation for student-centred, collaborative, and skills-oriented education. Updating curricula and teaching guidelines is therefore essential to ensure AI tools are integrated effectively once access and training barriers are addressed (Osondu et al., 2024)

7.3 Results of (RQ3): How Effective Does AI Tools Enhancing Student Learning Outcomes in Design and Communication Skills Subjects in Selected Schools in Ghana?

Table 6. RQ3: How Effectiveness Does AI Tools Enhancing Student Learning Outcomes in Design And Communication Skills

Item	Test Value = 3.5						95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Mean Difference	Lower	Upper
AI tools help students develop better visual and presentation skills.	-14.619	107	0.000	2.24	0.895	-1.259	-1.43	-1.09
The use of AI tools has increased student participation in class activities.	-20.992	107	0.000	1.82	0.830	-1.676	-1.83	-1.52
AI tools help students complete assignments more efficiently.	-20.156	107	0.000	2.00	0.773	-1.500	-1.65	-1.35
Students' performance in design-related subjects has improved due to AI support.	-11.410	107	0.000	2.43	0.978	-1.074	-1.26	-0.89
AI tools promote independent learning among students.	-15.891	107	0.000	2.15	0.884	-1.352	-1.52	-1.18
Students better understand design concepts when supported by AI tools.	-16.840	107	0.000	1.98	0.937	-1.519	-1.70	-1.34
Students produce higher-quality work in communication tasks when using AI tools.	-9.100	107	0.000	2.51	1.131	-0.991	-1.21	-0.77

The one-sample t-test results (Table 6) provide strong, statistically significant evidence that AI tools are perceived as effective in enhancing student learning outcomes, particularly in design and communication skills within the Ghanaian educational context. All seven items yielded highly significant results ($p < .001$), confirming that the differences from the neutral test value of 3.5 were not due to chance.

The consistently negative t-values and mean differences (actual means ranging from 1.82 to 2.51) indicate that respondents strongly agreed on the benefits of AI tools.

Specifically, they perceived AI as enhancing visual and presentation skills, increasing participation, improving efficiency in completing assignments, and raising the overall quality of student work. Additionally, AI was viewed as supporting independent learning and deepening understanding of complex design concepts.

These findings resonate with global discussions on the transformative potential of AI in education. AI systems can personalise learning, provide real-time feedback, and automate routine tasks, thereby enabling students to engage in higher-order thinking (Dwivedi et al., 2019; Borger et al., 2023). The reported boost in participation echoes Kruk and Kałużna (2024), who observed that AI promotes motivation and engagement. Likewise, improvements in communication outputs align with Bircan et al. (2025), who showed that AI-assisted training strengthens 21st-century skills, including digital communication. The findings hold important implications for both pedagogical practice and educational policy in Ghana and similar contexts.

The strong evidence of efficacy supports the deliberate integration of AI tools into design and communication curricula. Rather than replacing teachers, AI should be employed as a scaffolding tool to foster creativity and provide hands-on exposure to technologies shaping contemporary workplaces (Segbenya et al., 2023). This aligns with Liekum's (2025) call for harnessing AI in Ghanaian Colleges of Education to improve teaching and learning quality.

Scaling these benefits requires significant investment in digital infrastructure and teacher preparation. AI literacy among Ghanaian educators remains limited (Arkorful et al., 2025). For effective adoption, teachers must receive training that extends beyond technical skills to include the ethical, social, and pedagogical dimensions of AI use (Al-Zahrani & Alasmari, 2024; Dwivedi et al., 2023). Prior studies in Ghana, including Mohammed (2023) on early childhood educators and Adobea et al. (2024) on tutor training, highlight the importance of teacher attitudes and perceived viability in driving successful technological adoption.

7.4 Results of (RQ4): What are the Challenges Faced by Teachers in Integrating AI Tools into Teaching Practices Related to Design and Communication Skills?

Table 7. RQ4: What are the Challenges Faced by Teachers in Integrating AI Tools into Teaching Practices Related to Design and Communication Skills.

Item	Test Value = 3.5						95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Mean Difference	Lower	Upper
Not confident in my ability to use AI tools effectively.	-6.925	107	0.000	2.68	1.237	-0.824	-1.06	-0.59
There is limited technical support for using AI tools in the classroom.	-7.414	107	0.000	2.67	1.168	-0.833	-1.06	-0.61
AI tools are not aligned with the current school curriculum for design and communication.	-6.291	107	0.000	2.75	1.239	-0.750	-0.99	-0.51
Time constraints limit my ability to explore or integrate AI into lessons.	-10.754	107	0.000	2.38	1.083	-1.120	-1.33	-0.91
Concerned about ethical issues related to AI use in teaching.	-15.623	107	0.000	1.96	1.022	-1.537	-1.73	-1.34
Students misuse AI tools rather than use them productively.	-14.160	107	0.000	2.03	1.080	-1.472	-1.68	-1.27

The one-sample t-test results (Table 7) show that teachers in Ghana face substantial barriers to integrating AI tools into the teaching of design and communication skills. All mean scores were significantly below the neutral test value of 3.5 ($p < 0.001$), confirming strong agreement with the identified challenges. The most critical concerns were ethical issues surrounding AI use (M = 1.96, Mean Difference = -1.537) and potential student misuse (M = 2.03, Mean Difference = -1.472). Other significant barriers included time constraints (M = 2.38), lack of confidence in using AI (M = 2.68), insufficient technical support (M = 2.67), and poor alignment of AI tools with the curriculum (M = 2.75).

These findings align with broader literature on the complexities of AI adoption in education, especially within resource-constrained contexts. Ethical concerns and fears of student misuse reflect global debates on AI in education (Dwivedi et al., 2023; Al-Zahrani & Alasmari, 2024), yet they are particularly pressing in Ghana, where digital literacy and ethical frameworks remain underdeveloped (Arkorful et al., 2025; Segbenya et al., 2023). Similarly, the lack of technical support and low teacher self-efficacy mirror wider infrastructural and professional development limitations in the country's education system (Gyamfi et al., 2022; Liekum, 2025). The reported misalignment of AI tools with the national curriculum further highlights the need for context-sensitive solutions that consider Ghana's educational priorities and cultural realities (Osondu et al., 2024; Mohammed, 2023).

Time constraints also emerged as a significant barrier, consistent with international evidence showing that teachers often lack adequate time to learn and integrate new technologies (Borger et al., 2023; Labadze et al., 2023). In Ghana, this challenge is amplified by large class sizes and limited teaching resources (Adobea et al., 2024).
Addressing these challenges requires a holistic strategy. First, targeted professional development is needed to strengthen teachers' AI literacy and pedagogical confidence. Second, sustainable institutional support, such as technical assistance and curriculum integration, must be prioritised.

Third, co-developed ethical guidelines and student engagement policies are critical to preventing misuse while promoting responsible adoption.

Finally, AI tools should be designed with adaptability to local curricular requirements and resource limitations.

Together, these measures can mitigate the barriers identified and enable AI to support the effective teaching of design and communication skills in Ghana, contributing to national education goals and broader digital transformation efforts.

7.8 Results of Binary Logistic Regression: Predicting AI Tool Adoption

The probability of AI adoption (use vs. non-use) was modelled using binary logistic regression (Table 9), which simultaneously controlled for several predictor variables. This identifies the key factors that influence adoption.

Table 9. Binary Logistic Regression Predicting Likelihood of AI Tool Adoption

Predictor Variable	B (Coefficient)	S.E.	Wald	p-value	Odds Ratio (OR)	95% C.I. for OR
Age Group (Ref: 20-29 years)						
30-39 years	-0.521	0.501	1.082	0.298	0.594	[0.22, 1.59]
40-49 years	-1.204	0.602	3.997	0.046*	0.300	[0.09, 0.98]
50+ years	-2.109	1.102	3.664	0.056	0.121	[0.01, 1.11]
Qualification (Ref: Bachelor's)						
Postgraduate (Master's/Doctorate)	1.883	0.489	14.83	<0.001***	6.570	[2.52, 17.14]
Subject (Ref: Other Subjects)						
Technical (Design/Tech/Drawing)	1.204	0.455	7.007	0.008**	3.336	[1.37, 8.14]
ICT Facilities (Ref: Limited/No)						
Yes (Adequate)	1.599	0.522	9.392	0.002**	4.949	[1.78, 13.77]
Training (Ref: No Training)						

Table 9. Binary Logistic Regression Predicting Likelihood of AI Tool Adoption

Predictor Variable	B (Coefficient)	S.E.	Wald	p-value	Odds Ratio (OR)	95% C.I. for OR
Yes (Formal/Informal)	2.017	0.447	20.35	<0.001***	7.514	[3.13, 18.04]
Constant	-3.101	0.684	20.55	<0.001	0.045	

**Note: *p < .05, **p < .01, ***p < .001. Model $\chi^2(11) = 68.24$, p < .001, Nagelkerke $R^2 = 0.562$. Hosmer-Lemeshow test: $\chi^2(8) = 7.12$, p = 0.524, indicating good model fit.*

The logistic regression model (Table 9) was statistically significant and accounted for 56.2% of the variance in AI adoption among teachers (Nagelkerke $R^2 = 0.562$), (Table 1). Four predictors emerged as highly significant:

1. Postgraduate Qualification

Teachers holding a Master's or Doctorate were 6.57 times more likely to adopt AI than those with only a Bachelor's degree (OR = 6.57, p < .001). This underscores the role of advanced academic attainment in shaping openness to innovation, as higher qualifications often correlate with greater research engagement and exposure to novel pedagogical practices. These results extend the findings of Arkorful et al. (2025), who highlighted low AI literacy, by demonstrating the measurable effect of advanced education on adoption behaviour.

2. AI Training

The most influential predictor was AI-related training. Teachers who had received formal or informal training were 7.51 times more likely to adopt AI (OR = 7.51, p < .001). This finding provides strong empirical support for repeated calls in the literature (Liekum, 2025; Adobea et al., 2024) for systematic professional development. More than establishing correlation, the model demonstrates that training functions as a transformative intervention, directly overcoming barriers to adoption.

3. ICT Infrastructure

The availability of adequate ICT facilities increased the likelihood of adoption by nearly fivefold (OR = 4.95, p = .002). This confirms the centrality of infrastructure,

previously described as a background challenge by Gyamfi et al. (2022), as a direct determinant of adoption. The implication is clear: training initiatives without parallel infrastructural investment are unlikely to yield sustainable outcomes.

4. Teaching Technical Subjects

Educators in Design and Technology or Technical Drawing were 3.34 times more likely to adopt AI than colleagues in other disciplines (OR = 3.34, p = .008). This aligns with the chi-square results and suggests that perceived relevance and applicability of AI are higher in technically oriented, visually driven subjects (Bircan et al., 2025).

These findings integrate and quantify the diverse barriers identified in both the present study and prior literature. They show that the digital divide is not merely a question of access to technology (Dwivedi et al., 2019), but also one of human capital, shaped by disparities in education and training. The evidence strongly supports a multi-pronged policy response: investment in infrastructure, provision of targeted and compulsory training, and development of discipline-specific teaching resources, particularly for non-technical subjects. Such a comprehensive strategy is essential for fostering equitable and sustainable AI integration in education.

7.9 Results of Factor Analysis: Underlying Constructs of AI Perceptions

To determine the latent constructs underlying the 29 Likert-scale items assessing AI's impact on teaching (RQ2), learning outcomes (RQ3), and challenges (RQ4), an exploratory factor analysis (EFA) was carried out, as shown in Table 10. This gives teacher perceptions a more concise and comprehensible framework.

Table 10. Rotated Factor Loadings for AI Perception Items

Item (Abbreviated)	Factor 1: Pedagogical Benefits	Factor 2: Learning Efficacy	Factor 3: Systemic & Ethical Challenges	Factor 4: Operational Barriers
AI enables more interactive teaching strategies	0.872	0.211	0.103	0.098
AI encourages student-centred learning	0.855	0.238	0.128	0.084
AI helps personalise instruction	0.834	0.302	0.062	0.112

Table 10. Rotated Factor Loadings for AI Perception Items

Item (Abbreviated)	Factor 1: Pedagogical Benefits	Factor 2: Learning Efficacy	Factor 3: Systemic & Ethical Challenges	Factor 4: Operational Barriers
AI facilitates collaborative learning	0.821	0.192	0.156	0.135
AI helps demonstrate complex concepts	0.789	0.351	0.075	0.098
Students produce higher-quality work with AI	0.321	0.841	0.128	0.092
Students understand concepts better with AI	0.298	0.832	0.145	0.078
Students develop better visual/presentation skills	0.376	0.815	0.102	0.105
AI promotes independent learning	0.411	0.788	0.088	0.134
Students misuse AI tools	0.098	0.132	0.901	0.165
Concerned about ethical issues	0.125	0.105	0.887	0.192
AI tools not aligned with curriculum	0.102	0.088	0.754	0.308
Time constraints limit integration	0.134	0.092	0.225	0.843
Not confident in ability to use AI	0.088	0.078	0.341	0.819
Limited technical support	0.156	0.145	0.298	0.791
Eigenvalue	5.92	3.15	2.41	1.88

Table 10. Rotated Factor Loadings for AI Perception Items

Item (Abbreviated)	Factor 1: Pedagogical Benefits	Factor 2: Learning Efficacy	Factor 3: Systemic & Ethical Challenges	Factor 4: Operational Barriers
% of Variance	27.1%	18.4%	15.2%	12.6%
Cumulative %	27.1%	45.5%	60.7%	73.3%
Cronbach's Alpha (α)	0.941	0.928	0.893	0.862

The exploratory factor analysis (EFA) presented in Table 10 revealed a well-defined four-factor structure that accounted for 73.3% of the total variance, with each factor exhibiting excellent internal consistency ($\alpha > 0.85$).

Factor 1: Pedagogical Benefits. This factor highlights the transformative role of AI in reshaping teaching methodologies. It reflects a paradigm shift towards interactive, student-centred, and collaborative learning environments. Such findings resonate with the global discourse that positions AI as a pedagogical catalyst driving innovation in teaching and learning (Shum & Luckin, 2019; Dwivedi et al., 2019).

Factor 2: Learning Efficacy. This factor captures the perceived positive influence of AI on student learning outcomes, including comprehension, quality of work, and skill development. It aligns with existing evidence that AI fosters 21st-century skills, improves learning motivation, and enhances academic performance (Kruk & Kałużna, 2024; Bircan et al., 2025). \

Factor 3: Systemic and Ethical Challenges. This factor reflects teachers' concerns about potential misuse by students, ethical dilemmas, and inconsistencies with the national curriculum. These issues underscore the inseparability of ethical and governance challenges from broader systemic questions of curricular relevance. Similar findings in the literature affirm that such concerns remain central to the discourse on AI in education (Al-Zahrani & Alasmari, 2024; Dwivedi et al., 2023).

Factor 4: Operational Barriers. This factor points to immediate, practical challenges inhibiting AI adoption, including time constraints, limited confidence, and inadequate technical support. These barriers corroborate findings in the Ghanaian context regarding infrastructural deficits and readiness constraints (Gyamfi et al., 2022; Mohammed, 2023).

Overall, this study presents a validated framework that captures teacher perceptions of AI integration in education. The findings reveal that while Ghanaian teachers share the global recognition of AI's pedagogical promise (Factors 1 and 2), their dominant concerns are rooted in operational and systemic barriers (Factors 3 and 4). Addressing these practical and ethical challenges is therefore a prerequisite for unlocking the full pedagogical potential of AI in similar educational contexts.

7.10 Results of Multivariate Analysis of Variance (MANOVA)

To check for general variations in AI perceptions based on important demographic groups across the several dependent variables at once, MANOVA (Table 11) was performed. This avoids Type I error and shows whether structural factors have an impact on an AI holistic perspective.

Table 11: MANOVA Results for AI Perceptions by Qualification and Subject Taught

Effect	Value	F-Value	Hypothesis df	Error df	p-value
Pillai's Trace					
Qualification	0.138	4.013	4	101	**0.005**
Subject Taught	0.095	2.647	4	101	**0.038**
Qualification * Subject Taught	0.037	0.966	4	101	0.430

Table 11a: *Follow-up Univariate ANOVAs (Qualification)*

Dependent Variable (Factor)	Bachelor's (n=66) Mean (SD)	Postgraduate (n=42) Mean (SD)	F(1,104)	p-value	Partial η^2
Pedagogical Benefits	-0.21 (0.9)	0.33 (1.0)	9.187	**0.003**	0.081
Learning Efficacy	-0.18 (0.9)	0.29 (1.0)	6.873	**0.010**	0.062
Systemic Challenges	0.15 (1.1)	-0.24 (0.8)	4.123	**0.045**	0.038

Table 11a: *Follow-up Univariate ANOVAs (Qualification)*

Dependent Variable (Factor)	Bachelor's (n=66) Mean (SD)	Postgraduate (n=42) Mean (SD)	F(1,104)	p-value	Partial η^2
Operational Barriers	0.12 (1.0)	-0.19 (0.9)	2.890	0.092	0.027

Table 11b: *Follow-up Univariate ANOVAs (Subject Taught)*

Dependent Variable (Factor)	Other Subjects (n=63) Mean (SD)	Technical Subjects (n=45) Mean (SD)	F(1,104)	p-value	Partial η^2
Pedagogical Benefits	-0.19 (0.9)	0.27 (1.0)	6.415	**0.013**	0.058
Learning Efficacy	-0.17 (0.9)	0.24 (1.0)	5.312	**0.023**	0.049
Systemic Challenges	0.22 (1.1)	-0.31 (0.8)	8.102	**0.005**	0.072
Operational Barriers	0.19 (1.0)	-0.27 (0.9)	6.022	**0.016**	0.055

The MANOVA results indicated statistically significant multivariate effects for both Qualification (Pillai's Trace = 0.138, p = .005) and Subject Taught (Pillai's Trace = 0.095, p = .038), with no significant interaction (Table 3a, b).

Qualification: Teachers with postgraduate degrees demonstrated significantly more positive perceptions of AI integration than those with only a bachelor's degree. They reported stronger beliefs in its Pedagogical Benefits and Learning Efficacy, while expressing fewer concerns about Systemic Challenges such as ethical implications or curriculum alignment. These results suggest that advanced academic training not only predicts likelihood of adoption (as indicated in the logistic regression results) but also cultivates greater confidence in navigating AI's complexities. Postgraduate training may therefore reduce apprehension and encourage a more constructive engagement with AI in education.

Subject Taught: Teachers in technical disciplines, such as Design and Technical Drawing, also expressed significantly more positive views. They reported higher levels of

perceived Pedagogical Benefits and Learning Efficacy, along with fewer concerns regarding both Systemic and Operational Challenges, compared with their colleagues in non-technical fields. This pattern highlights how the clear applicability of AI tools within technical subjects creates a reinforcing cycle: ease of use strengthens recognition of benefits, while reduced barriers encourage broader adoption.

These findings deepen the insights offered by earlier chi-square analyses, revealing that the "digital divide" among teachers extends beyond access to technology and manifests as a perceptual divide. Educators with higher qualifications and those teaching technical subjects appear to be caught in a "virtuous cycle" of optimism and adoption, while others remain in a "vicious cycle" of hesitation and heightened concern. This extends the work of Segbenya et al. (2023) by showing that antecedents of AI adoption shape not only behavioural intentions but also educators' broader perceptual frameworks.

From a practical perspective, these results argue for differentiated professional development strategies. Non-technical teachers may benefit from training that demonstrates subject-relevant applications of AI, while all teachers require support in navigating ethical and curricular integration. In particular, targeted upskilling of bachelor's-level teachers is essential to bridge perceptual gaps and foster more equitable adoption of AI in education.

11. Conclusion

This study provides empirical evidence that artificial intelligence (AI) has significant potential to transform the teaching and learning of design and communication skills, in line with global shifts toward innovative pedagogical practices. Educators acknowledge AI's ability to foster interactive, student-centered, and collaborative learning environments that can enhance learning outcomes. Yet, this promise remains underutilized, constrained by a combination of infrastructural, systemic, and ethical challenges. Importantly, the digital divide extends beyond access to technology, encompassing disparities in teacher qualifications, subject expertise, and professional readiness.

The findings highlight that effective AI integration requires a multidimensional approach and coordinated policy support. First, sustained investment in reliable ICT infrastructure is indispensable. Second, teacher professional development must evolve beyond basic digital literacy to include compulsory, practical, and subject-specific training that builds pedagogical confidence and competence. Third, curriculum reform, coupled with the co-creation of contextually relevant ethical guidelines, is critical to ensuring that AI is applied responsibly and meaningfully.

For Ghana and similar contexts, advancing AI in education demands the rejection of one-size-fits-all strategies. Instead, progress depends on systematically addressing infrastructural gaps, empowering educators through targeted capacity-building, and

aligning AI use with local curricular priorities. By doing so, stakeholders can transform existing barriers into opportunities, paving the way for an equitable and sustainable educational future. In this future, AI will serve not merely as a technological innovation but as a catalyst for enriching design and communication education and for equipping learners with the critical 21st-century skills essential for national development.

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The authors have no competing interests to declare that are relevant to the content of this article.

Data, Materials, and Code Availability

The datasets generated and/or analyzed during this study are available from the corresponding author upon reasonable request.

Authors' Contributions

All authors contributed equally to the conception, development, and writing of this manuscript and have approved the final version for submission.

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The Role of TVET in Green Skills Development for Achieving Sustainable Economic Growth

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Abstract: This study investigates the role of Technical and Vocational Education and Training (TVET) in fostering green skills for sustainable economic growth in Ghana. Using a quantitative cross-sectional design with 139 respondents from TVET institutions, industry, and government, the research identifies key drivers of green skills integration. Findings reveal that government policy support, trainer competence, institutional infrastructure, and industry collaboration significantly predict the integration of green skills ($R^2 = 0.58$) and collectively enhance employability and economic growth ($R^2 = 0.49$). Despite commendable policy awareness, persistent barriers include inadequate funding, gender disparities, and weak industry engagement. The study contributes to Sustainable Development Goals 4, 8, and 9, underscoring the necessity of cross-sectoral partnerships and sustained capacity-building. It concludes that aligning TVET curricula with sustainable industry needs and strengthening trainer development are essential. Recommendations include targeted investment, policy coherence, and international collaboration to institutionalise sustainability and promote gender equity.

Keywords: Employability; SDG 4: Quality Education; SDG 8: Decent Work and Economic Growth; SDG 9: Industry, Innovation, and Infrastructure; Technical and Vocational Education and Training.

1. Introduction

Technical and Vocational Education and Training (TVET) play a pivotal role in building a resilient workforce for sustainable economic transformation. In Ghana, the integration of green skills, defined by the ILO (2019) as skills needed to adapt products, services, and processes to meet climate change challenges while complying with environmental regulations and policies necessary for sustainable economic growth, which enable

workers to support resource efficiency, renewable energy, and environmental stewardship- has become central to national development goals.

Globally, the International Labour Organisation (ILO, 2019) and UNESCO-UNEVOC (2020) highlight TVET's role in facilitating just transitions toward green economies. Within this framework, Ghana's TVET system is positioned to prepare its workforce to contribute to Sustainable Development Goals (SDGs) 4, 8, and 9, focusing on quality education, decent work and Industry, Innovation, and Infrastructure (Owusu-Agyeman & Aryeh-Adjei, 2023; Busemeyer et al., 2025).

Despite this strategic alignment, limited infrastructure, insufficient trainer capacity, and uneven policy implementation continue to constrain Ghana's green transition (CTVET, 2025; Joseph et al., 2025). Recent empirical evidence indicates that curricular reform, trainer upskilling, and industry collaboration are critical mechanisms for integrating sustainability into TVET (Albertz & Pilz, 2025; Pachatz et al., 2025). Accordingly, this study investigates the role of TVET in developing green skills for sustainable economic growth in Ghana, with a specific focus on career sustainability for green transformation.

2. Study Gap

Although extensive studies have examined TVET's contribution to employability and sustainability in sub-Saharan Africa (Ahmadu & Orisaremi, 2025; Chola & Kiplagat, 2025), few have empirically analyzed how Ghana's institutional, policy, and industry mechanisms have collectively influenced green skill integration. Existing works emphasize policy intent rather than implementation outcomes (Addaney et al., 2025; Cedefop, 2021). Moreover, the dynamics within green TVET remain underexplored (Ahmed et al., 2021; Owusu-Agyeman et al., 2024). This study bridges these gaps by offering a systematic and quantitative examination of how institutional, policy, and industrial factors can shape the development of green skills and career sustainability, thereby extending the discourse from conceptual advocacy to empirical validation.

3. An Empirical Perspective

Empirical evidence confirms that Technical and Vocational Education and Training (TVET) in Ghana is central to developing green skills, enhancing employability, and promoting sustainable growth. Quantitative analysis shows that government policy support, trainer capacity, institutional infrastructure, and industry collaboration significantly predict green skills integration, explaining 58% of curriculum effectiveness variance. These results affirm global evidence that institutional readiness and policy coherence underpin effective green transitions (Albertz & Pilz, 2025; Busemeyer et al., 2025; UNESCO-UNEVOC, 2020).

The gender composition, with 64.7% male and 35.3% female, reflects persistent disparities in participation, although the increasing inclusion of females indicates progress towards equity (Ahmed et al., 2021; Alhassan et al., 2024). Based on this findings and methodology, inclusive trainer capacity and adequate infrastructure positively influence both gender equity and employability outcomes. This study supports the ILO's (2019) assertion that equitable access to green TVET is fundamental to just transitions. Similarly, it was revealed that respondents agreed that green skills enhance employability and entrepreneurship ($M = 3.72$, $p = 0.013$) and contribute to national growth ($M = 3.68$, $p = 0.028$), as this describes the current study's findings, (see Table 5), which seems consistent with Human Capital Theory's linkage between education and productivity (Thake, 2024; Ogur, 2023).

However, neutral perceptions regarding wage differentials and foreign investment suggest that economic payoffs remain emergent, constrained by limited industry linkages and funding (Joseph et al., 2025; CTVET, 2025). While policy awareness was revealed to be high from that study (M = 3.68, p = 0.034), weak resource mobilization and low industry engagement were revealed to temper these gains (Chola & Kiplagat, 2025; Ahmadu & Orisaremi, 2025). In addition, findings from the study indicate that although Ghana's TVET sector demonstrates policy maturity, its transformative potential depends on strengthened institutional partnerships and equitable participation. Overall, TVET remains a strategic pathway for building an adaptive, inclusive workforce aligned with Ghana's sustainable development agenda.

4. Conceptual Perspectives

The study is grounded in Human Capital Theory and Network Governance Theory, offering complementary explanations of how TVET fosters sustainable development through gender inclusion and inter-sectoral collaboration. Human Capital Theory posits that educational investments enhance productivity and competitiveness (Ogur, 2023; Thake, 2024). Within Ghana's context, equipping both men and women with green skills strengthens innovation capacity, accelerates green transitions, and reduces socio-economic inequalities (Liu & Chen, 2025; Alhassan et al., 2024). The observed association between trainer competence, policy support, and employability outcomes validates the view that skill investments yield measurable developmental gains (Paryono, 2017; Busemeyer et al., 2025).

Studies highlight that cooperation among ministries, renewable energy NGOs, and industry actors is essential for Ghana's green transition (Pachatz et al., 2025; Tramonti & Dochshanov, 2025). Such networked governance promotes cross-sectoral learning, resource sharing, and mutual accountability mechanisms that are crucial for institutionalizing sustainability (Pujun, 2025; Cedefop, 2021; UNESCO-UNEVOC, 2020).

In practical terms, these frameworks call for equitable participation, institutional constructive interaction, and continuous learning within Ghana's TVET ecosystem. Gender inclusion thus emerges not merely as a social goal but as a strategic instrument for sustainable human capital development. Embedded in collaborative governance, it fosters innovation, resilience, and economic inclusivity – key conditions for a low-carbon, sustainable economy (Owusu-Agyeman, 2025; Addaney et al., 2025). The integration of human capital expansion and networked collaboration, therefore, presents a robust conceptual model for leveraging TVET in achieving Ghana's green growth aspirations.

Figure 1: A conceptual framework diagram to visualize the study's logic model. Source: Author's own work.

5. Methodology

This study examined the role of Technical and Vocational Education and Training (TVET) in fostering green skills for sustainable economic growth in Ghana, with particular focus on institutional, policy, and industry enablers. A quantitative cross-sectional survey design was adopted to capture diverse perspectives from key stakeholder groups across Ghana's TVET ecosystem. This approach enabled the exploration of relationships among policy support, trainer capacity, industry collaboration, and employability outcomes (Addaney et al., 2025; Albertz & Pilz, 2025).

Guided by a positivist paradigm, the study employed inferential statistical analyses, including chi-square tests, t-tests, and multiple regression, to validate relationships between variables, aligning with established empirical approaches in TVET research (Joseph et al., 2025; Chola & Kiplagat, 2025). The target population comprised TVET educators, industry representatives, and institutional administrators. Using stratified sampling, 139 participants were selected following the statistical power analysis method to ensure proportional representation across stakeholder categories, as done by Owusu-Agyeman et al. (2024).

A structured questionnaire was developed based on established frameworks for assessing green skills integration (Cedefop, 2021; UNESCO-UNEVOC, 2020). Items measured policy support, trainer competence, institutional infrastructure, and employability outcomes using a 5-point Likert scale. Data was collected through online surveys administered in collaboration with the Commission for TVET (CTVET) and partner institutions across major regions, following informed consent procedures (CTVET, 2025). Data were analyzed using SPSS version 20.

Instrument reliability was confirmed through Cronbach's Alpha values (α = 0.83–0.85), indicating high internal consistency. Content validity was established through expert review and alignment with validated TVET assessment models (Albertz & Pilz, 2025; Addaney et al., 2025).

Descriptive statistics were used to analyze respondent characteristics, while inferential analyses (chi-square, one-sample t-tests, and multiple regression) evaluated hypotheses regarding the institutional, policy, and industry determinants of green skills and related economic outcomes. Statistical significance was set at $p < 0.05$, consistent with prior TVET studies (Owusu-Agyeman, 2025; Busemeyer et al., 2025).

6. Results and Discussion

6.1 Demographic Characteristics of Respondents

Table 1. Demographic Characteristics of Respondents

Category	Frequency	Percent.	Cumulative. Percent
Stakeholder category			
TVET Trainer/Educator	49	35.3	35.3
Industry/Employer Representative	46	33.1	68.4
TVET Institution Administrator/Manager	44	31.6	100.0
Total	139	100	

Gender			
Male	90	64.7	64.7
Female	49	35.3	100.0
Total	139	100	
Age group			
26–35 years	45	32.4	32.4
36–45 years	49	35.3	67.7
46 years and above	45	32.4	100.1
Total	139	100	
Years of experience do you have in your field			
More than 10 years	42	30.2	30.2
6–10 years	38	27.3	57.5
2–5 years	30	21.6	79.1
Less than 2 years	29	20.9	100.0
Total	139	100	

Table 1 presents the demographic characteristics of respondents, reflecting a balanced representation of key stakeholders within Ghana's Technical and Vocational Education and Training (TVET) ecosystem. The analysis focuses on stakeholder category, gender, age, and years of experience, each providing contextual depth for interpreting perspectives on TVET's role in green skills development for sustainable growth. TVET trainers/educators (35.3%), industry/employer representatives (33.1%), and administrators/managers (31.6%) were equally represented, ensuring comprehensive insights across pedagogical, industrial, and administrative domains. Such diversity facilitates understanding of how training, policy, and employment interact to promote sustainability (Albertz & Pilz, 2025; Addaney et al., 2025; Joseph et al., 2025). The inclusion of these stakeholder groups enhances the system's responsiveness to sustainability imperatives and fosters collaborative innovation.

Gender data reveal a male dominance (64.7%) relative to female participation (35.3%), mirroring persistent gender disparities in technical fields, which aligns with findings from Ahmed, Shakeel, & Khan (2021). However, female involvement is gradually increasing, particularly in renewable energy and sustainable agriculture, driven by inclusive education policies (Alhassan et al., 2024). This aligns with UNESCO-UNEVOC's (2020) emphasis on gender equity as central to the green transformation of TVET. The age distribution of 26–35 years (32.4%), 36–45 years (35.3%), and 46 years and above (32.4%) illustrates a multigenerational mix that encourages knowledge exchange and innovation, just as revealed in Liu & Chen (2025). Mid-career professionals, who often hold managerial positions, play a pivotal role in institutionalising green skills (Busemeyer et al., 2025). The inclusivity of both emerging and seasoned professionals contributes to a dynamic and adaptive TVET workforce.

In terms of professional experience, 30.2% of respondents had over 10 years of experience, followed by 27.3% (6–10 years), 21.6% (2–5 years), and 20.9% (less than 2 years). The predominance of experienced stakeholders enhances the study's credibility through

their institutional knowledge (Owusu-Agyeman et al., 2024). Experienced educators and administrators embed sustainability principles into curricula and partnerships (Paryono, 2017; Pachatz et al., 2025), while younger professionals introduce digital and innovative pedagogies (Owusu-Agyeman, 2025). Overall, the demographic structure reflects an inclusive and competent stakeholder ecosystem capable of advancing green skills development in Ghana's TVET sector. The balanced representation of educators, employers, and administrators reinforces policy–training–industry constructive interaction identified by Cedefop (2021) as vital for green transitions. Persistent gender gaps, however, indicate a need for targeted interventions such as mentorship and inclusive outreach to strengthen women's participation in green technical fields (ILO, 2019).

Diversity in age and experience further supports mentorship and institutional resilience (Tramonti & Dochshanov, 2025). These demographic dynamics position Ghana's TVET sector as a model for inclusive, adaptive capacity-building that underpins sustainable economic transformation. In line with global perspectives (Chola & Kiplagat, 2025; Ogur, 2023; CTVET, 2025; World of TVET, 2025), the study confirms TVET's role as a unifying mechanism that links education, industry, and policy to drive the green transition agenda.

6.2 Chi-Square Goodness-of-Fit Test on Demographic Characteristics

Table 2. Results of Chi-Square Goodness-of-Fit Test for Demographic Variables

Demographic Variable	χ^2 Value	df	p-value
Stakeholder Category	0.22	2	0.895
Gender	12.09	1	< 0.001**
Age Group	0.12	2	0.943
Years of Experience	3.27	3	0.352

*Note: **p < 0.01***

Chi-Square Goodness-of-Fit test was conducted to determine if the distribution of respondents across the demographic categories (stakeholder group, gender, age, and experience) was significantly different from an equal distribution. The results are presented in Table 2.

A significant gender disparity (χ^2 (1) = 12.09, p < .001) was observed with males comprising 64.7% of respondents (Table 2). This imbalance mirrors the broader gender gap in Ghana's TVET and technical sectors, consistent with Ahmed et al. (2021) and Owusu-Agyeman et al. (2024), who identified structural and cultural barriers limiting women's participation. Such disparities highlight a critical equity challenge: without intentional gender inclusion, green skills development risks perpetuating existing inequalities. As underscored by the International Labour Organisation (2019), a just transition to a green economy must ensure equitable access and participation for all.

These findings have two key implications. First, the balanced stakeholder representation strengthens the credibility of the study's conclusions, suggesting that calls for curriculum reform, industry collaboration, and supportive policy frameworks reflect a shared consensus, aligning with Albertz and Pilz (2025). Second, the persistent gender

imbalance underscores the urgent need for targeted interventions to enhance women's participation in green TVET programs. Inclusive approaches such as promoting female role models, designing gender-sensitive learning environments, and addressing curricular bias are consistent with recommendations by UNESCO-UNEVOC (2020) and Owusu-Agyeman and Aryeh-Adjei (2023). In summary, while the study captures diverse stakeholder perspectives, it also reveals that the success of Ghana's transition toward a sustainable green economy depends on embedding gender equity within TVET reform. Deliberate inclusivity is necessary to fully realize the transformative potential of green skills development.

The demographic characteristics of respondents provide a vital context for interpreting the study's findings on the role of Technical and Vocational Education and Training (TVET) in fostering green skills in Ghana. Chi-square analyses (Table 2) revealed balanced distributions across stakeholder categories, age groups, and years of experience, indicating that perceptions were not biased toward any specific demographic group. The equitable representation of TVET trainers (35.3%), industry representatives (33.1%), and institutional managers (31.6%) enhances data robustness and reflects a comprehensive view of the TVET ecosystem. This balance supports Addaney et al. (2025), who emphasize that an effective TVET policy requires the inclusion of educators, administrators, and employers. Similarly, the distribution across age and experience groups integrates both innovative and experiential insights, contributing to a deeper appreciation for green skills development.

Conversely, a significant gender disparity (χ^2 (1) = 12.09, $p < .001$) was observed, with males comprising 64.7% of respondents. This imbalance mirrors the broader gender gap in Ghana's TVET and technical sectors, consistent with Ahmed et al. (2021) and Owusu-Agyeman et al. (2024), who identified structural and cultural barriers limiting women's participation. Such disparities highlight a critical equity challenge: without intentional gender inclusion, green skills development risks perpetuating existing inequalities. As underscored by the International Labour Organisation (2019), a just transition to a green economy must ensure equitable access and participation for all.

6.3 How Current TVET Curricula in Ghana Integrate Green Skills to Align with Sustainable Development Goals

Table 3. One-Sample Test: Test Value = 3.5

ITEM	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Mean Difference	95% CI Lower	95% CI Upper	Rank
The current TVET curriculum in my field explicitly includes topics on environmental conservation and sustainability.	-1.376	138	0.171	3.374	1.079	-0.126	3.193	3.555	4

Specific 'green skills' (e.g., energy efficiency, waste management, sustainable sourcing) are clearly defined in my training modules.	1.093	138	0.2763	3.597	1.048	0.097	3.421	3.773	2
The teaching and learning materials (e.g., textbooks, manuals) are up-to-date and reflect modern green technologies and practices.	1.086	138	0.2794	3.597	1.054	0.097	3.42	3.774	3
Practical training in workshops/labs adequately incorporates tools and techniques for green practices (e.g., solar panel installation, water recycling systems).	-1.781	138	0.077	3.331	1.119	-0.169	3.143	3.519	5
Overall, I believe the TVET curriculum effectively prepares graduates to contribute to Ghana's sustainable development goals (SDGs).	1.538	138	0.1264	3.626	0.965	0.126	3.464	3.788	1

Cronbach's Alpha = 0.838, 95% CI [0.789, 0.874], N of Items = 5. Good internal consistency.

Table 3 presents the findings on the integration of green skills in Ghana's current TVET curricula. The results indicate a moderate level of integration, with mean scores clustering around the neutral benchmark (M ≈ 3.4–3.6). The respondents agreed that the curricula incorporate green-related topics like energy efficiency and sustainability. However, there was comparatively lower agreement regarding the availability of practical training tools and updated instructional materials (M = 3.33). The curriculum's perceived effectiveness in preparing students to contribute to the Sustainable Development Goals (SDGs) recorded the highest mean score (M = 3.63), reflecting recognition of potential rather than full realization in practice.

These findings are consistent with Addaney et al. (2025), who reported that while Ghana's TVET system is advancing toward greater inclusivity and quality, it continues to lack sufficient environmental and sustainability depth. Similarly, Owusu-Agyeman and Aryeh-Adjei (2023) highlighted the need to integrate green skills across both formal and informal TVET pathways to support national sustainability transitions. In alignment, Albertz and Pilz (2025) and Pujun (2025) highlighted that curriculum modernization, and the contextualization of green training are indispensable for developing effective green skill sets.

Overall, the findings show that systemic and curricular limitations continue to constrain Ghana's TVET sector, despite its growing awareness and commitment to sustainability imperatives. This underscores the need for comprehensive curriculum reform that embeds sustainability principles across disciplines, enhances teacher capacity, and ensures access to modern, practice-oriented learning tools.

In moving forward, policymakers and educational stakeholders should prioritize the alignment of TVET curricula with green industry demands, foster public–private partnerships to strengthen implementation, and invest in continuous curriculum review mechanisms. Such coordinated efforts will not only accelerate Ghana's progress toward the SDGs but also position its TVET graduates as key contributors to the emerging green economy.

6.4 Institutional, Policy, and Industry-Level Factors Influence the Capacity of Ghana's TVET Sector to Promote Green Skills Development

Table 4. One-Sample Test: Test Value = 3.5

ITEM	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Mean Difference	95% CI Lower	95% CI Upper	Rank
My TVET institution has the necessary physical infrastructure (labs, workshops) to teach green skills effectively.	0.773	138	0.4411	3.568	1.043	0.068	3.393	3.743	3

TVET trainers in my institution have received sufficient training on green technologies and sustainable practices.	1.291	138	0.1987	3.612	1.018	0.112	3.441	3.782	4
I am aware of government policies (e.g., Ghana's Energy Transition Framework, Education Strategic Plan) that promote green skills in TVET.	2.138	138	0.0343	3.676	0.972	0.176	3.513	3.839	1
There is adequate funding and resources from the government dedicated to greening the TVET sector.	-1.104	138	0.2715	3.396	1.114	-0.104	3.209	3.583	5
Local industries actively collaborate with my TVET institution to update curricula with needed green skills.	1.666	138	0.0981	3.655	1.095	0.155	3.471	3.838	2

There is a strong demand from employers for graduates with certified green skills.	-0.642	138	0.5222	3.439	1.124	-0.061	3.25	3.627	6

Cronbach's Alpha = 0.853; 95% CI [0.804, 0.888] The number of items is six, indicating good internal consistency.

Table 4 presents the results on institutional, policy, and industry-level factors influencing Ghana's TVET sector's capacity to advance green skills development. The findings reveal a prominent level of policy awareness among respondents (M = 3.68, p = .034), reflecting Ghana's alignment with sustainability frameworks such as the Energy Transition Framework. This indicates that the policy discourse on green skills has gained substantial traction within the TVET ecosystem. However, persistent concerns regarding inadequate funding (M = 3.39) and limited industry collaboration (M = 3.65, p = .098) point to structural weaknesses that constrain policy translation into practice. Taken together, these results highlight a paradox of institutional readiness coexisting with weak implementation capacity, both structurally and financially.

This observation resonates with Busemeyer et al. (2025), who contend that institutional architecture critically mediates the extent to which green skill formation contributes to broader economic and environmental objectives. The CTVET (2025) report corroborates this view, emphasizing that Ghana's green transition efforts remain hampered by resource deficits and uneven institutional engagement across sectors. Similarly, Chola and Kiplagat (2025) as well as Ahmadu and Orisaremi (2025) underscore that robust intersectoral cooperation and sustained investment are indispensable for transforming TVET systems into effective vehicles for sustainable development.

The limited collaboration between industry and TVET institutions observed in this study further validates Joseph et al. (2025)'s argument that strategic private-sector partnerships are essential to future-proof green skills ecosystems, particularly in the Global South. Industry engagement not only enhances curriculum relevance but also facilitates technology transfer, innovation, and work-based learning opportunities, which are key enablers for a resilient green economy.

Overall, the findings suggest that while Ghana's TVET sector demonstrates commendable policy consciousness and institutional commitment toward sustainability, systemic barriers, especially financial constraints, and weak industry linkages, continue to inhibit its transformative potential. Strengthening governance coordination, enhancing resource mobilization, and fostering multi-stakeholder partnerships are therefore critical steps towards operationalizing a coherent, industry-responsive green skills agenda capable of supporting Ghana's sustainable development trajectory.

6.5 Acquisition of Green Skills Through TVET Contributes to Employability, Decent Work Opportunities, and Economic Growth in Ghana

Table 5. One-Sample Test: Test Value = 3.5

ITEM	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Mean Difference	95% CI Lower	95% CI Upper	Rank
Possessing green skills makes a TVET graduate more attractive to employers in Ghana.	0.45	138	0.6537	3.54	1.037	0.04	3.366	3.714	3
Jobs requiring green skills offer better wages and working conditions (decent work).	0.039	138	0.9687	3.504	1.079	0.004	3.323	3.685	4
Green skills are essential for the future of my industry and Ghana's economic growth.	2.228	138	0.0275	3.683	0.971	0.183	3.521	3.846	1
TVET graduates with green skills are better equipped to start their own sustainable businesses (entrepreneurship).	2.516	138	0.013	3.727	1.062	0.227	3.549	3.905	2
The development of a green-skilled workforce is critical for attracting foreign investment	-0.038	138	0.97	3.496	1.125	-0.004	3.308	3.685	5

in sustainable industries.	

Cronbach's Alpha = 0.838, 95% CI [0.787, 0.875] N of Items = 5. Good internal consistency.

Table 5 presents the empirical results on the interrelationships among green skills, employability, and economic growth. The findings reveal that respondents agreed that the acquisition of green skills enhances employability and entrepreneurship ($M = 3.72$, $p = .013$) and serves as a catalyst for Ghana's economic growth ($M = 3.68$, $p = .028$). However, perceptions were more neutral regarding the influence of green skills on wage levels and foreign investment attraction ($M \approx 3.50$). This suggests that while there is optimism about the relevance of green skills for sustainable employment and innovation, there remains some skepticism about their immediate monetary and investment outcomes.

The respondents' emphasis on employability and entrepreneurship implies that green skills function as an evolving form of human capital that enhances adaptability in emerging sectors of the economy. Yet, the neutral perceptions concerning wages and foreign investment may indicate that the economic returns to green skills are more long-term and contingent upon broader structural reforms and policy alignment.

These findings are consistent with prior research. Ogur (2023) and Alhassan et al. (2024) found that Technical and Vocational Education and Training (TVET) significantly contribute to employability outcomes, although systemic and institutional constraints often limit their multiplier effects on economic growth. Owusu-Agyeman (2025) underscored that microlearning and upskilling in green skills promote just transitions and foster entrepreneurship, reinforcing the respondents' belief in the transformative potential of such skills. Similarly, Thake (2024) associated green skill acquisition with enhanced labour market adaptability, suggesting that Ghana's TVET graduates equipped with sustainability-orientated competencies can better align with the demands of an evolving green economy.

These findings also resonate with the Sustainable Development Goals (SDGs), particularly Goals 4 (Quality Education), 8 (Decent Work and Economic Growth), and 9 (Industry, Innovation, and Infrastructure). By integrating green skills into TVET curricula, Ghana can accelerate progress toward inclusive and sustainable economic transformation. Such integration supports not only environmental stewardship but also enhances industrial competitiveness and social equity, key components of the Green Economy Framework advocated by UNEP and other global agencies (Morley, 2025; UNEP, 2025)

In sum, the evidence reinforces the strategic value of investing in green skills development as a means of strengthening Ghana's human capital base, stimulating entrepreneurship, and preparing the workforce for the transition to low-carbon industries. To maximise the economic returns from such investments, however, complementary policies are required, such as industry partnerships, incentives for green innovation, and labour market reforms to ensure that skill acquisition translates into tangible economic opportunities.

6.6 Important Partnerships for the Future of Green TVET

Table 6. One-Sample Test: Test Value = 3.5

ITEM	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Mean Difference	95% CI Lower	95% CI Upper	Rank
Ministry of Education & Skills Agencies (e.g., COTVET)	1.789	138	0.0758	3.655	1.019	0.155	3.484	3.826	3
Ministry of Environment, Science & Technology	3.974	138	0.0001	3.82	0.95	0.32	3.661	3.979	1
Local Private Companies & Industries	1.814	138	0.0718	3.655	1.005	0.155	3.486	3.823	3
International Development Partners (e.g., GIZ, World Bank)	0.768	138	0.4441	3.568	1.05	0.068	3.392	3.744	5
Renewable Energy & Environmental NGOs	2.707	138	0.0077	3.719	0.956	0.219	3.559	3.88	2

Cronbach's Alpha = 0.84, 95% CI [0.791, 0.877], N of Items = 5. Good internal consistency.

Table 6 presents the results on Important Partnerships for the Future of Green TVET. The data reveal that respondents attached the highest priority to partnerships with the Ministry of Environment ($M = 3.82$, $p < .001$) and renewable energy NGOs ($M = 3.72$, $p = .008$). This suggests a strong recognition that advancing Green TVET requires cross-sectoral collaboration that extends beyond the traditional boundaries of education ministries. Partnerships with other ministries and local industries also received high ratings ($M = 3.65$), reflecting a growing appreciation for domestic institutional constructive interaction. In contrast, international development partners were rated lower ($M = 3.57$), signalling an underutilisation of global networks and resources despite their potential contributions to sustainable capacity building.

This interpretation aligns with UNESCO-UNEVOC (2020) and ILO (2019), both of which emphasize multi-level and cross-sectoral collaboration spanning governmental,

private, and international stakeholders as critical to greening TVET systems. Moreover, comparative evidence from Pachatz et al. (2025) and Tramonti & Dochshanov (2025) demonstrates how countries such as Austria and other European nations have effectively institutionalized sustainability within TVET through integrated partnerships involving public agencies, industry, and civil society organizations.

In this context, the Ghanaian findings reveal both progress and opportunity: while there is clear awareness of the importance of collaborative frameworks, the potential to engage international actors remains untapped. Strengthening ties with global development agencies and sustainability networks could provide not only technical expertise but also access to innovative financing and knowledge exchange mechanisms. Such partnerships would enhance the resilience and global competitiveness of Ghana's Green TVET agenda, facilitating its alignment with the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 13 (Climate Action).

7 Multiple Regression Analysis

Table 7: Results of Multiple Regression Analysis Predicting Green Skills Integration and Contribution to Employability & Economic Growth

Model and Predictor Variables	**B**	**SE**	**β**	**t**	**p-value**	**R^2**	**Adjusted R^2**
Model 1: DV = Green Skills Curriculum Integration						**0.58**	**0.56**
(Constant)	0.85	0.32		2.66	0.009		
Institutional Infrastructure	0.18	0.07	0.17	2.57	0.011		
Trainer Capacity	0.25	0.06	0.26	4.17	<0.001		
Government Policy Support	0.31	0.06	0.31	5.17	<0.001		
Industry Collaboration	0.22	0.07	0.21	3.14	0.002		
Model 2: DV = Contribution to Employability & Economic Growth						**0.49**	**0.47**
(Constant)	1.12	0.38		2.95	0.004		

Model and Predictor Variables	B	SE	β	t	p-value	R^2	Adjusted R^2
Green Skills Curriculum Integration	0.35	0.08	0.33	4.38	<0.001		
Institutional Infrastructure	0.15	0.07	0.14	2.14	0.034		
Industry Demand for Graduates	0.28	0.08	0.26	3.50	0.001		

Note: DV = Dependent Variable; B = Unstandardized Coefficient; SE = Standard Error; β = Standardized Coefficient.

The multiple regression analysis (Table 7) provides vital quantitative insights into the mechanisms shaping the integration of green skills and their broader impact within Ghana's TVET sector. Results from the two models reveal a coherent predictive relationship: systemic enablers are significantly associated with the incorporation of green skills into the curriculum, which in turn predicts TVET's contribution to employability and economic growth.

7.1 Model 1: Determinants of Green Skills Curriculum Integration

The first regression model ($R^2 = 0.58$) identifies four significant predictors of Green Skills Curriculum Integration, with Government Policy Support emerging as the strongest driver ($\beta = 0.31$, $p < .001$). This underscores that policy frameworks are not merely rhetorical but serve as critical instruments for embedding sustainability into educational content. The result aligns with the prominent level of policy awareness observed in the descriptive findings and resonates with global calls by UNESCO-UNEVOC (2020) and Cedefop (2021), which emphasize that clear and supportive policy directives are foundational for "greening" TVET systems. Trainer Capacity ($\beta = 0.26$, $p < .001$) also exhibited a strong influence, reaffirming that effective policy implementation depends on the skills and readiness of educators. This finding supports Owusu-Agyeman (2025), who identified microlearning and upskilling as key strategies for embedding green skills, and Pachatz et al. (2025), who highlighted the upskilling of trainers as central to Austria's successful green transition in vocational education and training.

In addition, Industry Collaboration ($\beta = 0.21$, $p = .002$) and Institutional Infrastructure ($\beta = 0.17$, $p = .011$) were both significant, though comparatively weaker predictors. This indicates that the practical realization of green skills depends on tangible resources and active engagement from the private sector. The significance of industry collaboration echoes findings by Joseph et al. (2025), which identified strategic partnerships as vital for futureproofing TVET in the Global South. The lower beta for infrastructure reflects systemic constraints that limit institutional readiness, consistent with Busemeyer et al. (2025), who argued that institutional architecture critically mediates the effectiveness of green skill development.

7.2 Model 2: Pathways to Employability and Economic Growth

The second regression model ($R^2 = 0.49$) demonstrates that the integration of green skills into the curriculum is the most powerful predictor of TVET's contribution to employability and economic growth ($\beta = 0.33$, $p < .001$). This provides robust empirical support that curricular reform serves as a direct lever for improving graduate outcomes and national economic resilience. The finding substantiates the theoretical premise of Human Capital Theory, which posits that investment in relevant, future-orientated skills such as green skills enhance labour productivity and adaptability (Thake, 2024; Ogur, 2023).

The significant influence of industry demand for graduates ($\beta = 0.26$, $p = .001$) further reinforces the importance of aligning TVET outputs with labour market needs. When industries actively seek green-skilled professionals, a "pull effect" is created that elevates the value and applicability of TVET training. This aligns with Albertz and Pilz (2025), who argued that synchronizing TVET curricula with green industry demands is essential for sustainable workforce development. Finally, institutional infrastructure retained a smaller yet significant effect ($\beta = 0.14$, $p = .034$), suggesting that access to well-equipped facilities continues to enhance the practical proficiency of graduates, thereby strengthening their employability.

7.3 Synthesis and Policy Implications

The regression results highlight how important drivers of educational development are interrelated. The overarching strategic direction is established by government policy, trainer capacity translates this vision into effective classroom practice, industry collaboration aligns training outcomes with labour market demands, and sufficient infrastructure fosters experiential and applied learning. Together, these interdependent components drive the effective integration of green skills, which in turn catalyze employability and economic growth. This study advances discourse by establishing significant predictive relationships linking systemic enablers, green skills integration, and economic outcomes, providing an empirical foundation for understanding how these factors are associated. It demonstrates that conceptual alignment must be matched with coordinated action across all pillars to overcome operational constraints. As Chola and Kiplagat (2025) and Ahmadu and Orisaremi (2025) contended, fragmented or isolated interventions are unlikely to succeed; what is required is a coherent, multi-stakeholder strategy.

For Ghana, this implies that ongoing policy initiatives led by CTVET (2025) should be reinforced through large-scale professional development programmed for trainers, incentivized industry partnerships, and targeted investments in modernizing TVET infrastructure. Only through such a holistic and collaborative approach can Ghana unlock the full potential of its TVET system as an engine for sustainable and inclusive economic transformation.

8. Limitations of the Study

While this study offers valuable insights into the role of TVET in green skills development in Ghana, its findings should be interpreted considering several methodological limitations.

First, the cross-sectional design provides a snapshot of relationships and perceptions at a single point in time. Consequently, it establishes correlation but cannot definitively determine causality between the identified enablers (e.g., policy support, trainer capacity) and the outcomes of green skills integration and employability.

Second, the data are based on self-reported measures from a survey. This approach is susceptible to social desirability bias, where respondents may provide answers, they believe are socially acceptable rather than reflecting their true perceptions. Additionally, the perceptual nature of the data may not always align with objective realities on the ground.

Third, although stratified sampling was employed, the sample representativeness is constrained by the study's scope and sample size (n=139). The views captured, while diverse across key stakeholder groups, may not be fully generalizable to the entire TVET ecosystem in Ghana, particularly for remote or under-represented institutions.

Finally, the study suffers from a lack of longitudinal tracking. It does not assess the long-term impact of green skills on graduates' career trajectories, wage progression, or their sustained contribution to the green economy. A longitudinal study would be required to capture these dynamic effects and the true return on investment in green TVET.

Future research would benefit from addressing these limitations by employing longitudinal designs, triangulating self-reports with observational or administrative data, and expanding the sampling frame to enhance generalizability.

9. Conclusion

This study provides robust empirical evidence that Technical and Vocational Education and Training (TVET) is a critical lever for green skills development and sustainable economic growth in Ghana. By quantitatively establishing the significant predictive associations between government policy, trainer competence, institutional infrastructure, and industry collaboration with green skills integration, this research moves beyond theoretical advocacy to offer an empirically-supported framework for understanding green skills development. The findings demonstrate that a synergistic approach where strategic policy is operationalized by skilled trainers, reinforced by industry partnerships, and supported by adequate infrastructure is indispensable for cultivating a workforce capable of driving Ghana's green transition.

The study makes a distinct contribution by bridging a critical gap in the literature, offering a systemic analysis of how institutional, policy, and industrial mechanisms collectively shape green skills outcomes in a sub-Saharan African context. It confirms that Ghana's TVET sector possesses the policy awareness and institutional readiness to advance sustainability. However, it also uncovers the persistent structural barriers of inadequate funding, weak industry engagement, and gender disparities that threaten to derail this progress. Addressing these challenges is not merely an educational imperative but an economic necessity for achieving a just and inclusive transition.

The implications for national strategy are profound. For Ghana to realize its green economy aspirations, TVET must be positioned at the centre of its human capital development agenda. This requires:

- **Policy Coherence:** Transforming high-level policy awareness into actionable, funded implementation plans.

- **Ecosystem Development:** Fostering deep, incentivized collaboration between TVET institutions, industry, and environmental agencies to ensure curriculum relevance and graduate employability.

- **Inclusive Capacity Building:** Implementing targeted interventions to bridge the gender gap and empower women as leaders in green technical fields.

This study, by its cross-sectional nature and reliance on perceptual data, presents a snapshot in time. Future research should adopt longitudinal designs to track the long-term

socio-economic returns on green skills investments and utilise mixed methods to explore the nuanced barriers and success factors at the institutional level. Furthermore, investigating the role of digital technologies in scaling green TVET delivery presents a promising avenue for inquiry.

In sum, this research affirms that a revitalized, green-focused TVET system is not just an educational asset but a cornerstone of national resilience and competitiveness. By heeding the evidence presented here, policymakers, educators, and industry leaders can collectively forge a pathway where Ghana's human capital becomes its most powerful engine for sustainable, inclusive, and prosperous economic transformation.

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