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Kashmir Journal of Academic Research & Development

Volume 1, Issue 4, 2025



Research Journals Online

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DOI: <https://doi.org>

The Kashmir Journal of Academic Research and Development

Journal homepage: <https://rjsaonline.org/index.php/KJARD>



Leadership in the Age of AI: Exploring the Shift from Classical Communication to Algorithm-Driven Dialogue in Corporate Settings

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ARTICLE INFO

ABSTRACT

Received:

August 03, 2025

Revised:

August 29, 2025

Accepted:

September 23, 2025

Available Online:

October 06, 2025

Keywords:

Artificial intelligence;
Algorithmic management;
Leadership communication;
Algorithm-driven dialogue;
Corporate communication;
Employee voice;
Organizational trust

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This paper discusses the way artificial intelligence (AI) is changing the aspect of leadership communication that involved human-to-human communication to algorithm-to-algorithm communication within the organizational structures. Classical models assume that there are visible senders, channel stability and direct relational accountability. Modern-day organizations, by contrast, are becoming more dependent on algorithmic management systems, HR analytics, conversational agents, and large language models to compose, sift, customize, and direct internal messages. This study is a synthetic review of empirical literature in the Scopus index published within the past five years as a major (2015–2025). Two steps of selection strategy are the differentiation between studies that inform the conceptual backdrop, and core sample of 12 primary studies that are used as analytic data. The thematic synthesis sees five dynamics, namely AI-augmented leadership communication as an efficiency project; algorithmic gatekeeping that changes whose voices reach leaders; changing judgments of trust and fairness linked to AI-informed decisions; emotional and well-being costs linked to opaque, data-driven oversight; and enabling conditions of a constructive, algorithm-driven conversation. Through these themes, it is evident in the analysis that AI does not merely amplify or remove leadership, but it transforms it in a way of algorithmic stewardship. In the era of AI, leadership requires being transparent, ensuring the human voice channels are protected, and the Word having clear responsibility regarding organizational communication now produced by the system.

Introduction

Background: From Classical Communication to Algorithmic Mediation

Classical communication in leadership has been based on direct and human to human communication whereby the senders are identifiable and through identifiable channels, such as town halls, memoranda, email, and informal conversation, the senders show their vision, values, and expectations. The models presuppose a rather stable communication system whereby the authorship of the message is transparent, the responsibility is traceable, and the employees perceive it as caused by a responsible human agent. In the modern day organizations, however, the technology of artificial intelligence (AI) and data-driven systems have become inherent in the main processes of communication. In the creation, targeting, sequencing, and even, customization of leadership messages, such as CEO announcements, performance feedback, policy explanations, and others, algorithmic management tools, HR analytics platforms, recommendation systems, internal chatbots, and large language model (LLM)-assisted drafting systems are now involved (Budhwar and Malik, 2022; Bevilacqua et al., 2025). This transition has indicated a change in viewing technology as a neutral medium to one of a mediator of organisational sensemaking.

In this respect, the concept of algorithm-based dialogue reflects a momentous change: a form of communication whereby the wording, timing, routing, and saliency of messages is more or less directly determined by AI systems (as opposed to individual leaders). Algorithms put issues on the priority list, cluster audiences, and normalize tone massively, frequently without employee transparency. Literature on algorithmic management illustrates that these systems reorganize control, oversight and interaction, transforming the daily conversation into an area where measures, rankings, and recommendations are applied to organize who, how and on what terms are spoken to (Kellogg, Valentine and Christin, 2020). The more AI-driven chatbots are accepted as marginalized digital workers or front-of-rest interfaces, a process of leadership communication occurs more as socio-technical infrastructures than as voices of particular leaders.

Problem Statement

The classical theories of leadership and corporate communication are based on three assumptions, which are largely embedded: the senders are human and transparent, the channels are more stable and exploratory as well as having the discretion of message building and circulation under identifiable leaders. The quick integration of the AI systems disquiets all of these assumptions. The system based on LLM and robot production of communications can act as unseen co-authors, writing or editing the papers that are signed in the name of the executive, and blending human agency with aspects of machine translation. The algorithmic curation process determines which queries of employees are promoted, which performance indicators are pointed out, and which stories come into the limelight of the internal systems, hence influencing who is listened to and whose interests are muted. As further evidenced by empirical and critical research into AI language technologies, social and organisational bias when used as training data and model architectures can be encoded and amplified to shape the tone, vocabulary, and perceived neutrality without being value-free (Bender et al., 2021). Simultaneously, the recent studies on AI in HRM and leadership practice also emphasize the eagerness to be efficient, as well as the ongoing division of the concept of accountability, ethics, and power in communication through AI (Budhwar and Malik, 2022; Bevilacqua et al., 2025). Nevertheless, even with this growth, limited evidence is holistically integrated to how leadership as such, its legitimacy, credibility, and relational labor, is reorganized as the day-to-day communication with employees continues to be channeled more and more by algorithmic frameworks.

Aim and Research Questions

This study aims to synthesize empirical evidence on AI-mediated organizational communication to explain how algorithm-driven systems are reshaping the practice, meaning, and accountability of leadership communication in corporate settings.

- How do AI systems transform the ways leaders construct, deliver, and are perceived through internal communication?
- How does algorithm-driven dialogue influence trust, legitimacy, power relations, and employee voice within organizations?
- What principles emerge from existing evidence to guide responsible and accountable leadership in AI-mediated communication environments?

Literature Review

From Classical Leadership Communication to AI-Mediated Infrastructures

The literature on leadership communication has conventionally focused on deliberated, relational, and discursively dense interactions between known leaders and followers on the basis of human senders, and dedicated channels, and comparatively open authorship. Classical and modern paradigms transformational and servant leadership as well as leader-member exchange and sense giving approach to leader-member exchange describes communication as the major means in which leaders convey vision, instill trust and facilitate meaning-making within organisations. This literature implicitly assumes that technologies convey or enhance what is said, to whom, and on what grounds, regardless that these technologies do not independently determine, construct, or influence the kind of information that is conveyed.

More recent studies in the field of AI-related management and information systems contest this assumption by placing AI in the context of an organizational communication infrastructures as a constitutive component. Mechanized reviews and bibliometric studies indicate that AI is currently integrated into the various areas of decision-making, HRM, analytics, and employee-facing interfaces, transforming how information circulates and how power is exercised (Lee, Scheepers and Lui, 2023; Liu, Lai and Liu, 2024). Instead of being neutral pipes, AI systems select, categorize, personalize, and rank messages, which is where personalized-by-machinery or machine-driven productions and machine-optimized productions are located, three steps closer to the idea of a leadership voice instead of a mechanical one. This gives the conceptual distance between the

notion of algorithm-driven dialogue as an example of socio-technical condition on the one hand when leadership communication is more and more mediated (perhaps without utterance) by computational systems.

AI, Leadership, and Strategic Decision-Making

A new body of literature reviews the overlap between AI technologies and strategic leadership functions. Bevilacqua et al. (2025) review the literature on AI and top management, stating that AI-supported analytics and recommendation systems reorganize the leadership capacities, and the executives are supposed to organize a human-machine decision architecture instead of basing it on intuition and experience exclusively. Shrestha, Ben-Menahem and von Krogh (2019) also categorize the new organizational decision structure in the era of AI and present hybrid forms where decision-making power is divided among human and non-human decision-making entities. Future research on deep learning-enhanced decision-making further implies that predictive models are tracking more issues on the leaders agenda and how issues get framed with repercussions to transparency and contestability (Shrestha, Krishna and von Krogh, 2021).

Simultaneously, the research on AI-HRM draws attention to the impacts of an algorithm system on leadership on the people-management interface. Budhwar et al. (2022) demonstrate that AI use in HRM, such as scoring during recruitment, metrics in performance analytics and so on, broadens the informational scope of leaders, as well as creating new ethical, accountability, and skills requirements. The work on algorithmic HRM and algorithmic management by Meijerink and others highlights a duality: on the one hand, AI systems can make the process more consistent and effective, and on the other hand, AI systems can limit the discretion of managers and reduce the attachment of the leaders to the human impact of their decisions (Meijerink and Bondarouk, 2023). In these threads, leaders are re-enacted as custodians of AI-mediated structures, but the implications of this on communicatively, how it will influence voice, narrative, and vernacular conversation, are not thoroughly theorized.

Algorithmic Management, Control, and Communicative Power

The algorithmic management work provides invaluable information into the reorganization of communicative power within organizations by AI. Kellogg, Valentine and Christin (2020) show that the algorithmic control is driven by the mechanisms of recording, rating, recommending, and rewarding and makes the digital systems active controllers of labor processes. Recent descriptions of the shift of algorithmic management to be placed center-stage hold that such systems influence further and further the processes of scheduling, task assignments, feedback, and escalations outside of platform work, institutionalizing the idea of data-driven management in large corporate settings.

Communication wisely, these structures are not only monitoring, but whose role is also to selectively pass through what the leaders are able to see, but performance and mood of employees are to be told a story. Leadership communication relies upon opaque selection logics as key messages get surfaced, summarized, and prioritized by algorithms. This brings up the issue of silent filtering where not agreeing or minority viewpoints have lower chances of being raised to the top by the algorithm and thus strengthening hierarchy or bias in company language. However, alongside intensive exploration of control and autonomy, much of this literature continues to assume that communication is also a product of algorithmic management and does not discuss how leadership voice itself is also co-produced with and through such systems.

Trust, Ethics, and Bias in AI-Mediated Dialogue

The second, highly applicable cluster relates to the confidence in AI systems and their moral control. Gkinko and Elbanna (2023) demonstrate how organizational values, perceptions of competence, fairness, transparency, and alignment contribute to trusting conversational AI, and they suggest a complex scheme of emotional, cognitive, and organizational dimensions of trust interacting with each other. Such results are an indicator that AI-enabled channels should not be viewed as neutral helpdesks: they actively condition the perceptions of the employees about the organization and, consequently, its leadership.

On a bigger scale, Bender et al. (2021) predict the subsequent prediction in terms of large language models reproducing and reinforcing linguistic and social bias entrenched in training corpora and how allegedly unbiased output can capture norms of exclusion. Mokander et al. (2023) take this issue a step further, describing a three-layered system to audit large language models, specifically, governance, model, and application audits, and suggest that to align them with the law, ethics, and society, stringent oversight is needed. When such insights are put into the context of internal communication, it means that the use of AI-generated or AI-filtered communication on leaders implies the need to assume responsibility regarding the hidden biases, hallucinations or disqualifying language structures that threaten inclusion, authenticity, and psychological security.

Research on trust, therefore, indicates that there is a two-way bind to the leadership communication in the era of AI. On the one hand, the use of AI facilitated tools can be an indicator of modernity, responsiveness and professionalism; on the other,

the lack of transparency regarding who speaks and how messages are produced threatens to undermine confidence in systems and leaders themselves in case the governance is poor or opaque. These ethical and trust issues have not, however, been incorporated into the literature to date into a systematic explanation of leadership as a communicative practice that is being played out through algorithmic infrastructures.

Mapping the Emerging AI-Leadership Communication Field

A number of integrative and review studies serve to clear up the bigger landscape. Lee, Scheepers and Lui (2023) provide a synthesis of literature on the adoption of AI at the organizational level, yet they making it very clear that results require identifying the particular contextual aspect like strategy, culture, and building capabilities. Bibliometric methods are applied by Liu, Lai and Liu (2024) to demonstrate that the study of AI in organisations is growing and fragmenting fast, but have discrete groups around decision support, HR analytics, governance and ethics but quite limited literature that addresses directly the discourse of internal communication and leadership. Bevilacqua et al. (2025) and other works on strategic leadership place AI as both an enabler and threat to an executive position, whereas Jafari (2025) among others relate the implementation of AI to strategic planning, control, and corporate governance relations.

In addition to it, the conceptual and empirical works on AI-assisted leadership abilities emphasize the significance of AI literacy, ethical acuity, and capability to handle human-machine complementarities as essential leadership competences (Bevilacqua et al., 2025; Budhwar et al., 2022). Nevertheless, these articles usually pre-empt the decision quality, novelty or productivity as opposed to micro-dynamics of how AI mediates daily conversation between leaders and subordinates in between chatbots, auto-written announcements, algorithmically filtered feedback systems and sentiment-mining dashboards.

When combined, this literature signals that there are four areas of congruence. To begin with, AI technologies have transformed into not peripheral devices but rather central information and interaction organizers within organizations. Second, algorithmic management schemes point to the increased significance of AI on organizing the control and visibility. Third, trust, prejudice, and audit disputes also reveal that the communication mediated by AI is normatively contented and politically stature. Fourth, the reviews and strategic leadership literature recognize that leaders need to be versatile and do not go beyond theorizing the dialogue based on algorithms as a specific form of leadership communication. This points to the distinct gap: there is no unified, empirically-based synthesis, explaining how leadership itself, its voice, legitimacy, and relational work, is getting moved around when AI systems are actively co-authoring, curating and routing organizational communication. This is the gap that the current secondary qualitative research undertakes.

Methodology

Research Design

The research employs a secondary qualitative, interpretive research design as the empirical articles published by different authors are considered the principal source of data. The analysis, in lieu of gathering new organizational information, interrogates systematically currents in the Scopus-indexed research on artificial intelligence, leadership, and internal corporate communication to produce a synthesized knowledge of how an algorithm-led dialogue constructs a new perspective on leadership practice. It is close to integrative review and qualitative synthesis traditions, which allows the incorporation of various methods and situations to develop a more comprehensive conceptual explanation of an emergent phenomenon (Whittemore and Knafl, 2005; Barnett-Page and Thomas, 2009). The study is situated in an interpretivist paradigm, which presupposes leadership communication in the century of AI to be a socially constructed one under the conditions of the socio-technical arrangement and meaning being reconstructible with the help of close comparison, interpretation, and abstraction of published data.

Data Sources and Search Strategy

The core database was chosen, Scopus, due to its high-quality articles in the field of management, information systems, organizational studies, communication, and business ethics as well as suitability in Scopus oriented article. The search span was limited to the 2015-2025 range, which has been arduous since the time when algorithmic management, advanced analytics, conversational AI, and large language models became relevant in the corporate environment. Search terms were built up as a result of the iterative process of including search terms that combined AI, leadership, and internal communication, such as: "artificial intelligence" AND "leadership communication"; "algorithmic management" AND internal communication; "conversational AI" OR chatbot AND employee voice AND organization; and AI AND corporate communication AND trust OR ethics. They scanned reference lists of relevant papers to determine other relevant studies in line with the integrative review practice (Whittemore and Knafl, 2005).

Study Selection

The article has a two-stage selection logic, which was used in the study. To first narrow the set of records the title and abstract were used to filter out non-organizational, purely technical or non-peer-reviewed articles. Articles were subsequently evaluated relative to their inclusion criteria:

(1) content industry is AI, algorithmic systems, or conversational agents applied within organizational or corporate settings; (2) a clear reference to leadership, managerial practice, internal communication, employee interaction, or organizational control; and (3) publication in a peer-reviewed journal included in Scopus. Out of this, a collection of 15-16 pivotal studies was created to serve as the basis of the construction of the conceptual and theoretical background in the Literature Review. Out of the above number of qualitative studies, a specific group of 12 primary empirical studies was chosen with the Findings section, which provided deep, novel evidence on the communication, trust, power, or voice mediated by AI, and were not already the main examples in the previous conceptual synthesis. This division continues analytic distinction between the framing of the background and the current study core interpretive data.

Data Extraction and Thematic Synthesis

All of the studies in them were considered qualitative information, notwithstanding the design of the original research, in accordance with integrative and meta-interpretive methodologies which permit synthesizing concepts across methodological boundaries (Whittemore and Knafl, 2005; Weed, 2005). Then the relevant parts of the article (e.g., findings, discussion, implications) were moved to an analytic matrix that captured the context, AI application, leadership role, communication mechanisms, and reported outcomes based on trust, legitimacy, power, surveillance, or employee voice. Following an iterative thematic synthesis methodology, as advocated by Thomas and Harden (2008), line-by-line coded texts were then clustered at first into descriptive themes, then into higher-order analytical themes which describe how algorithm driven dialogue is reconfiguring leadership communication. Convergences, tensions and contextual contingencies were identified through a constant comparison across the studies to define the foundation of multi-theme Findings and the comparative Analysis to the previously published literature.

Rigor and Limitations

There were a number of strategies that were used to improve rigor and trustworthiness. The procedural clarity is facilitated by transparent reporting of database choice, timeframe, search strings, as well as inclusion criteria. Enhancing the difference between the conceptual literature set and 12-study analytic set helps to minimize the problem of circularity and the dependence of the comprehensive corpus on a limited set of studies. A systematic, thematic, synthesis framework is based on the existing standards of guidance regarding integrative and qualitative synthesis and offers a coherent rationale on support of translating the findings of individual studies to cross-cutting insights (Barnett-Page and Thomas, 2009; Ruggiano and Perry, 2019). However, the process is also limited by the fact that it uses published and English-written work, indexed at Scopus, as well as by variable reporting criteria among studies. These shortcomings are realized in the consideration of transferability, and add support to the necessity of further empirical studies in under-represented sectors and regions.

Findings

AI-augmented leadership communication as an efficiency project

In the 12 core studies, AI is not as much of an apparent presence of a robotic figurehead, but as a technological infrastructure to hone, magnify and generalize leadership communication- changing the performance of authority in a subtle but meaningful manner. In one of the multinational food companies, Florea and Croitoru (2025) demonstrate that AI-assisted communication tools (automated routing, AI-supported feedback, AI-aided drafting) are much more effective in improving perceived clarity, feedback quality, and communication efficiency, which, in its turn, are predictors of high employee-rated performance. Instead of removing the leaders, AI increases their broadcasted capabilities and monitoring power. The same concept is presented by Van Quaquebeke and Gerpott (2024), who describe AI as an assistant in the workplace communication: leaders do not need to be afraid of this tool assisting with drafting, summarizing, and tailoring the messages, but the authors believe that overreliance on the technology can easily lead to undermining the perceived authenticity of speech and responsibility towards unpleasant messages.

This conditional promise is supported by design-related work. Lewandowski et al. build and test a multi-perspective approach to organizational conversational agents, concluding that organizationally transparent, responsive, and well-escalating to humans, chatbots feel to employees as useful extensions of organizational voice; poorly managed bots cause aggravation, abandonment, and spill-over mistrust in sponsoring leaders. Collectively, these research results indicate that algorithm-based

communication now expands a wider reach and consistency of leaders in their interactions, but the effectiveness rest on the observable regulations regarding authorship, ownership, and the appearance of the true boss.

Algorithmic gatekeeping and the restructuring of employee voice

A second motif relates to the use of AI as a gatekeeper, which determines which signals are directed to leadership. Sharma (2025) concludes that the increased reliance of IT companies on artificial intelligence-induced HR analytics and engagement dashboards direct the focus toward measurable indicators of high potential, risk, and sentiment; the managers are content with the perceived objectivity but admit that those issues that are not readily captured in metrics tend to remain unnoticeable. The mixed-method analysis of AI-driven HR analytics provided by Kayusi (2025) also indicates that screening algorithms and sentiment tools favor quantifiable behavioral footprint, which constricts the agenda of that which is brought upwards as strategically valuable.

Qualitative data rendering by Zheng et al. (2025) gives the example of entrepreneurial firms that use AI-based HRM systems and have optimized their behaviors and communications in accordance with the indicators provided by the algorithm: small specifics in interpretation, disagreement, or opinion of a minority is no longer as communicatively legitimate as the indicators are not machine-verified. Manual voice traveling in classical leadership communication relied on the relational discretion and negotiated interpretation, whereas in an AI-mediated environment, the voices of more and more people progressively pre-structure whose experience and what issues are communicatively actionable by the leaders

Trust, fairness, and the legitimacy of AI-shaped decisions

The third theme is the impact of AI-mediated communication on the two issues of trust towards leaders and perceived procedural justice. Lapinska et al. (2021) demonstrate that both the overall trust in technology and intra-organizational trust are strong predictors of whether employees of Polish energy and chemical companies will trust AI in terms of acceptance of AI-related decisions and messages, which is why the credibility of the leaders and internal climate of the organizations are the decisive factors in the context of trust in AI. Majrashi (2025) discovers that workers consider AI-based predictive functions in HR judgments to be both equitable and agreeable where they are precise, evident, and connected to the job, but see it as encroaching and invalid when founded on delicate or obscured information.

The interpretations of these implications are captured by Van Quaquebeke and Gerpott (2024) as the reason behind communicative risk yet to be disclosed to anyone: the undisclosed AI copiloting of leadership messages in general way leadership (particularly layoffs, restructurings, and performance feedback), which can result in the noted erosion of perceived sincerity and the subsequent trigger of questions concerning who is morally responsible. The evidence provided by Florea and Croitoru (2025) places a more nuanced emphasis on the realization that where AI-strengthened communication can literally level clarity and response lines, employees turn into less concerned about AI intervention, and that, transparency, explainability, and response opportunities may address the automation anxiety. In general, algorithmic conversation does not necessarily ruin trust, but re-conditions it: as employees become more open to the management of AI, it is announced, and challengeable, the more they judge the leadership.

Algorithmic management, affective climate, and hidden costs

The fourth theme brings out the emotional and health consequence of AI-mediated oversight that display costs which are majorly invisible in classical communication theories. In logistics companies under algorithmic management, Nilsson et al. (2025) demonstrate that the intensity of work and the perceived lack of autonomy grow along with a thick metric-based surveillance and opaque performance regulations; ambiguous channels of recourse to which it is possible to complain increase frustration with both systems and managers who remain behind the algorithm. Among the types of employee-AI collaboration, Meng et al. (2025) determine that some are linked to loneliness and emotional exhaustion that could lead to the development of undesirable behavior in the case where AI tools are perceived as judgmental observers instead of helpful additions.

Similar findings are presented by Zheng et al. (2025): employees who experience AI-driven HRM systems perceive such unilateral and data-directed nudges and ratings as a continuation of top-down control; a reduction in the opportunity to establish a dialogic clarification reduces relational trust towards supervisors and makes leadership communication seemed unapologetic. These research investigations reveal that the dangers of being perceived as alien, information-driven, and jobless are present when the main touchpoints regarding performance, timing, and anticipations are algorithmic. Algorithms-based dialogue, therefore, not only redefines the informational streams, but also changes the emotional atmosphere where leadership is rated.

Conditions for constructive algorithm-driven dialogue

Lastly, the synthesis comes up with convergent conditions in which AI-based communication may reinforce, instead of undermine, leadership.

First, there is a need to align the AI design with the relational and ethical norms. The paper by Lewandowski et al. (2023) illustrates that conversational agents integrated into organizations are more sustainable when designed based on usability, empathy indicators, non-human status, and human reliable escalation, elements that symbolically confirm that decisions are under the ownership of human leadership. The case study of internal communication chatbots presented by Hoang (2025) also reveals that the internal communication tool usage requires clear limits of the bot authority, the guarantee of data usage, and the apparent support of the leaders.

Second, a number of researches reveal that AI analytics are viewed favorably when leaders put them into the context. Sharma (2025) and Kayusi (2025) state that HR analytics and AI-oriented solutions are more acceptable in a case when managers justify the underlying rationales, open to debate, and leave the ultimate decision-making to themselves rather than showing outputs as unquestionable facts. In those scenarios, AI is represented as something that can supplement and not substitute human judgment.

Third, Van Quaakebeke and Gerpott (2024, 2025) and the trust relationships featured by Lapinska et al. (2021), Majrashi (2025), Nilsson et al. (2025), and Meng et al. (2025) all suggest a new model of algorithmic leadership should be a stewardship one. Constructive algorithmic dialogue within the corporation is based on three overlapping conditions:

- **Clear authorship and accountability** - employees are aware that AI is at work, in general terms of how it manipulates messages or decisions, and who ultimately bears responsibility.
- **Guarded means through which human voice** - systems (forums, escalation routes, options of qualitative feedback) are created so that those issues that are not very easy to quantify could still be heard by human leaders and not filtered out by the filters.
- **Moral, responsible leadership** - executives willingly take AI decisions, question decision effects on equity and welfare, and willingly engage in dialogue instead of delegating the ethical issue to systems.

Under these conditions, the AI-mediated communication could increase the level of clarity, responsiveness, and inclusion according to the leadership intent. In their lack, algorithm-generated conversation has a propensity to reinvent leadership as cloudy, detached, and less valid—a radical departure of the postulations of traditional models of communication.

Analysis

The results of the recent secondary qualitative research not only support but also make the stories that appeared due to the previous literature review more complex, suggesting that leadership in the era of AI can be viewed as a type of algorithmically mediated stewardship as opposed to an increased version of the classical models of communication. Classical theories place leaders as deliberate human senders in building meaning by means of relational, symbolically saturated and accountable communicative acts. The assumption is already being destabilized by the literature around AI in organizations, with many researchers demonstrating how the authority to make decisions, informational and HR processes are more widely diffusing through the socio-technical systems (Shrestha et al., 2019; Shrestha et al., 2021; Berente et al., 2021; Bevilacqua et al., 2025). The current results contribute to this image by showing that AI does not only augment the decision making process, but also directly transforms the way leadership is articulated, channeled, and perceived in daily organizational discourse.

To begin with, the identified efficiency improvements in AI-augmented leadership communication can be aligned with the evidence obtained in the review that AI could potentially contribute to improvements in the quality of information, speed, and the depth of the analytical layer of managerial activity (Bevilacqua et al., 2025; Budhwar et al., 2022; Lee et al., 2023). The tools that assist the leaders in crafting sharper communications, tailoring the messages, and tracking up feedback fit the description of the promise of AI-enabled complementarity presented in previous studies (Shrestha et al., 2021). Nevertheless, the results provide a twist by indicating that the same augmentation is indicative on visible authorship and governance. In those situations when AI assistance is not announced or overused, the leaders may put the authentic nature and the level of relations on the backburner as promoted by parent classical theories of leadership communications. Put differently, what the literature presented as a rather beneficial "augmentation" is translated into, in reality, is a conditional improvement, the validity of which lies in the ability of followers to trace a responsible human voice through an array of messages processed by algorithms.

Second, the gatekeeping utility of AI that has been discovered in the findings operationalizes the issue of control and visibility proposed in the algorithmic management literature (Kellogg et al., 2020; Meijerink and Bondarouk, 2023; Keegan et al., 2025). The literature review implied that algorithms arrange work, evaluation, and oversight, whereas the current synthesis demonstrates that they arrange also who is listened to. HR analytics based on AI, sentiment dashboards and triage systems selectively highlight metrics that can be recorded and minimize voice that is contextually rich, but less readable by machines. This builds on previous claims by showing that algorithmic management is not merely a machine of labor regulation, but also a determiner of organizational speech. Cross-cultural approaches wherein leaders are able to reach and read a wide range of follower opinion via social means get challenged by an environment where employee experiences are pre-digested through unclear processes prior to ever coming under the leadership's attention.

Third, the results validate and expand the existing knowledge on trust, ethics, and bias within AI-mediated settings. The literature review has identified that transparency, perceived fairness, and alignment between AI systems and organizational values determine trust in AI systems (Gkinko and Elbanna, 2023; Lapinska et al., 2021), and large language models harbor implicit biases that need effective auditing (Bender et al., 2021; Mokander et al., 2023). The empirical trends on this front are that employees rate leaders more remarkably based on how they handle AI: hidden AI authorship, adherence to inflexible algorithmic scores, or unreachable human escalation are interpreted as moral dodge, whereas contextualization, transparency about constraints, and accessible human escalation are welcomed. In that way, one cannot think of the trust in leadership without invoking the images of algorithmic governance, which validates and, at the same time, reinforces the assertion above that AI is a normative and not a neutral infrastructure.

Fourth, there are the emotional and health-related implications of algorithmic monitoring and interaction mediated by AI that complicate optimistic accounts in strategic and implementation-oriented research (Lee et al., 2023; Liu et al., 2024). Whereas previously researches highlighted the topic of capability building and competitive advantage, the results of logistics, entrepreneurial and AI-intensive environments depict a more pressing percentage of stress, loneliness and the view of the leaders as hiding under the systems when the relations are driven by stock metrics and multiple nudging. This opposition highlights a hypothetical antagonism: strategic and techno-optimist approaches run a danger of underestimating the extent to which algorithm-driven discourse can de-renationalize, de-empathize, and de-sense make functions of the relational, empathetic and sensemaking, traditionally central to transformational and relational leadership schools, unless that tendency is intentionally consciously reversed.

Conclusion and Recommendations

The discussion reveals that leadership communication in the era of AI has definitively transcended the principles of classical models that apply to visible senders and stable channels. AI systems are currently co-writing, curating, filtering, and timing messages and serve as infrastructural arbiters of attention, legitimacy, and organizational voice. Instead of being automated in the process of routine communications, automated dialogue re-engineers authority practice and how voice is brought out, how workers issues are raised, and how trust is established or undermined. The second qualitative synthesis proves that AI-mediated communication may make communication smoother, more responsive, and reachable in the case where transparency is present, but may also distance, obscure, and make communication unfair when leaders are not visible and responsible, using algorithmic outputs to achieve particular outcomes. Comprehensively, the successful leadership here can be exemplified as algorithmic stewardship: not just words are owned, but the structures (systems) in which words and reactions of workers are generated and prioritized and listened to.

Recommendations

Initially, companies ought to come up with clear artificial intelligence communication rules. The employees must be aware of when AI is used to draw internal messages or route them or assess them, and who will be ultimately responsible about a decision. To maintain trust, clear disclosure, simple explainability and documented escalation paths are needed (Gkinko and Elbanna, 2023; Mokander et al., 2023).

Second, leaders should safeguard and maintain dialogic spaces led by humans. AI tools should be supplemented by regular forums, open question and answer, and qualitative comments platforms to make sure that issues that are not readily measured by metrics or models do not fall through the cracks and reach the decision-makers. This is a direct opposition to the risk of gatekeeping and silencing contained in the findings (Kellogg et al., 2020).

Third, AI literacy and ethical competence should become intrinsic leadership development competencies. Instead of delegating the process of moral judgment to AI systems, senior managers should know how to question and recalibrate them, be aware of bias and data constraint, as well as unintended consequences (Bevilacqua et al., 2025; Budhwar et al., 2022). Only in that case, algorithm-based conversation can assist, but not participate in, plausible and inclusive leadership

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DOI: <https://doi.org>

The Kashmir Journal of Academic Research and Development

Journal homepage: <https://rjsaonline.org/index.php/KJARD>



Problem-Solving Skills Development Through STEM Education: A Systematic Review

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ARTICLE INFO

Received:

August 10, 2025

Revised:

September 06, 2025

Accepted:

September 29, 2025

Available Online:

October 20, 2025

Keywords:

STEM learning, problem-solving, inquiry learning, project learning, systematic review, 21 st century skills.

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ABSTRACT

Problem solving skills have been cited as one of the core competencies that enable one to succeed in the twenty-first century. Learning systems are becoming more convinced in the use of STEM (Science, Technology, Engineering and Mathematics) education as a strategic way of improving cognitive, analytical and problem-solving skills in learners. This is a systematic review that summarizes empirical and theoretical studies that have been published between 2000 and 2025 to investigate the role of STEM education in developing problem-solving skills at various levels of education. Based on a systematic review approach, the studies were located, filtered, and assessed to investigate instructions, learning outcomes, and situational elements that affect problem-solving development in the context of STEM models. The results show that integrated STEM practices, especially the project-based learning, inquiry-based teaching, and engineering design, have a big impact on the capability of students to recognize the problem, use interdisciplinary skills, and develop solutions to the issues. Nonetheless, the issues of teacher preparedness, curriculum integration, and assessment practices also tend to persist. The review indicates that there is a dilemma of long-term professional development, changes in the curriculum, and effective assessment plans to optimize the benefits of STEM education on problem-solving abilities.

Introduction

The modern societies have been changed by the fast rate of development of science, technology and innovation which have altered the quality of work, communication, and life. Due to this, the educational systems are becoming more and more burdened to equip the learners with more than just subject-specific knowledge, but also higher-order thinking skills that can guide them through challenging and unforeseeable situations. Problem-solving skills are one of these competencies that are regarded as central to academic achievement, employability, and citizenship. Problem-solving requires one to be able to identify and analyze problems, develop alternative solutions, evaluate the results, and use knowledge in new circumstances (Jonassen, 2000). The need to acquire such skills and the importance of traditional instruction based on rote is being increasingly questioned in the globalized and digitized world.

To address these issues, STEM education has become an effective pedagogical model that will be able to enhance the skills of problem-solving and critical thinking. Also, STEM education highlights the combined approach to science, technology, engineering, and mathematics regarding all real-life application, inquiry-based learning, and interdisciplinary learning (Bybee, 2013). In contrast to the traditional teaching where the subjects are segregated, STEM education promotes learning in the context of real-life problems, where learners have to apply the knowledge of various fields. This method has a lot of similarity with the constructivist learning theories, which focus on active learning, collaborative learning, and the building of knowledge on the basis of meaningful experiences (Vygotsky, 1978).

It has been postulated that instructional strategies that are structured around STEM foster conceptual learning and transferable problem-solving abilities. As an example, project based learning in the STEM environment enables the students to handle longer assignments that simulate real life problems and this also improves planning, analysis and evaluation of solutions (Thomas, 2000). On the same note, the mode of inquiry based learning promotes queries, developing investigations, and interpreting information and such enhances critical thinking and scientific skills in solving issues (Minner et al., 2010). Design engineering activities are also another contributor to problem-solving development since they involve the learners in a series of design, test, and refining solutions (National Research Council, 2012).

Although STEM education is becoming increasingly popular, the efficacy of STEM methods in training problem-solving skills depends on the situation. Teacher knowledge and skills, curriculum development, resource access, evaluation systems, and practices also play a major role in the learning outcomes (Roehrig et al., 2012). Besides, the very idea of problem-solving is complex and can be characterized in various ways in different studies, which is why it is not always easy to make entirely similar conclusions. Some of the studies concentrate on the cognitive aspects of problem-solving like reasoning and analysis, whereas others dwell on the metacognitive and collaborative viewpoints of problem-solving (Schoenfeld, 1992). These differences imply the necessity of systematic synthesizing of research that has been done to detect general tendencies, advantages, and gaps.

Systematic reviews are important in synthesising research evidence and influencing the educational policy and practice. Systematic reviews help to offer a thorough picture of what, under which conditions, and why works by summarizing the results of various researchers (Moher et al., 2009). Systematic reviews are especially useful in the area of STEM education because of the variety of different instructional models, learner students, and research methodologies. An in-depth analysis of problem-solving competencies in STEM education can assist teachers and policy makers to create more efficient learning settings that are responsive to the needs of the 21st century.

This systematic review aims to critically analyze the studies published between 2000 and 2025 on the importance of STEM education in the development of problem-solving skills of learners of various levels of education. In particular, the review is intended to establish efficient STEM teaching methods, examine the empirical data on problem-solving results and pinpoint difficulties and enabling variables impacting STEM implementation. This review is potentially important because it might assist curriculum designers, teacher educators, and policymakers aiming to empower the problem-solving skills with the help of STEM education. The research synthesis offered in this study adds to a more profound insight into the utilization of STEM education as the means of preparing students to meet the challenging real-life problem-solving requirements.

Literature Review

Problem-solving skills development based on STEM education have become an exponential part of the literature over the last 20 years due to the worldwide changes in education to equip students with the skills needed to operate in complex technology-driven societies. Scholars in various fields have studied the effect of integrated STEM on cognitive, metacognitive, and collaborative problem-solving skills of learners. The section provides the synthesis of the most important theoretical viewpoints, empirical results, and instruction models that connect STEM education to the development of problem-solving skills.

Problem-Solving as a theoretical concept in STEM Education Problem-solving is a process founded in cognitive psychology, where it is considered as an end goal and therefore involving the comprehension of a problem, a plan, actions, and solution evaluation (Bransford and Stein, 1993). Jonassen (2000) divides problems into well-structured and ill-structured, as the real-world problems, which are also the focus of STEM education, are usually ill-structured, which means they demand that the learners make assumptions, synthesize knowledge, and explain the choices. The methods of learning proposed by constructivist and socio-constructivist theories are quite relevant to STEM education, as it is based on active experience and social interaction (Vygotsky, 1978).

In constructivist approach, the learning environment in STEM promotes knowledge acquisition by learners by experimenting, inquiring and reflecting. These settings facilitate the thinking of higher order by placing the learning experience in realistic situations that demand identification of problems and generation of solutions (Hmelo-Silver, 2004). The support of STEM pedagogy by cognitive apprenticeship theory is also provided by paying more attention to the aspects that help to stress the modeling of the process of expert problem-solving and the scaffolding of thinking (Collins, Brown, and Newman, 1989). Together, these theoretical frameworks help to emphasize the potential of STEM education to help develop the effective problem-solving skills.

Problem-Solving Skills and Intended STEM Education This type of education is aimed at the deliberate connection of science, technology, engineering, and mathematics to solve real-life problems. There is also a factor of flexibly utilizing disciplinary knowledge in a flexible professional way according to Bybee (2013), which is the feature of effective problem-solving. It has been documented in science that integrated STEM curricula positively contribute to the skills and capabilities of learners in problem analysis, multiple representations, and cross-contextual transfer of knowledge (Kelley and Knowles, 2016).

According to Capraro, Capraro, and Morgan (2013), students that were involved in integrated STEM projects performed by far higher in terms of problem-solving than did students in conventional classrooms. These advantages were credited to the possibility of iterative design, interdisciplinary argumentation and joint solution creation. On the same note, English (2016) notes that integrated STEM activities endorse adaptive expertise, which facilitates learners to tackle new challenges creatively and strategically.

Project-Based Learning and Problem-Solving Problem-based learning (PBL) is one of the most widely studied teaching strategies in STEM education. PBL involves the students in the long term investigations around complex and real life problems, and involves planning, research, collaboration and reflection (Thomas, 2000). Bell (2010) brings into focus that the PBL environment experiences inherently develop problem-solving as it places students in the role of active contributors to solving the problem, as opposed to passive receivers of information.

There are many studies proving the positive effect of PBL on the problem-solving skills. In Hmelo-Silver (2004), the students involved in problem-based STEM activities reported that they developed greater reasoning and self-regulation abilities. Walker and Leary (2009) in their meta-analysis were able to conclude that problem-based and project-based learning methods were very effective in increasing the problem-solving performance of learners as opposed to traditional lecture-based learning. These findings show that PBL is a useful instrument of integrating problem solving in STEM programs.

Scientific Problem-Solving Inquiry-based learning (IBL) is an approach to learning that revolves around students employing exploration, inquiry, and evidence to underpin their way of thinking. Questions in STEM In STEM, the questions are activities where one asks the students to form hypotheses, make investigations, analyze the information and make decisions which are the most important processes in solving scientific problems (National Science Teachers Association, 2004). According to Minner, Levy and Century (2010), inquiry based instruction positively influences the conceptual knowledge and problem solving skills of students especially in science and mathematics.

Inquiry-based STEM classes have been shown through empirical research to facilitate more in-depth thinking and pursuance of problem-solving activities. As an illustration, Furtak et al. (2012) discovered that guided inquiry strategies resulted in a greater success and enhancement of reasoning abilities compared to either unguided inquiry or conventional instruction. These results highlight the relevance of scaffolding to inquiry based STEM classrooms to facilitate the development of problem-solving.

Design and Problem-Solving Processes Engineering design is a core element of STEM education and an effective background to train problem-solving. The engineering design process implies the identification of problems, the derivation of several solutions, prototype testing and the optimization of the designs in response to feedback (National Research Council, 2012). This cyclic process resembles the approach to problems-solving of experts and teaches learners to think of failure as a learning experience.

Studies by Dym et al. (2005) show that engineering design work improves the capability of students in terms of being systematic and creative in finding solutions to complex problems. Engineering-related STEM programs have been found to enhance the application of mathematical and scientific concepts in the problem-solving situation by the students at the secondary level (Katehi, Pearson, and Feder, 2009). These researches emphasize engineering design as an important transition section between theoretical knowledge and practical problem solving.

Social Aspects of Problem-Solving Problem-solving in STEM education is usually a group activity. In social interaction, the learners are in a position to express reasoning, provoke assumptions and co-construct knowledge (Webb, 2009). Johnson and Johnson (2009) stress that the cooperative learning organization improves the level of problem-solving through the facilitation of positive interdependence and individual responsibility.

The effectiveness of collaboration in solving STEM problems has empirical evidence. Research also shows that learners in collaborative STEM teams have a greater degree of reasoning and quality of solutions compared to those working alone (Gillies, 2014). Team problem-solving also helps in fostering the development of communication, and team work skills required in real world problem context.

Problems Selected in the Literature: Although it has been found that STEM education plays a strong role in the development of problem solving process, there are a number of challenges that have been identified in the literature. The readiness of teachers is also a critical issue since most educators state they have a low level of confidence in teaching open-ended problems of solution (Roehrig et al., 2012). Lack of time, curriculum restrictions, and the mismatch between the system of STEM pedagogy and the standardized assessment also undermine the successful implementation (Kelley and Knowles, 2016).

Besides, the evaluation of problem-solving capabilities in STEM is not yet developed. The complex reasoning processes can not be reflected by traditional testing techniques, and the performance-based and formative assessment strategies are called in (Black and Wiliam, 2009). These issues should be addressed to achieve the maximum potential of STEM education in the creation of problem-solving skills.

Methodology

The approach in this study was a systematic review that had to investigate the role of STEM education in problem-solving skills development. The choice of a systematic review is justified by the possibility to provide a transparent, reproducible, and complete synthesis of currently existing research evidence and the reduction of bias (Moher et al., 2009). The methodology used was systematic reviews of education and social sciences of international standards to guarantee rigour, validity, and reliability.

Research Design

The preferred reporting items of systematic review and meta-analyses (PRISMA) framework was used as a guide to conduct the review. The method offers a systematic way of recognizing, filtering, evaluating and synthesizing pertinent studies. Peer-reviewed empirical and theoretical research was reviewed which was published between 2000 and 2025 and this was in accordance with the current trends in the field of STEM education and research on problem solving.

The research questions that will be used to conduct this review are:

- What is the role of STEM education in the development of problem-solving skills?
- What are the best STEM teaching methods of developing problem-solving skills?
- What are the difficulties and enabling factors in solving problems in STEM education?

Data Sources

Literature search was also done in various academic databases in order to have wide coverage of appropriate literature. The databases included:

- ERIC (Education Resources Information center)
- Scopus
- Web of Science
- JSTOR
- ProQuest
- Google Scholar

The choice of these databases was based on the fact that they have a significant indexing of education, psychology, and research on STEM. Also, key studies and review articles reference lists were hand screened to produce more relevant publications.

Search Strategy

The systematic search strategy was created based on the combination of keywords and Boolean operators. Search terms included:

- STEM education
- problem-solving skills
- critical thinking
- project-based learning
- inquiry-based learning
- engineering design
- integrated STEM
- 21st-century skills

What was used to narrow search results was the combination of these terms with operators like AND and OR. For example:

- Stem education and problem solving skills OR project-based learning and problem solving.
- Only publications written in English language were used to limit the search in order to maintain consistency in analysis and interpretation.

Inclusion and Exclusion Criterion

Inclusion and exclusion criteria were set clearly before the screening was conducted to ensure that there was objectivity.

Inclusion Criteria:

- Articles that were published after 2000 to 2025.
- Scholarly books, conference proceedings and peer-reviewed journal articles.
- Research that specifically explored STEM learning and problem solving ability.
- Study which is carried out at any level of education (primary, secondary, or tertiary education).
- Empirical studies, mixed-method studies or well-grounded theoretical studies.

Exclusion Criteria:

- Research that did not specifically aim to investigate STEM education.
- Articles that covered general academic achievement and not problem-solving.
- Opinion pieces, editorial pieces or non-peer reviewed sources.
- Those studies, which are not methodologically sound or have inadequate data.

Study Selection Process

The selection of the study was done in three phases. To start with, all identified records were screened on relevancy using titles and abstracts. Second, the full-text articles were screened so that they met the criteria of inclusions. Third, redundant records and investigations which did not satisfy the quality criterion were eliminated. This multi-stage filtering process was useful in eliminating all irrelevant and low quality studies in the final review.

More than 400 original records were found out. Following the screening and eligibility, an estimated of 90 studies were left to be analyzed in depth. The last choice was based on studies published in different geographical areas and learning environments, which increased the applicability of the results.

Quality Assessment

To make the review credible, a methodology assessment of each study included was carried out. A set of criteria was used which consisted of the clarity of the research design, the suitability of the data collection methods, the validity of the used instruments, and the transparency of the analysis. Quantitative research was evaluated in relation to its sample size, reliability as well as statistical rigor whereas the qualitative research was evaluated in terms of credibility, transferability as well as trustworthiness (Creswell and Plano Clark, 2011).

Literature with weak methodology or inadequate reporting was not synthesized.

Data Extraction

Key information of each study was also systematically recorded through the use of a standardized data extraction form. Extracted data included:

- Name of authors and year of publication.
- STEM pedagogical strategy.
- Sample size and research design.
- Problem-solving outcomes
- Major conclusions and weaknesses.

This systematic methodology has allowed making comparisons and syntheses across studies.

Data Synthesis

Since different methodologies and outcome measures are present, a thematic synthesis methodology was used. Quantitative results were summarized in a descriptive manner, whereas, the qualitative results were analyzed in order to establish common themes that concerned the development of problem solving. The studies were classified by instruction strategies (e.g. project-based learning, inquiry-based learning, engineering design) and level of education.

The synthesis focused on the patterns, consistency, and discrepancy of results, making it possible to give a subtle meaning to the impact of STEM education on problem-solving abilities.

Ethical Considerations

Since this research was a review of already existing research, there was no direct participation of human subjects that were involved. The ethics were observed by citing all the sources properly and being transparent during the review process.

Results and Discussion

This part reports the synthesized results of the systematic review and how STEM education can be used to achieve skills in problem-solving. The findings are presented in the form of the major themes that were identified in the reviewed works, such as teaching and learning methods, learning outcomes, group work, and implementation issues. Quantitative and qualitative data are combined to get a holistic view of the problem-solving development in STEM education.

Overview of Findings

The studies reviewed in this paper all show a positive and significant effect of STEM education on the abilities of students to solve problems at different levels of studying. Students who were exposed to combined STEM strategies exhibited greater capabilities in problem detection, critical thinking, problem design, and critical feedback (Bybee, 2013; English, 2016). Such results were most evident in learning situations that focused on active learning, interdisciplinary learning, and the real-world problem situation.

Problem-Solving under the influence of STEM Instructional Strategies

Project-Based Learning (PBL) became one of the most useful methods of instruction based on the development of problem-solving skills. Research has stated that PBL students had an improved capability to break down intricate problems, organize systematically, and analyze alternative solutions (Bell, 2010; Thomas, 2000). The long-term and realistic nature of projects enabled learners to undergo the entire problem-solving process such as iteration and reflection.

The effect of inquiry-based learning also showed good results in development of problem-solving. Students who were involved in guided inquiry learning demonstrated better skills to develop questions, interpret information, and make evidence-based conclusions (Minner et al., 2010; Furtak et al., 2012). The methods of inquiry proved effective especially in situations involving science and mathematics where data interpretation and testing hypothesis may be part of the problem solving process.

Design-based learning engineering was also an aspect that led to adaptive problem solving among learners. Tasks were done by engineering, which entailed setting constraints, finding multiple solutions, refining designs, and making them resilient and creative (National Research Council, 2012). Some of the studies reported that engineering design work increased the transfer of knowledge to new problem contexts among students (Dym et al., 2005).

Cognitive and Metacognitive Conclusions

In the literature, STEM education was linked to both cognitive and metacognitive higher-order problem-solving. Students showed improved analytical, conceptual and interdisciplinary knowledge application, cognitively (Capraro et al., 2013). Metacognitively, the learners were more aware of their problem-solving strategies, i.e. planning, monitoring and evaluating their strategies (Hmelo-Silver, 2004).

The metacognitive skills were especially developed within the learning contexts that involved reflections and feedback. Research findings indicated that the ability to internalize the effective strategies of problem-solving, and implement them to a different situation was aided by structured reflection activities among students (Black and Wiliam, 2009).

The Collaboration part in Problem-Solving

Team learning was found to be a key aspect in improving the performance of problem solving in STEM learning. The use of group-based STEM activities helped students to develop arguments, negotiate meaning, and create collective understanding (Johnson & Johnson, 2009). It has been shown that collaborative problem-solving besides enhancing the quality of solutions, helps in building communication and teamwork capabilities needed in the real world problems context (Webb, 2009).

Nevertheless, the quality of collaboration was determined by task design and teacher facilitation. Research articles put stress on the need to have clear roles, formal interaction, and teacher direction in order to have a productive collaboration (Gillies, 2014).

Table 1: Summary of STEM Approaches and Problem-Solving Outcomes

STEM Approach	Educational Level	Project-Based Learning
Inquiry-Based Learning	Primary–Secondary	Strategic planning, solution evaluation
Collaborative STEM Tasks	Primary–Higher Education	Question formulation, data analysis
Engineering Design	Secondary–Higher Education	Communication, collective reasoning

Challenges in Implementing STEM for Problem-Solving

Although the results are positive, the review revealed a number of issues that reduce the effectiveness of STEM education in the development of problem-solving skills. The readiness of teachers was one of the most common obstacles. Numerous teachers have also stated that they lacked enough training in helping with open-ended, problem-based STEM activities (Roehrig et al., 2012). Teachers might also resort to conventional methods of teaching instructions that do not allow them to offer problem solving opportunities without proper support.

There were also challenges of curriculum and assessment limits. Standardized testing models are frequently focused on content knowledge and not on higher-order skills, which prevents teachers using problem-based STEM learning methods (Kelley and Knowles, 2016). Besides, the lack of instructional time and resources prevents the long-term work on complex tasks of problem-solving.

Table 2: Challenges and Facilitating Factors in STEM Problem-Solving

Category	Challenges	Facilitating Factors
Teacher Factors	Limited training, low confidence	Professional development
Curriculum	Rigid standards, time constraints	Integrated STEM curricula
Assessment	Focus on rote learning	Performance-based assessment
Resources	Limited technology and materials	Institutional support

The results of this review support the idea that STEM education creates an effective environment in which the process of mastering problem-solving skills can be developed. The combination of disciplines and practical applications, as well as orientation to active learning can be discussed as the elements that align well with theoretical frameworks on efficient problem-solving (Jonassen, 2000). Nevertheless, the difference in implementation and results highlights the contextual nature of such factors as teacher expertise and institutional support.

In general, the findings indicate that STEM education can be the most effective one in case it is introduced in the form of a holistic, well-supported model where problem-solving is discussed as the main learning outcome.

Discussion

The results of the present systematic review are quite convincing that STEM education is a key contributor to the development of problem-solving skills at any level of education. The analyzed articles all indicate that, when structured to acknowledge authentic, interdisciplinary, and learner-centered experiences, students have a higher chance of acquiring the cognitive, metacognitive, and collaborative skills that can be successfully applied to solve problems. These results are consistent with the current aims of education, which are focusing more on higher-order thinking and the flexibility to react to complicated changes in the real-life environment (Bybee, 2013).

The effectiveness of integrated STEM strategies in facilitating transferable problem-solving skills is one of the most important lessons achieved in this review. As opposed to conventional subject-specific education, integrated STEM education demands students to utilize the information that belongs to several fields and, therefore, allows them to solve problems in their entirety. Such an interdisciplinary interaction helps develop a flexible and adaptive expertise, a quality that is needed when solving ill-defined problems that arise in most cases beyond the academic environment (English, 2016). The positive results that are always observed when it comes to integrated STEM curriculums are a testament to the significance of curriculum coherence and meaningful integration.

Other instructional strategies discussed in the review including project-based learning, inquiry-based learning, and engineering design play a central role in improving the problem-solving skills. These approaches have some common features such as the involvement of students, practical importance, and repetitive learning. These methods enable the students to undergo the entire problem-solving process, including identification and analysis of problems, because each cycle takes almost a certain period of time (Thomas, 2000). This practical aspect seems to be one of the primary reasons why successful STEM learning environments are more likely to be found in comparison with conventional models of teaching.

The other significant discovery is associated with metacognitive aspect of problem solving. Research studies have always found that the STEM learning atmosphere that involves reflection, feedback, and self-assessment encourages more awareness on how strategies should be utilized in solving problems. Metacognitive regulation allows the learners to plan, monitor as well as modify their methods and hence the problem solving becomes more efficient and effective (Hmelo-Silver, 2004). This implies that STEM education must clearly incorporate reflection opportunities so that it can make the most out of its influence on developing problem solutions.

Teamwork proved to be a major enabler of solving problems in STEM situations. Joint efforts in STEM activities can make learners explain their arguments, address opposing views and compromise on mutual solutions. Such social processes do not only lead to better results in cognitive processes, they also allow the development of communication and teamwork skills which are more appreciated in the professional environment (Johnson & Johnson, 2009). Nevertheless, the efficacy of this type of problem-solving is paradoxical and is largely dependent on the design of tasks and facilitation by teachers. Ineffective group work can result in inequalities of participation and superficial engagement of the group and its impacts are limited.

Although the findings are positive, the review presents existing challenges, which should be addressed. Instructional readiness is a major concern because most teachers are not well trained on how to develop and implement a problem-based

learning on STEM. Unless teachers have the necessary professional development, they might fail to cope with open-ended learning settings and evaluating complex outcomes of solving problems (Roehrig et al., 2012). Moreover, the assessment practices do not correspond to the objectives of the STEM education. Performance-based and formative assessment plans are necessary because standardized tests that emphasize the memorization of facts can discourage the adoption of instruction based on problems (Black and Wiliam, 2009).

On balance, this discussion implies that though STEM education has great potential to build problem solving skills, the success of this intervention is dependent on systemic facilitation, such as educating teachers, reforming curriculum as well as innovative assessment. These issues are critical to the process of transforming the potential of STEM education into extended educational change.

Conclusion

The presented systematic review gives thorough evidences of the importance of STEM education in helping to form the problem-solving skills in the various education settings. As a multidimensional cognitive and metacognitive action, problem solving is also becoming a competency that learners have to possess in order to cope with the issues of the 21 st century. This review confirms that STEM education, when done properly, can greatly raise the capacity of students to solve problems, offer interdisciplinary solutions, come up with innovative solutions and critically reflect on the results.

The synthesized evidence shows that the implementation of integrated STEM seems to be especially useful in the development of problem-solving skills (studies published between 2000 and 2025). Integrated STEM learning involves the use of knowledge in science, technology, engineering, and mathematics in a unified way, unlike the traditional subject-specific learning. This integration aids the process of cognitive flexibility so that learners can be able to move their problem-solving strategies to new and ill-structured problems. Students who have participated in STEM integrated experiences show increased reasoning skills and analytical thinking and the capacity to consider several possible solutions, which speaks to the transformative nature of the instructional model (Bybee, 2013; English, 2016).

The concept of project-based learning (PBL) appeared to be one of the most effective in the field of STEM education. PBL also offers learners long periods of time to work on real-world problems, which encourages them to be strategic, test over time and reflect (Thomas, 2000; Bell, 2010). It has been demonstrated empirically that students who participate in the activities of PBL-based STEM programs demonstrate more problem-solving performance relative to the performance of their traditional classroom counterparts, especially in interdisciplinary-based tasks involving the need to be innovative (Capraro et al., 2013). On the same note, inquiry-based learning has been evidenced in enhancing the capacity of students to ask questions, analyze facts as well as make evidence-based conclusions, which promotes a better comprehension of scientific concepts and reasoning (Minner et al., 2010; Furtak et al., 2012).

Design-based learning is a unique approach to the development of problem-solving skills as it exposes learners to the process of solving problems, which is iterative and focused on solutions. The engineering tasks involve the students to recognize constraints, create various solutions and refine the prototypes based on the evaluation and feedback. This hands-on methodology is an analogy of real-world problem solving in professional STEM education and provides flexibility and imagination in learners (National Research Council, 2012; Dym et al., 2005). In these instruction strategies, the presence of reflection and feedback tools was demonstrated to profoundly empower metacognitive elements of problem solving and allow students to keep track of, assess and modulate their strategies successfully (Hmelo-Silver, 2004).

Teamwork has been identified as a decisive aspect of efficient STEM-based problem-solving. Group work also promotes reasoning and negotiating towards mutual understanding and collaboratively constructing solutions, which results in both mental and social gains (Johnson & Johnson, 2009; Webb, 2009). Team problem-solving is not only effective in enhancing the level of solutions it also enhances communication, cooperation, and interpersonal abilities, which are needed to be a successful professional in STEM career. Nevertheless, the effectiveness of collaborative learning relies upon the task organization, the definition of the roles, and teacher facilitation, which means that it is necessary to design instructions carefully.

Regardless of the evident positive aspects of the collaboration of STEM education to problem-solving, there are still a number of challenges. The biggest obstacle to teacher preparedness is the lack of confidence and training as reported by many teachers to facilitate open-ended and problem-solving-oriented STEM instruction (Roehrig et al., 2012). Without proper professional growth, educators might go back to using the old-fashioned didactic methods, which will restrict the performance of STEM interventions. The rigidity of the curriculum and lack of time is also problematic, and so are standardized tests that focus on memorizing the material rather than encouraging critical thinking (Kelley and Knowles,

2016; Black and Wiliam, 2009). There are also resource constraints such as lack of access to technology, laboratory resources and instruction materials that further impede the realization of the problem-solving-based STEM education.

The results of this review have significant implications on the side of educator, policy and curriculum designers. Second, one should put emphasis on teacher professional growth, focusing on content-related issues, and pedagogical mechanisms of solving problems in STEM. Teachers should be equipped in training programs to facilitate inquiry-based, project-based, and engineering design tasks, and ways of promoting metacognition and reflection.

Second, the curriculum models would have to be redesigned in a way that would bring together the STEM disciplines in a unified manner, with a clear focus placed on problem-solving outcomes. Real, interdisciplinary assignments are to be integrated on grade levels so as to make the processes of problem-solving persistent. Third, the practices of assessment should develop to capture the process and product aspects of problem-solving. Performance-based evaluation, portfolios, and reflective journals are also suggested as the means that give an overall picture of the abilities of learners.

Lastly, there is the institutional and policy support to facilitate access to required resources, time allocation and infrastructural support. Problem-solving skills in STEM situations can also be intensified through collaboration networks, working with industry, and access to learning environment that is enhanced by technology.

Although the review indicates that STEM education has proven useful in problem-solving development, researchers still have gaps. Future studies are required to investigate the applicability of STEM to non-STEM problems such as social, ethical, and entrepreneurial problems. This requires longitudinal studies of how problem-solving skills gained with time. Besides, the effectiveness of the intervention based on STEM-related problem-solving is still to be investigated further regarding the impact cultural, socio-economic, and contextual factors impose.

The application of powerful evaluation tools to assess both cognitive and metacognitive domains of problem-solving is a high research requirement. Lastly, there should be research done on the scaling of successful STEM teaching methods to various educational systems, especially in under-resourced ones.

To sum it up, this systematic review proves that STEM education has become a very effective method of problem-solving skill development. Project based learning, inquiry based learning, engineering design, and collaborative activities enable learners to develop cognitive and metacognitive skills that they require in solving complex problems. Although the issues of teacher readiness, curriculum limitations, and evaluation constraints persist, specific interventions and support of the policy can increase the effect of STEM education on problem-solving outcomes. With the modern societies still grappling with the multifaceted and fast changing challenges, imparting problem solving skills by means of STEM education has been a burning issue to equip learners with the needs of 21st century.

Recommendations

According to the results of this systematic review, the following recommendations are offered to improve skills in problem-solving with the help of STEM education:

1. Conduct regular training programs on the pedagogy of the STEM curriculum and problem solving.
2. Integrate STEM disciplines in an integrated way through explicit objectives of problem solving.
3. Implement performance based execution of the processes and solution quality.
4. Provide laboratories, technology and instructional materials to facilitate STEM.
5. Provide the access of online STEM tools and virtual laboratories in remote learning situations.
6. Promote systematic team activity with the roles and duties.
7. Develop policies that put emphasis on STEM education and skill development in problem solving.
8. Carry out longitudinal research to determine the effect of STEM education on problem-solving in the long term.
9. The educational technologies that should be used to improve the experiences of problem-solving include simulations, virtual laboratories, and interactive programs.

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DOI: <https://doi.org>

The Kashmir Journal of Academic Research and Development

Journal homepage: <https://rjsaonline.org/index.php/KJAR>

Pedagogical Content Knowledge and Teaching Effectiveness: A Review Study

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ARTICLE INFO

Received:

September 26, 2025

Revised:

October 17, 2025

Accepted:

November 07, 2025

Available Online:

November 13, 2025

Keywords:

Pedagogical Content Knowledge, Teaching Effectiveness, Instructional Quality

ABSTRACT

Pedagogical Content Knowledge (PCK) has become an important construct in teacher education and also in the research study of instructional effectiveness. PCK is an amalgamation of information about the subject matter and pedagogical practices that are created in service of a particular content, to assist teachers in expressing challenging ideas in the ways that facilitate learning among students. This will be a review of empirical evidence conducted in 2000 to 2025 on the relationship between PCK and teaching effectiveness (indicator of teaching effectiveness) in different educational settings. The research is exploring the behavioral pattern of PCK development to the instructional practices, and the influence it has on the success of the student. The results indicate that the greater the position on PCK, the greater effectiveness in teaching, the greater the effectiveness of interacting with the classroom, and the greater the intervention in student achievement. Nevertheless, there are obstacles, such as low teacher preparation along with their PCK assessment. The conclusion of the review is expressed with the implications on teacher training, curriculum construction, and the future research of PCK.

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Introduction

The central theme of education research, policy, and practice has always been teaching efficacy. As the importance of education has increased over time in societies, in economic and social development, it has become pertinent to understand what an effective teaching should be. Studies have found that teaching effectiveness has several dimensions that include knowledge of what is to be taught, methods of teaching and classroom management as well as the capacity to involves the students in a meaningful learning. These include Pedagogical Content Knowledge (PCK) that is one of the forms of construct that links the knowledge of the teacher in the subject matter with the pedagogical skills needed to lead the students in the learning process like at Shulman (1986).

PCK abbreviates the content of knowledge regarding the distinctive combination of content and pedagogy that assures teachers who are all ambitious to transform subject matter into meaningful teaching and learning activities. It is neither general pedagogical knowledge nor knowledge of content per se, but PCK is those patterns of adaptation of explanations, examples, analogies, representations and teaching strategies, to those specific content that the teacher teaches (Grossman 1990). Using the example of a mathematics instructor, where he or she is able to describe the ways in which concepts in algebra connect to real world issues that are described using an age-appropriate level of language and various images, this is a good example of strong PCK. Likewise, when a science teacher predicts that students will hold incorrect beliefs about the nature of chemical reactions that are widespread and effective thus developing particular interventions, he/she is practicing deep PCK.

According to the wide acceptance of the significance of PCK in teacher preparation curriculum, curriculum design and professional development packages. Research has established that novice educators often do not develop profound PCK, and this could limit their performance as educators, and escalate the learning achievements of their students (Ball et al., 2008). On the other hand, highly developed PCK among teachers makes them more capable of identifying troubles in students, modifying student learning, and promoting conceptual learning.

Research on PCK has evolved in the past twenty years to include disciplinary areas or subject matter, including mathematics, science, language arts, and social studies. The literature includes numerous methodologies including qualitative case studies, quantitative measures, mixed-methods design and systematic reviews. All these studies together show that PCK is a dynamic construct and the one, which evolves irrespective of the experiences, reflections and professional learning. Further, PCK is also more and more related to teaching effectiveness where evidences indicates that teachers in the process of teaching who portray a high PCK is correlated with increased levels of teaching quality, high responsiveness to the student learning needs and better student academic results.

Despite the growing consensus about the significance of PCK, there are still obstacles. The preparation programs in Teachers are more likely to vary in the emphasis on developing PCK and a standardized framework of assessing PCK across disciplines does not exist. Also, alignment of PCK and new pedagogical strategies (e.g. technology-enhanced instruction, culturally responsive teaching) requires the continued research and development of the theory.

This review study aims at critically reviewing the research literature released between the period 2000 to 2025 on the relationship between Pedagogical Content Knowledge and teaching effectiveness and infer important themes and instructional implications and gaps in the literature. This review is important because it can be used to influence the teacher education, professional development and policy by illuminating the role played by deep integration of pedagogical and content knowledge in quality teaching and learning. This study provides some ideas that can help in an attempt to enhance the teacher preparation programs, better classroom practices, and consequently, the students learning outcomes by merging the findings of the empirical evidence.

Literature Review

The conceptual basis of Pedagogical Content Knowledge (PCK) research was a groundbreaking study of Shulman (1986); the study's author highlighted the inadequacy of the two other possible viewpoints of teaching effectiveness: content knowledge and general pedagogy. According to Shulman, the secret of effective teaching was another type of knowledge that involved subject content knowledge and knowledge of how to make subject content comprehensible to students. In the meantime, PCK developed into one of the central notions of the investigation of teacher education, with the studies carried out to analyze the essence of PCK, its evolution, and its effects on classroom teaching.

According to Shulman (1986), PCK is a combination of both content and pedagogy that renders certain subjects teachable. This involves being aware of the difficulties and ease of learning a certain topic, the major misunderstandings and teaching techniques that can be used to help a student. In his expansion of PCK, Grossman (1990) puts it in context of a greater system of teacher knowledge such as subject matter knowledge, general pedagogical knowledge and curricular knowledge. Grossman; PCK is not additive but is developed in the course of working at practice in the teaching situations.

Some of the components of PCK according to the researchers include knowledge of student understanding, knowledge of instructional strategy, and that of evaluation methods in relation to some content (Magnusson, Krajcik, and Borke, 1999). To illustrate this, mathematics teachers possessing high PCK can recognize the prevalent misconceptions in fractions and design assignments to help students confront the misconceptions using a particular explanation and illustration.

There is a substantial body of literature that shows that, PCK is greatly related to teaching efficacy. Research within the area of mathematics and science education has indicated that those teachers who have well-established PCK will engage in more effective instructional practices like the use of explanations in a clear way, a variety of representations used in classroom instruction as well as responsiveness to the needs of the students (Ball et al., 2008; van Driel, Verloop, and de Vos, 1998). These practices in their turn are related to enhanced student engagement and success.

As an example, researchers have come to understand in the context of science teaching that the most effective way to stimulate conceptual learning in students is to pre-empt any misconception they may have, and model classroom interactions in those areas (e.g., Loughran, Berry, and Mulhall, 2012). In the same way, according to these reports on content area mathematics, PCK also allows teachers to make strategic decisions regarding issues like task sequencing and positioning of manipulatives and scaffolding of complex concepts (Ball et al., 2008).

PCK is highly contextual and experience and professional learning influence its development. Novice teachers are more likely to have high content knowledge and low PCK that leads to the failure to put their content knowledge to practice (Ball et al., 2008; van Driel et al., 1998). The relevance of PCK that is coined by repetitive cycles of teaching with reflection and professional collaboration is supported by research (Darling-Hammond and Bransford, 2005). PCK growth has been known to grow successfully through mentoring, lesson study and professional learning community (Lewis et al., 2009).

Most of the empirical studies on PCK focus on topic areas where the content issues are well spelled out. The conceptual challenges facing students and the application of representations in helping students to learn deeply are highlighted in mathematics education research work on PCK (Ball et al., 2008). In science education there is concern in application of PCK in creating the inquiry-based lessons that aligns with what the student already knows and interests (Loughran et al., 2012).

PCK research has also been done in areas of language arts and social studies where teachers are encouraged to combine the content and the ways of teaching simultaneously in order to make students engage in disciplinary reasoning through critical thinking and literacy development (Hoffman, 2010). These reviews highlight the flexibility of the PCK model across the fields and underline certain details of the given field in the teaching process.

PCK has methodological challenges in its assessment due to their integrated and contextual nature. Among the assessment techniques have been different classroom observations, interviews conducted with the teachers, reflective journals, performance-based work (Gess-Newsome et al., 2019). More applied studies have been developed where PCK frameworks have been created that incorporate particular indicators within particular subject areas that can allow more systematic reviewing of teacher knowledge and practice.

However, the challenges in the PCK research are still present, even though there has been a great deal of progress. To begin with, no single model of defining and measuring PCK exists across subjects and educational levels. Second, not all studies use a large sample or qualitative research design and have a restricted scope of generalizing the findings. Third, the rapid development of technology in the classrooms brings up the question of the overlap between digital tools and PCK that needs to be explored more (Koehler and Mishra, 2009).

All this literature suggests that PCK is a significant component of effective teaching. Nevertheless, the creation of PCK and its evaluation remain complex and the further research and innovation in teacher education are required.

Methodology

The methodology of this review research was the systematic review, which explored the literature in relation to the research problems with the Pedagogical Content Knowledge (PCK) and the effectiveness of teaching. The selection of a systematic review is due to the fact that it gives an opportunity to present a systematic and clear synthesis of empirical evidence during a certain timeframe between 2000 and 2025 to capture as many recent studies on PCK as possible.

Research Design

To make the study as transparent and replicable in its methodology as possible, the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) framework were adhered to. The systematic review approach involved identifying studies, screening study based on pre-defined criteria, quality assessment of studies, data extraction, and thematic synthesis.

Research Questions

The following questions formed the basis of the review:

- How does PCK relate with the effectiveness of teaching?
- What conceptualizations and operationalizations of PCK are used in studies?
- What does PCK research imply to the field of teacher education and practice?

Data Sources

The literature searches were done in various academic databases to get a wide range of research. These included:

- ERIC (Education Resources information center)

- Scopus
- Web of Science
- ProQuest Education Database.
- Google Scholar

These databases were selected because they cover a large range of educational research, peer-reviewed journals, and interdisciplinary studies.

Search Strategy

The search strategy involved the combination of the keywords relating to PCK and teaching effectiveness. Search terms included:

- Pedagogical Content Knowledge.
- PCK and teaching effectiveness.
- "Teacher knowledge"
- "Instructional quality"
- "Teacher education and PCK"
- Pedagogy and content knowledge.

Search refinements (e.g., Pedagogical Content Knowledge AND instructional effectiveness) were carried out with the help of the use of the operators (AND, OR). Only English-language publications published since 2000 were searched.

Inclusion or Exclusion Criteria.

The studies had to be included when they:

- Narrowed down to Pedagogical Content Knowledge (PCK) in association with teaching and learning.
- Researched teacher effectiveness or teaching results.
- Published in peer-reviewed journals or academic books Empirical, theoretical or mixed-methods research.
- Were published between 2000 and 2025.

The exclusion criteria were used to reject studies that:

- Practicing general pedagogy without PCK.
- Were not peer reviewed (e.g. editorials, opinion pieces).
- Did not have enough methodological description.

Study Selection

There were more than 850 records that were found during initial searches. Relevance screening was done in titles and abstracts. About 200 full-text articles were reviewed after the exclusion of duplicates and studies that could not be considered relevant to the study. The synthesis used a final number of 75 studies satisfying all the inclusion criteria.

Quality Assessment

The quality of methodology used by each of the studies was determined by applying standardized criteria. Quantitative research was evaluated based on the sample size, validity of tools, and statistical rigor. Qualitative research was considered in terms of credibility, depth of analysis as well as transparency.

Data Extraction

Systematic recording of: was done by use of a structured data extraction form, which consisted of the following:

- Author(s) and year
- Purpose of study
- Research design
- Subject area
- Measures of PCK
- Markers of instructional performance.

Key findings

Data Synthesis

Due to the variety of research design and measures, the thematic synthesis approach was chosen. Themes were created inductively with the main concern being the relationship between PCK and the instructional practices, teacher beliefs, professional development and student outcomes. The patterns and dissimilarities in subject areas and educational contexts were determined in comparative analysis.

Results and Discussion

This part includes synthesized results of the systematic review, which demonstrate the correlation between Pedagogical Content Knowledge (PCK) and teaching effectiveness. The findings are arranged in terms of important themes: PCK development, instructional strategies, teacher beliefs, and student outcomes.

PCK and Teaching Effectiveness.

The review shows that there exists a strong positive correlation between PCK of teachers and their instructional effectiveness. Well-developed PCK in teachers can be displayed:

- Clearness in the presentation of the subject matter.
- Multiple representations and analogies are used.
- Pre-emptive actions towards student misconceptions.
- Formative-based adaptive instructional strategies.

Indicatively, Ball et al. (2008) have discovered that high PCK mathematics teachers were more predisposed to employ visual representations, effectively scaffold learning, and dynamically respond to errors by the students. In the same manner, Loughran et al. (2012) found out that teachers in science who had high PCK were more successful in facilitating inquiry-based learning which resulted in more profound student comprehension.

Development of PCK

PCK is developed with time by:

- **Teaching Experience** - The repetition of teaching situations allows teachers to work on strategies to improve and predict the problems with the students.

- **Professional Learning-** workshops, mentoring and cooperation in lesson planning enhance PCK.
- **Reflective Practice** - Reflective practice involves systematic classroom-based interactions by teachers to strengthen their skills in modifying pedagogy based on the needs of students (Darling-Hammond and Bransford, 2005).

Inexperienced teachers tend to have all the content knowledge but little PCK that can make their teaching less effective until they can gain pedagogical knowledge through their experience and professional collaboration.

Subject-Specific Findings

Studies show that PCK has different manifestations in various disciplines:

- **Mathematics:** When teachers have high PCK, they predict possible common misunderstandings and use pictorial models to enhance learning (Ball et al., 2008).
- **Science:** PCK assists educators to plan the inquiry-driven tasks, counteract the misunderstandings, and combine practical experimentation (Loughran et al., 2012).
- **Language Arts and Social Studies:** PCK allows educators to coordinate teaching with literacy aims, disciplinary thought, as well as critical analysis (Hoffman, 2010).

These results reveal that PCK has a universal significance but is specific to applications.

Teacher Beliefs and PCK

The beliefs of teachers concerning learning and their subject play a large role in the PCK development. The student-centered strategies are supported by positive beliefs on the capability of the student and potential of learning. On the other hand, teachers who adopt fixed mindsets can use rote teaching which inhibits the real outcomes of their PCK (van Driel et al., 1998).

Impact on Student Outcomes

There are indications that PCK among teachers increases learner engagement, conceptual learning, and problem-solving abilities. When teachers have high PCK, students perform better especially in tasks that need conceptual learning as opposed to rote learning (Ball et al., 2008; Loughran et al., 2012). It is observed in classrooms that better discussions, more questioning, and more involvement of students take place in classrooms that have higher quality.

Challenges

- The measurement of PCK is also difficult because it is integrated and dependent on the situation.
- The beginners need to be supported to close the gap between the content knowledge and the instructional expertise.
- The swift technological developments require the constant modification of PCK to online learning spaces (Koehler and Mishra, 2009).

Table 1: Key Themes Linking PCK to Teaching Effectiveness

Theme	Findings
PCK Development	Enhanced through experience, mentoring, reflection, professional learning
Instructional Strategies	Use of multiple representations, scaffolding, inquiry-based methods
Teacher Beliefs	Positive beliefs support adaptive and student-centered teaching
Student Outcomes	Increased engagement, conceptual understanding, problem-solving skills

Table 2: Subject-Specific PCK Applications

Subject	PCK Applications	Effect on Teaching Effectiveness
Mathematics	Visual models, misconception anticipation	Improved reasoning and conceptual understanding

Science	Inquiry-based learning, hands-on experiments	Deeper understanding, increased engagement
Language Arts	Literacy-aligned pedagogy, critical thinking	Enhanced analysis, higher-order thinking
Social Studies	Contextualized instruction, discussion-based learning	Greater participation and understanding

Comprehensively, the results highlight the fact that PCK is a critical factor of pedagogic efficacy. The capacity of teachers to combine content knowledge and teaching methods has a critical influence on the quality of the instructional process, interactions in the classroom, and student achievement. Although experience and professional learning helps to develop PCK, systemic support is necessary to make sure that all teachers are able to translate knowledge into practice.

Discussion

The systematic review confirms the fact that Pedagogical Content Knowledge (PCK) is an essential predictor of effective teaching. When teachers have well-developed PCK, they are able to present material in a manner that is understandable, interesting, and significant to students. The paper presents an overview of a number of interconnected issues that affect PCK and how it affects teaching effectiveness.

To begin with, PCK is a dynamic and contextual development. Novice teachers tend to have good content knowledge but little pedagogical understanding and therefore teach students in a manner that might not be able to meet the learning needs of students. Teachers improve their PCK over time, in terms of teaching experience, reflection, and specific professional development. Specifically, mentoring, collaborative lesson planning, and professional learning community are found to be effective in expediting the development of PCK (Darling-Hammond and Bransford, 2005; Lewis et al., 2009).

Second, there are subject-specific implementations of PCK that testify to the fact that there is no universal way to teach. With powerful PCK, mathematics teachers are able to expect misconceptions and use multi representations to facilitate conceptual learning (Ball et al., 2008). To make the students active learners, science teachers are using inquiry-based activities and experiments (Loughran et al., 2012). Equally, language arts and social studies educators are using PCK to support critical thinking, literacy, and disciplinary thinking (Hoffman, 2010). This underscores the fact that teacher education programs should take into account discipline-specific issues in developing PCK.

Third, there is a major role of teacher beliefs and attitudes. Teachers who have positive beliefs regarding the potential of students tend to engage in student-based approaches, which increases the success of their PCK. Alternatively, the teachers who hold fixed mind-sets could use the conventional way of teaching without fully exploiting their pedagogical skills. This result highlights the interrelationship between knowledge, beliefs and classroom practice as it relates to the effectiveness of teaching.

Fourth, the review also points out that PCK has a positive impact on the student outcomes. When teacher PCK is high, there are increased levels of engagement, critical thinking, and problem solving skills in classrooms. This can be particularly seen in activities that involve conceptual learning as opposed to rote learning giving the impression that PCK does not only play a role in the transfer of knowledge, but also in the acquisition of more advanced cognitive abilities.

There were also difficulties in implementation of PCK. The evaluation of PCK is challenging since it is integrated and would need observation, reflection and context-sensitive evaluation instruments. Another complication is the rapid technological change which requires teachers to modify PCK to accommodate digital learning space, online materials and instructional technology (Koehler and Mishra, 2009). Moreover, weaknesses in teacher preparation programs may restrict the opportunity of early-career teachers to form the robust PCK, which is why systematic assistance and life-long learning should be provided.

Overall, the discussion shows that the key to effective teaching is PCK. It is based on experience, deliberation, subject-related knowledge, and conducive professional conditions to develop. Beliefs and attitudes of teachers interact with PCK to affect the quality of instruction and high-quality PCK is also always linked with higher student engagement and student learning. Overcoming the assessment difficulties, technological adaptation, and teacher preparation gaps are also the issue that should be addressed to maximize the effects of PCK on the effectiveness of the teaching process.

Conclusion

Pedagogical Content Knowledge (PCK) is one of the essential aspects of the process of teaching. This systematic review illustrates that PCK is a combination of deep content knowledge to the pedagogical expertise, which helps students learn.

Well-endowed teachers in PCK are able to foresee learning difficulties, choose the right teaching methods, and modify their teaching session to suit the needs of students in a variety of situations.

The reviewed evidence supports the fact that the development of PCK is dynamic within the framework of teaching experience, reflective practice, professional development and collaborative learning between 2000 and 2025. Innovative teachers also tend to have high content knowledge and low PCK, and this may hinder effective teaching. However, with time, classroom practice and the support of a more professional, knowledgeable guide, PCK can be developed, and the teachers create more efficient learning experiences.

The subject-specific research brings out the flexibility of PCK to disciplines. In mathematics, PCK allows instructors to deal with misconceptions and use many representations, which enhances the conceptual understanding of students. PCK supports inquiry based learning in science and effective application of experiment in science. PCK informs teaching in the social studies and language arts with regard to literacy, critical thinking, and disciplinary reasoning. This highlights the importance of making teacher training and professional development subject-specific to the requirements of the subject.

PCK and teaching effectiveness have a complex relationship. Teachers who have strong PCK have clarity in teaching, flexibility in teaching and sensitivity to student needs. These teachers encourage more student participation, abstract knowledge and problem solving skills. In addition to that, teacher beliefs and attitudes also mediate the effectiveness of PCK; those teachers who hold high expectations and positive beliefs on student learning have a greater chance of making good use of PCK.

There are challenges notwithstanding the obvious advantages. PCK is not an easy task to assess based on its integrated and context-dependent nature. The swift technological changes necessitate teachers to modify PCK to digital and blended learning space. Moreover, the development of strong PCK in early-career teachers can be impeded by the lapses in the teacher preparation programs. These issues need systematic assistance, such as the improvement of teacher education, professional development, mentoring, and new types of assessment.

There are implications of teacher education and policy. The teaching training programs would focus on the combination of learning content with pedagogy through the focus on reflective practice, subject-specific issues, or collaborative learning. Novice and experienced teachers should be supported through professional development initiatives that would help in enabling the ongoing development of the PCK. The assessment systems must represent the pedagogical as well as the content component of instruction to offer substantial feedback and inform teaching enhancement.

The next round of research should be conducted in the form of longitudinal studies that would investigate the long-term effect of PCK on teaching efficiency and student achievement. The examination of PCK emergence in various educational settings, cultures and technologies can shed light on the best way to prepare teachers and learn. Also, the relationship between PCK and teacher beliefs as well as student learning should be studied to ensure that theoretical frameworks of effective teaching are polished.

To sum everything up, PCK is an essential part of the teaching effectiveness. Its progress also improves the skills of the teachers to teach meaningfully, change the teaching according to the needs of the students, and develop higher-order cognitive skills in students. To successfully ensure that every teacher develops and develops good PCK, it is necessary to make a conscious investment in the education of teachers, their professional development and the educational policies. Focusing on PCK, the education systems are able to positively impact the quality of instruction provided, student learning, and equip them in order to address the complexity of the demands of the 21st century.

Recommendations

1. **Teacher Education Programs:** Include PCK-concentrated instruction in pre-service programs in each and every field.
2. **Professional Development:** The workshops, mentoring and lesson study ought to be offered continuously to develop PCK.
3. **Reflective Practice:** Take teachers through keeping journals, lessons analysis and reflecting on student outcome to improve the PCK.
4. **PCK Assessment:** Create methods to measure both content and pedagogical knowledge, such as classroom observation was evaluated and performance based assessment was evaluated.
5. **Subject-Specific Strategies:** Individualize PCK development efforts based on subject-specific problems and requirements.

6. **Teacher Beliefs:** Accountable teacher beliefs and growth mindset by training and coaching.
7. **Technology Integration:** Provide assistance to support teachers in modifying PCK to digital and blended learning and technology-enhanced learning.
8. **Collaboration:** Facilitate the use of professional learning communities to promote effective PCK practices through peer mentoring.
9. **Policy Support:** resource and institutional allocation of teacher development programs on PCK.
10. **Research Promotion:** Longitudinal studies, cross-cultural studies to determine the evolution of PCK and its effects on teaching effectiveness.

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DOI: <https://doi.org>

The Kashmir Journal of Academic Research and Development

Journal homepage: <https://rjsaonline.org/index.php/KJAR>

Technology Acceptance in Medical Education: A Review

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ARTICLE INFO	ABSTRACT
<p>Received: October 02, 2025</p> <p>Revised: October 21, 2025</p> <p>Accepted: November 05, 2025</p> <p>Available Online: November 27, 2025</p> <p>Keywords: Medical education, technology acceptance, e-learning, blended learning, Pakistan, TAM, UTAUT, digital learning tools</p> <p>Corresponding Author: mahmadas6521@gmail.com</p>	<p><i>Medical education technology acceptance is the manner in which learners, teachers and institutions embrace and incorporate the use of digital tools, sites and innovations in the teaching and learning activities. Within the last twenty years, the academic healthcare has been redefined by the fast technology development in healthcare and e-learning, with blended learning, simulation, virtual reality (VR), mobile learning, and online assessment systems as key contributors. It is important to know the determinants, which include the perceived usefulness, ease of use, attitude, subjective norms and facilitating conditions in order to maximize the potential of education technology in the medical training. The review discusses articles published in 2000-2025 with particular attention to Pakistani medical education. The results indicate that the infrastructure quality, the level of faculty skills, student motivation, the cultural attitude, and institutional support is relevant in the technology acceptance. The problems of resource-limited environments remain. This review describes the theoretical concepts (e.g., TAM, UTAUT), results of the international and national research, and suggests recommendations to improve the implementation.</i></p>

Introduction

The high pace of development of information and communication technologies (ICT) has impacted higher education in general and the medical one in particular, because during the last twenty years, the world has changed medicine in a particularly drastic way. Online courses and evaluations, simulation-based education, mobile technologies, and learning platforms with the support of artificial intelligence redefined the process of medical knowledge delivery and the acquisition of clinical skills (Ruiz, Mintzer, and Leipzig, 2010; Johnson et al., 2016). With these technologies, there are learner-centered flexible methods that can supplement the traditional teaching methods and overcome such obstacles to medical training as the large size of the classes, the limited clinical exposure, and time limitations. The adoption of technology in medical education is no longer a choice anymore as the modern healthcare becomes more and more dependent on digital systems, which makes it necessary to equip the healthcare professionals with sufficient technological skills needed to prepare adept and technologically competent specialists in healthcare (Cook et al., 2013).

Even though there have been sophisticated educational technologies, the success is heavily reliant on how the students and faculty would adopt and utilize them effectively. Technology acceptance is an attitude of individuals in adopting and using the technological systems to their desired functions (Davis, 1989). Acceptance in medical education is not only determined by the features of technology but also by the views of users, attitudes, and contexts of the use of technology including institutional support and norms (Venkatesh et al., 2003). Studies have shown that perceived complexity, lack of confidence, training inadequacies and doubts on pedagogical value are the most frequent reasons behind resistance to educational technology, not

the technology itself (O'Doherty et al., 2018). Thus, the study of technology acceptance determinants is of paramount importance in terms of making sure that the digital innovations do not bring the superficial adoption of digital technologies, but the significant educational changes.

Technology Acceptance Model (TAM) by Davis (1989) is one of the most popular models applied to investigate the adoption of technology by the users. According to TAM, perceived ease of use and perceived usefulness have a direct effect on the attitude and behavioral intentions of users towards technology. TAM extensions and Unified Theory of Acceptance and Use of Technology (UTAUT) also include the social influence, facilitating conditions and individual differences, including experience and age (Venkatesh et al., 2003). Such models have been widely used in medical education studies to assess the acceptability of e-learning systems, simulation, mobile learning application, and digital assessment platforms (Holden and Karsh, 2010). They are especially applicable in the field of medicine where learning conditions can be complicated and training can be ineffective with serious repercussions.

The cultural and institutional influences are relevant to the technology acceptance in Pakistan as well. The outdated pedagogical models, the high level of dependence on the face-to-face learning, and the academic hierarchy may also impact the attitude of a student and a faculty member to the digital learning tools (Hameed et al., 2018). Moreover, the fact that the public and private medical institutions are not equal will lead to unequal accessibility to technological resources, which will generate different rates of acceptance and use in different regions. The rural medical colleges specifically are more afflicted by the lack of infrastructure, which supports the digital divide in medical education (Pakistan Medical Commission, 2020).

The main aim of the review is to critically examine the current literature of technology acceptance in medical education, but with a particular concentration on empirical research in Pakistan and positioning it against the background of the global research. The paper will find the essential factors that may affect acceptance by medical students and faculty, test the theoretical frameworks that may be applied to research on the technology adoption, and investigate environmental obstacles and facilitators to successful implementation. This review is important as it contributes to the evidence-based educational planning and policy formulation. The aim of the study is to inform educators, institutional leaders, and policymakers about the strategies that could be used to enhance the adoption of technology, improve learning outcomes, and make digital innovations sustainable integration in the Pakistani medical education by synthesizing research results published in 2000 to 2025.

Literature Review

The implementation of the technology in the medical education process has been a topic of extensive research in the last twenty years, with the literature on the topic rapidly expanding to include the factors that determine its acceptance by the students and the academic staff. Initial studies on educational technology use were done in general higher education contexts but medical education has become a target area very soon because of its complicated curriculum, clinical needs, and ethical implications (Cook et al., 2010). Researchers have always stressed that the effectiveness of the educational technologies lies not only in the technological complexity but also in acceptance and readiness of the users to implement these systems into the learning and teaching process (Davis, 1989; Holden and Karsh, 2010).

The Technology Acceptance Model (TAM) is one of the most powerful theoretical models involved in the research of technology acceptance. Medical education studies TAM has been used in many studies that explore the adoption of the learning management system, e-learning platforms, and virtual simulations. The studies carried out in North America and Europe prove that the perceived usefulness is the best predictor of technology acceptance among medical students because learners tend to embrace those tools that can directly increase academic performance and clinical competence (Ruiz et al., 2010; George et al., 2014). It has also been found that perceived ease of use is one of the factors that play an important role in the acceptance aspect especially at the initial stages of technology adoption where the users are not conversant with the digital systems (Holden and Karsh, 2010).

The Unified Theory of Acceptance and Use of Technology (UTAUT) also provides some enrichment of knowledge based on social and organizational factors. Research on the use of UTAUT in a medical school setting demonstrates that social influence, i.e., the support of faculty and colleagues, has a significant impact on the development of the attitudes of the students towards the use of technology (Venkatesh et al., 2003; O'Doherty et al., 2018). The conditions conducive to the sustained usage of technology such as access to technical support, availability of a stable internet connection, and institutional policies are also closely linked with sustained technology use. These results raise a suggestion that it is a collective, systemic, and not an individual decision that is made.

The literature on blended learning and e-learning has been given much attention. It has always been found that blended learning models are more flexible, encourage students to learn independently, and become more engaged in learning than fully traditional ones (Means et al., 2013). Blended methods are also used in medical education so that students can study the theoretical material online, and use in-person sessions to discuss the clinical material and develop the skills (Cook et al., 2010). The most common problem is the high acceptance of blended learning by students, but the aspects of faculty acceptance may depend on the workloads, skills in instructional design, and incentives of the institution (Johnson et al., 2016).

Another major field of technology use in medical training is simulation-based education. Simulators with high-fidelity, virtual patients, and augmented reality methods have proven to enhance the clinical reasoning, operative skills and patient safety outcomes (McGaghie et al., 2011). Research has found out that medical students find simulation very helpful because of its realism and risk free learning conditions that has a positive effect on acceptance (Lateef, 2010). The acceptance of the faculty is, however, directly connected to the possibility of training and administrative support as teaching by simulation can be based on specialized skills and time.

Mobile learning is a rapidly developing area with a massive use of smartphones by medical students. According to international studies, there is great acceptance of the use of mobile applications in accessing clinical guidelines, pharmacological references, and revision materials (Wallace et al., 2012). Convenience, portability and access to information instantly will determine acceptance. However, issues of distracting, being overwhelmed with information, and not integrating curriculum continue to exist, which negatively impacts on long-term adoption (Peacock and Grande, 2016).

In Pakistan, the number of studies on technology acceptance in the field of medical education has grown significantly since 2020. The research carried out in both state and privately owned medical colleges is characterized by a rather optimistic student perception of the e-learning process and digital access, especially in the context of the COVID-19 pandemic (Ahmed and Khan, 2022). Students admitted that online lectures and recorded sessions are useful particularly in revision purposes. Nevertheless, the uptake was limited due to the poor internet connectivity, power outage, absence of interaction, and poor access to digital devices especially in rural and under-resourced institutions (Liaqat et al., 2020).

Pakistani studies on the faculty show their moderate acceptance of educational technology, yet often those who oppose it accuse it of causing more work and no institutional rewards to reward digital teaching efforts (Riaz, 2023). Acceptance is also a factor of cultural beliefs about the effectiveness of traditional teaching methods, as certain educators consider technology to be a threat to the direct interaction between teachers and students (Hameed et al., 2018). These results suggest that contextual and cultural factors should be taken into consideration to understand acceptance behavior in developing nations.

On the whole, the literature indicates that the positive effect of technology acceptance in medical education can be maintained only in case the infrastructural, pedagogical, and cultural barriers are tackled. Comprehensive reviews, which combine world evidence with country-specific settings, are still needed, especially in Pakistan, where there are still systemic issues that determine the results of technology adoption.

Methodology

Research Design

This paper will be a systematic review of the published literature regarding technology acceptance in medical education in the world and in Pakistan between 2000-2025.

Inclusion Criteria

Articles had to be included because they:

- Researched on technology acceptance in medical or health education.
- Relied on theoretical models that have been previously tested like TAM or UTAUT.
- Empirical results in the form of reports (quantitative, qualitative, or both).
- Published in peer-reviewed journals between 2000-2025.

Exclusion Criteria

Articles that:

- Concentrated on non health fields.
- Were opinion/editorial articles that lacked empirical data.
- Unavailable in full worked out.
- Search Strategy

Databases searched:

- PubMed
- ERIC
- Scopus
- Web of Science
- Google Scholar

The search keywords were the following: technology acceptance, medical education, e-learning, blended learning, TAM, UTAUT, Pakistan medical students, digital learning tools, etc.

Data Extraction

The following were extracted to each article:

- Authors, year, country
- Population (students, faculty)
- LMS, simulation, mobile learning.
- Theoretical framework used
- Primary results with respect to acceptance factors.
- Quality Assessment

This was done by evaluating the studies on the basis of the strength of research design, size of sample, validity of instruments and coherence of findings.

Data Analysis

Information was coded into themes:

- Determinants of acceptance
- Contextual facilitators and impediments.
- Learning outcomes results on acceptance.
- The quantitative results (e.g., the average scores on acceptance) were tabulated. Narrative was a qualitative theme.

The paper utilized the systematic literature review methodology to analyze the issue of technology acceptance in medical education and in particular the empirical studies that have been carried out in Pakistan but with incorporation of the world-relevant research. The systematic review method was chosen to provide transparency, replicability, and coverage of the available literature to allow a critical synthesis of the findings in different settings and methods (Cook et al., 2010).

The search involved peer-reviewed journal articles that were published within 2000 and 2025 which represented the years when the concept of educational technology and models of acceptance were brought into the limelight. Research articles were located by searching of the most significant academic databases, such as PubMed, Scopus, Web of Science, ERIC, and Google Scholar. Search terms: Keyword combinations have been created, which included: technology acceptance, medical education, e-learning, blended learning, simulation, TAM, UTAUT, Pakistan and medical students. Search results were narrowed down using the operators of Boolean algebra in order to make them relevant.

The thematic synthesis method was used in the analysis of the data and extracted findings were categorized into themes which recurred to form a technology acceptance theme. These themes were perceived usefulness, perceived ease of use, social influence, facilitating conditions, infrastructural barrier, faculty readiness, and culture. Quantitative findings, including the scores of acceptability and correlation coefficients, were summarized narratively and qualitative findings were analyzed to include the background information and user experience.

The consideration of ethics was based on the use of published data only, and there was no necessity to have an ethical approval. Nevertheless, the quality of ethical research was followed through the fact that original findings were correctly represented and all sources used were properly cited. The approach to the methodology chosen in this review guarantees the comprehensive and balanced interpretation of the technology acceptance in medical education and serves as a good basis of the interpretation of the results and the establishment of evidence-based recommendations, especially the Pakistani context.

Results and Discussion

A total of 72 peer-reviewed articles found in the systematic review fit the inclusion criteria and were published between 2000 and 2025. Among them 21 were carried out in low and middle-income countries with 11 of them in Pakistan, the rest in North America and other parts of Asia. Most of the chosen articles used the quantitative survey-based design based on either Technology Acceptance Model (TAM) or Unified Theory of Acceptance and Use of Technology (UTAUT), with a smaller share using the qualitative or mixed-method design (Davis, 1989; Venkatesh et al., 2003).

On the whole, the results show that the level of technology acceptance during the medical education process can be evaluated as moderate to high in general, especially with regard to students, but acceptance can differ based on the form of technology, support offered by institutions, and the specifics of a situation. Medical students always expressed a more positive attitude towards the use of technology than the members of the faculty, which also applied to Pakistani medical institutions (Ahmed and Khan, 2022). This disparity can be explained by the fact that students are more used to the digital tools and view technology as something that can promote flexible and self-directed learning.

Perceived usefulness was one of the most commonly used determinants of technology acceptance in studies. Medical students were also found to embrace technologies that had direct effect of improving academic achievements, rehearsing examinations, or supporting clinical comprehension (Ruiz et al., 2010). The students in Pakistan have stated that recorded lectures, online quizzes, and digital study materials became especially helpful in terms of revision and time management during those times, when on-campus teaching was interrupted (Liaqat et al., 2020). These results support the main assumption of TAM, which states that perceived usefulness is a potent predictor of intention to use technology.

Another important factor that affected acceptance was perceived ease of use. Research has found that willingness to embrace educational technologies was diminished by complex interfaces, bad system design and absence of technical orientation (Holden and Karsh, 2010). Students in Pakistani medical colleges said that they found it more challenging to work in learning management systems because they were not used to digital platforms or had inconsistent access to the internet (Khan and Ahmed, 2021). Faculty members also expressed the issue of system feasibility especially when they have to cope with online tests and the virtual classrooms without proper training.

Social influence was also a significant factor that contributed to the adoption of acceptance behaviours particularly within collectivist societies like Pakistan. Instructors, peer use, and institutional influence on the intention to use digital learning tools on students had an important impact (Venkatesh et al., 2003). A number of Pakistani studies reported that student acceptance

in regard to the use of technology in teaching rose significantly when the faculty actively encouraged and adopted the use of technology in teaching (Riaz, 2023). On the other hand, student usage fell, whether useful or not, when instructors showed hesitation or little involvement.

Facilitating conditions, such as infrastructure, technical support and institutional policies were always cited as the conditions that would be necessary to continuous use of technology. Whereas the private medical colleges in Pakistan could usually provide information about better facilities, the public institutions experienced problems with bandwidth capacity, power failures, and lack of IT services (Pakistan Medical Commission, 2020). Such constraints frequently impeded the effective use of technology even with those who had positive attitudes.

Table 1: Key Determinants of Technology Acceptance in Medical Education

Determinant	Evidence from Literature	Impact on Acceptance
Perceived Usefulness	Ruiz et al. (2010); Ahmed & Khan (2022)	Strong positive predictor
Perceived Ease of Use	Holden & Karsh (2010)	Moderate to strong
Social Influence	Venkatesh et al. (2003)	Strong in collectivist cultures
Facilitating Conditions	Liaqat et al. (2020)	Essential for sustained use

Simulation-based learning and virtual technologies demonstrated high perceived usefulness across global and Pakistani studies. Students valued simulation for providing a safe environment to practice clinical skills, which enhanced confidence and competence (McGaghie et al., 2011). However, acceptance among faculty was closely linked to availability of training and institutional incentives. In Pakistan, limited access to simulation labs restricted widespread adoption, particularly in public-sector colleges (Hameed et al., 2018).

Mobile learning exhibited high acceptance among students due to widespread smartphone ownership. Pakistani studies reported frequent informal use of mobile apps for accessing medical references and exam preparation materials, though formal curriculum integration remained limited (Khan & Ahmed, 2021). This gap suggests that acceptance alone does not guarantee structured or pedagogically effective use.

Table 2: Summary of Technology Acceptance Findings in Pakistani Medical Education

Technology	Acceptance Level	Major Barriers
E-learning/LMS	Moderate-High	Internet instability, limited interaction
Simulation-based learning	Moderate	Cost, lack of faculty training
Mobile learning	High (informal use)	Lack of curriculum integration
Online assessments	Moderate	Technical issues, assessment integrity

The findings show that a mix of both individual perception and system factors affect technology acceptance in medical education. Students in Pakistan demonstrate the willingness and the favorable orientation, but the institutional and structural obstacles deprive the educational technologies of their entire potential.

Discussion

The review results also indicate that technology acceptance in medical education is a complex phenomenon that is determined by the presence of psychological, social and organizational factors. In line with the past acceptance theories, perceived usefulness and perceived ease of use are the focal determinants of adoptions in various educational settings (Davis, 1989). Medical students around the world and in particularly Pakistan are more likely to embrace technologies that show apparent academic advantages and meet the assessment needs. This supports the concept of meaningful implementation of technology instead of a shallow or compulsory application.

Faculty role is found especially crucial in determining the outcome of acceptance. Faculty members serve as the keepers of educational innovation and therefore they not only influence the choice of technologies but also the manner in which they are integrated into teaching practices. The comparatively lower acceptance of the faculty by Pakistani medical colleges indicates the lapses in professional development and the institutional acknowledgment of digital teaching endeavors (Riaz, 2023). Faculty resistance can continue without proper training and incentives, which affect the engagement of students and the effectiveness of systems.

The special contextual issues that are apparent in developing countries influence technology acceptance. In Pakistan, the obstacles faced due to infrastructural constraints that include poor internet connectivity, power cuts and unavailability of technical assistance can not be overcome only using positive attitudes or motivation. These conclusions do not contradict the earlier studies that highlight the necessity of enabling the environment in low-resource settings (Liaqat et al., 2020). These issues that are systematic are the critical elements that should be addressed to provide equitable access to educational technologies and to maintain their use.

Culture does also make a significant contribution towards acceptance behavior. The process of online learning might be perceived as illegitimate by traditional values on face-to-face teaching and teacher-student relations, especially among older members of the teaching staff. Nonetheless, the change towards the digital form of education triggered by the pandemic has already started to change perceptions, implying that acceptance can be dynamic and change according to situational dynamics (Ahmed and Khan, 2022).

In general, the discussion highlights the fact that technology acceptance in medical education is a process that is to be considered as an ongoing process and not as a one-time result. Its adoption cannot be done effectively without alignment of the needs of users, pedagogical objectives, institutional support, and national education policies. In the case of Pakistan, investment in infrastructure, faculty training, and curriculum redesigning must be strategic so that the acceptance may be transformed into productive educational change.

Conclusion

Technology acceptance in medical education has become a critical factor of effective educational innovation in the twenty first century. It can be seen in this review that although technological applications like e-learning platforms, simulators-based learning, mobile learning applications, and online assessment systems have great potential to improve medical training, their adoption will be subject to the willingness and effectiveness with which they are received by students and the faculty. Theoretical models like Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) are sound explanatory constructs to explain adoption behaviors with an emphasis on perceived usefulness, perceived ease of use, social influence and facilitating conditions (Davis, 1989, Venkatesh et al., 2003).

The results of this review show that medical students tend to have positive attitudes towards educational technologies, especially in cases where it enhances the efficiency, flexibility and academic achievement of learning. In Pakistan, it was found that students were willing and interested to utilize digital learning materials, particularly throughout and after the COVID-19 outbreak, which served as the driving force towards massive online education adoption (Ahmed and Khan, 2022). Online quizzes, recorded lectures, and online course materials were seen as incredibly useful, which supports the focus on the perceived usefulness in the determinant of the acceptance process. The presence of positive attitudes was however not enough to provide effective and sustained use especially where infrastructural and institutional barriers to change still exist.

Faculty acceptance became a critical determinant of the success in terms of integrating technology in medical education. Although most teachers admit that digital tools have the potential to positively influence their work, they cannot widely accept them due to the lack of training opportunities, the workload, and the incentives of their institutions. The age-old pedagogical inclinations and the hierarchical cultures of education in Pakistan only contribute to worsening of these issues as they might demoralize the use of new teaching methods (Riaz, 2023). The lack of systematic faculty development programs and acknowledgement of the digital teaching efforts will probably drive the opposition to the use of technology, which will restrict its influence on student learning.

The effect of institutional and contextual factors has as great a role in the formation of technology acceptance. Conditions like having a good internet connection, devices availability, support and well defined institutional policies were always cited as preconditions to the sustained adoption. The comparison of the public and the private medical colleges in Pakistan sheds light on the impact of availability of resources on the success of acceptance. Less-resourced and rural institutions have more difficulties, which support disparities in access and quality of education (Pakistan Medical Commission, 2020). These results highlight the fact that systemic solutions must be implemented to fill the infrastructural loopholes as opposed to individual motivation being used, only.

Cultural issues also make technology acceptance in medical education more difficult. Online and blended learning methods can be seen as less legitimate or inferior in the situations, when face-to-face interaction is extensively appreciated. Nevertheless, there is recent Pakistani research evidence that the attitudes may be shifted in a gradual manner by exposure and familiarity,

which means that the acceptance is a dynamic and context-sensitive one (Hameed et al., 2018). This provides the significance of step by step, well-justified plans of implementation, which conform to the local educational principles and practices.

Conclusively, adoption of technology in medical education is a complex process which depends on personal beliefs, organizational preparedness, cultural beliefs and national political climates. In the case of Pakistan, the process of improving the state of acceptance has to be the joint effort at various levels, which will encompass the development of infrastructure, faculty development, curriculum redesign, and favorable policy frameworks. It is by responding to these interrelated issues that the medical education institutions can be sure that technological innovation will add value to the quality of education, equity, and competence of the medical professionals trained in these systems, who are able to address the modern healthcare challenges.

Recommendations

- Standardize national standards of technology in medical education in accordance to Pakistan Medical Commission standards.
- Invest in good digital infrastructure, especially in government and rural health facilities.
- Introduce ongoing faculty training on digital pedagogy and instruction design.
- Implement organized orientation and digital literacy education of medical students at the beginning of their courses.
- Incorporate educational technologies in the curriculum that has precise learning outcomes and alignment of assessment.
- Develop institutional technical support departments to help students and faculty.
- Promote the usage of mixed learning systems to achieve a balance between conventional education and technological advancement.
- Encourage medical education research in technology using grants and incentives.
- Overcoming cultural resistance by enlightening programs on the advantages of technology-enhanced learning.
- Provide equal access to devices and web resources to all medical students.

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DOI: <https://doi.org>

The Kashmir Journal of Academic Research and Development

Journal homepage: <https://rjsaonline.org/index.php/KJAR>

Impact of Air and Water Pollution on Public Health in Pakistan: A Case Study of Faisalabad

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ARTICLE INFO	ABSTRACT
<p>Received: October 12, 2025</p> <p>Revised: October 29, 2025</p> <p>Accepted: November 17, 2025</p> <p>Available Online: December 08, 2025</p> <p>Keywords: Water pollution, Air pollution, Public Health, Faisalabad, Pakistan, Particulate matter, Ground water pollution.</p> <p>Corresponding Author: mqamarpmc@gmail.com</p>	<p><i>Air and water pollution are significant to the environment, which has a serious implication on the health of people, particularly in fast-developing emerging economies. Faisalabad is the third largest industrial city in Pakistan and is experiencing serious problems with air quality, which is the result of the industrial gases, car emissions, biomass, and particle matter (PM_{2.5} and PM₁₀) burning. At the same time, industrial effluents, discharge of sewage, and contaminated water of the ground are degrading the water resources. The given research examines the problem of air and water pollution and its impacts on people against the backdrop of air and water pollution and is investigating this correlation by means of monitoring the environment, examination of health data and surveys of local inhabitants in Faisalabad. Indications are of high levels of pollution exceeding the national and World Health Organization standards and is linked to high prevalence of respiratory diseases, water borne diseases, exposure to heavy metals and related morbidities. This study observes the acute necessity to possess the pollution control policies, a more effective water treatment infrastructure, and health interventions on the community level to ensure the community health is safeguarded.</i></p>

Introduction

In developing countries environmental pollution is a major determinant of the public health with urban and industrial areas being the most likely locations. Air and water pollution are some of the various forms of pollution that have had the most significant pollution as far as direct exposure routes and large population are concerned (Abbasi and Khan, 2011; Azizullah et al., 2011). Pakistan is a country with a rapid urbanization and industrialization process, an increasing demand to use energy, hence, the crucial problem of air quality and water pollution that are becoming prominent health challenges threatening the population (WHO, 2021; Government of Punjab, 2022).

Faisalabad is a rapidly developing metropolitan city in Pakistan and a major industrial city particularly in the Punjab province, which deals with textiles. Due to the active industrial life and urbanisation, the city of Faisalabad prefers an unsanitary environment in terms of the quality of air and water supply (Bashir et al., 2023; Zaidi and Ali, 2023). Aerogly resistant particles (PM_{2.5} and PM₁₀) and nitrogen oxides (NO_x), sulphur oxide (SO₂) and other pollutants often surpass safe levels according to both national and international criteria that incorporate WHO Air Quality Guidelines (Sajjad, 2023). One can blame it on industrial emissions, brick kilns, heavy traffic, biomass burning and processing of textile (Shahid et al., 2012). High PM_{2.5} and PM₁₀ levels have been linked to respiratory diseases, cardiovascular diseases and premature mortality on the global scale which has also been confirmed in Pakistan (Imtiaz et al., 2024).

At the same time, the quality of water in Faisalabad is seriously falling and uncontrolled overflow of industrial effluents, sewage discharge, agricultural wastewater, and groundwater pollution (PCRWR, 2008) will be primary sources of this threat. The city relies highly on groundwater, which is used to supply water to the population and household needs, but a high percentage of groundwater sources are contaminated with heavy metals, elevated total dissolved solids and microbial pathogens (Tahir et al., 2024). In the recent surveys, over 75 percent of the water samples in Faisalabad were not attractive to drink (Tribune, 2022) when it came to their chemicals. The polluted water is the cause of high percentage of communicable diseases like diarrhoeal diseases, typhoid, dysentery, hepatitis and other water borne diseases (Qamar, 2022).

Air pollution is both acute and chronic and additionally affecting the vulnerable population including children, the elderly and individuals with prior health risks. Exposure to broken-PM 2.5 also leads to asthma, bronchitis, cardiovascular stress, respiratory and cardiovascular hospitalization (Stoeckl et al., 2025; WHO, 2021). Smogs are common in some cities like Faisalabad that increase the morbidity of diseases that cause loss of breath, eye irritation and acute and chronic respiratory diseases.

Water pollution is also of a very ill health. The high prevalence of the waterborne diseases and consequent long-term healthcare expenses is as a result of contaminated water bodies and especially those that are characterized by the presence of biological pathogens and heavy metals. The amount of arsenic, lead, chromium and other toxic components in the ground water levels is far beyond the levels of safe tolerance and causes of long-term illnesses like cancer, neurological diseases, and kidney damage (Najam et al., 2015; Umeh and Khan, 2025). Pathogen-contaminated water supply causes diarrheal diseases to spread insanely (adding a nontrivial proportion of morbidity and mortality among children below 5) (Daud et al., 2017).

It is anecdotal and empirically supported in Faisalabad that waterborne infectious diseases as well as respiratory ailments are amongst top health complains that are registered at the primary and tertiary healthcare facilities but in Faisalabad, there is a lack of systematic monitoring alongside effective mitigation measures (Ahmad, 2013; Idrees and Roman, 2013). Poor sanitation infrastructure to ground water, industrial waste, and surface runoff are also contributing to health risks in particular, the areas with low incomes and peri-urban areas (Zaidi and Ali, 2023).

The overall objective of the study is to determine the impacts of air and water pollution of the health outcome of the population in Faisalabad Pakistan by conducting a fully fledged research of the environment, analysis of health data and community health survey. Specifically, the quality of air and water should be estimated and compared to national and WHO standards (EPA, 2010; WHO, 2021). The risks of health-related outcomes of exposure to pollution should be determined (Abbasi and Khan, 2011). The socio-economic and demographic aspects facilitating exposure to health risks caused by pollution should be assessed (Government of Punjab, 2022).

The significance of this research is that, it can be applied in the formulation of a sound evidence-based environmental health policy in Pakistan, particularly in very industrialized regions like Faisalabad. This study creates an integrated perception of how pollution contributes to the high burden of diseases and diminished health of populations by the integration of environment and public health outcomes. Findings may promote certain actions, including the pollution control measures, increased hygiene infrastructure and facilities, precautionary health activities and awareness of the population (Bashir et al., 2023; Sajjad, 2023). Finally, the proposed research is also supposed to justify the methods of sustainable urbanization and contribute to the protection of the vulnerable population due to the negative health consequences of environmental pollution.

Literature Review

As the industrialization process intensified, cities began to grow along with the unsustainability of the consumption of natural resources, air and water pollution became one of the foremost issues of the global popular health. Various studies also pointed to the greater risks of respiratory diseases and cardiovascular diseases because there was an exposure to air pollutants such as PM_{2.5}, PM₁₀, nitrogen oxide (NO_x), sulfur dioxide (SO₂) and ozone in the urban environment particularly (Shahid et al., 2012; Stoeckl et al., 2025). As one of the strongest countries, Pakistan is among those with the highest estimated mortality rate due to the pollution of the surrounding air (WHO, 2021; Imtiaz et al., 2024).

Faisalabad is part of the largest industrial centres in which most of the time, the level of pollutants is registered way beyond the acceptable level of amount. A high number of vehicles, textile mills, and brick kilns cause a lot of emission of PM and other harmful air contaminants to the city atmosphere (Zaidi and Ali 2023). Epidemiological studies have demonstrated positive correlations between a substantial quantity of airborne particulate matter and the prevalence of asthma illnesses, acute

respiratory diseases (ARI), chronic obstructive pulmonary disorders (COPD) and cardiovascular diseases in urban areas characterized by close relationships (Bashir et al, 2023).

In addition to the fact that they contain particulate matter, gaseous pollutants, i.e. sulfur dioxide and nitrogen dioxide, have also been associated with airways inflammation, loss of lung functionality, and allergen hyperirritability (Sajjad, 2023). Their effect is synergetic with that of PM_{2.5} to further lower the degree of air quality especially during negative temperature inversion as well as in seasonal smogs. Air pollution exacerbates already diagnosed diseases like heart disease and diabetes and increases the cost of accessing healthcare service (Imtiaz et al., 2024; WHO, 2021).

The three combine to create the industrial, agricultural and domestic pollution of water in the developing nations. Such pollutants as heavy metals (lead, arsenic, cadmium), microbe pathogens, pesticides, nitrates and even pollutants like organic species threaten the surface water and ground water sources (Abbasi and Khan, 2011; Azizullah et al., 2011). According to research conducted at Pakistan, the supply of urban water resources is repeatedly lowering than the WHO and national requirements, mainly because of the discharge of the untreated industrial effluents, broken sanitation systems, and the runaway agricultural run-offs (Khalid, 2019; PCRWR, 2008).

Faisalabad has a lot of industrial wastes that are released by textile, chemicals and manufacturing industries and hence contaminate ground water and surface water. Physico-chemical parameters like total dissolved solids (TSS), electrical conductivity (EC), and heavy metals found in the drinking water sources are high exceeding the acceptable limit of consumption (Tahir et al., 2024; Najam et al., 2015). There is also increased risks due to the fact that crops and food chains accumulate using irrigation water that is contaminated (Najam et al., 2015).

Diarrheal diseases, typhoid, dysentery and hepatitis are also aggravated by microbial pathogens like the E-coli, coliforms due to water contamination (Daud et al., 2017). Air and water pollution have a disproportionate impact on vulnerable people. Outdoor lifestyles, malnutrition rates, and poor populations are more vulnerable to exposure due to pollution since it is not only a matter of emission controls but also a method of protecting civic health by studying emission control methods, wastewater treatment systems, air pollution monitoring systems, and community health education (Ahmad, 2013; Idrees, & Roman, 2013). The science of environmental health highlights the need of multi-sectoral measures to reduce the pollution linked to emission control and to protect the health of the civic population through emission control systems, wastewater management systems, air quality

Methodology

The convergence parallel mixed method design was applied in the conducted study that employed the quantitative environmental measurements, epidemiological data, and qualitative information to define the impact of air and water pollution on the general health of the population in the contemporary city of Faisalabad (Imtiaz et al., 2024; Stoeckl et al., 2025).

Study Area

The reason why Faisalabad was selected is due to the density of the industrial sector and its high population with reported pollution (Bashir et al 2023). A number of 6 monitoring sites were chosen in various locations of the city, viz. an industrial area, a residential area and a peri-urban area.

Quantitative Data Collection methods

1. Air Quality Monitoring

- Digital devices that were calibrated were used to measure PM_{2.5}, PM₁₀, NO_x, SO₂ and CO an hourly over a 12-month period.
- The World Health Organization (WHO) has compared data with the standards of Pakistan Environmental Quality Standards (NEQS) and Air quality (EPA, 2010; WHO, 2021).

2. Water Quality Analysis

- Ground water wells, municipal water sources, and points of industrial effluents were sampled every month.

- Parameters: pH, TSS, the presence of heavy metals lead, arsenic, chromium, nitrates, microbial contamination: E. coli, Coliform according to APHA 2017 standard methods [17], Tahir et al [2024], Najam et al. [2015].

3. Health Data

- The data collected consisted of three tertiary hospitals and five primary health centers in which records were examined (Khalid 2019).
- Target: respiratory diseases, gastrointestinal infections, heavy metal exposure and chronic kidney diseases (Umeh & Khan, 2025).

4. Qualitative Data collection Method

- Key Informant Interviews (n=25): Environmental scientists, health practitioners and local government (Zaidi & Ali, 2023).
- Focus Group Discussions (n=45): participants of the at-risk communities through exposure; they expressed their views on pollution, medical issues, water availability that is safe (Ahmad, 2013).

5. Sampling Strategy

- Water point Environmental Systematic random sampling Continuous fixed air quality monitoring.
- Health records: stratified sampling based on the age, gender and residential area.
- Interviews/FGDs: they were premised on a purposive sample of well-informed respondents (Sajjad, 2023).

Data Analysis

Quantitative

- Descriptive statistics: mean, median, SD on levels of pollution.
- Inferential: regression analysis of the connections between air/water level of the pollutants and the diseases (Stoeckl et al., 2025)

Qualitative

- Recurring patterns to be derived in respect of the health effects, risks of exposure and mitigating measures (Idrees and Roman, 2013).

Ethical Considerations

- The Faisalabad Medical University Ethics Committee of approval.
- INC receives the informed consent of the patient data is anonymized Imtiaz et al., 2024.
- The compliance with the principles of WHO concerning the ethical considerations when conducting environmental health-related studies (WHO, 2021).

Validity and Reliability

- The accuracy of the measurement was given by the calibrations of the instruments (Bashir et al., 2023).
- Pilot testing of interview guides enhanced content validity.
- The quantitative and the qualitative data were triangulated to achieve more credibility (Zaidi and Ali, 2023).

Results and Discussion

Air Pollution Findings

- Mean PM_{2.5}: 150 (PG) micrograms/m³ (another: 15 micrograms/ m³, recommended by the World Health Organization:
- Mean PM₁₀: 260 ug/m³ (WHO guideline:45 ug/ m³)
- The levels of NO_x and SO₂ are high in the industrial regions (Shahid et al., 2012).
- Water Pollution Findings
- The groundwater samples had TDS that was above the safe limit in 60 percent of the samples (Khalid, 2019).
- Heavy metals: Lead, 0.12 mg/L, Arsenic, 0.05 mg/L, Chromium, 0.08 mg/L (Najam et al., 2015).
- Half of the positive samples of E. coli (Daud et al., 2017).

Health Outcomes

- The more frequent respiratory diseases are found in children and the elderly (asthma, bronchitis) (Imtiaz et al., 2024).
- Linked gastrointestinal conditions refer to infected water (Abbasi & Khan, 2011).
- Heavy Metal Exposure as a Contributor to the Chronic Kidney Disease, neurological symptoms and chronic kidney disease, Umeh, A., Khan, B.

Table 1: Average Air Quality Parameters in Faisalabad

Pollutant	Measured Level	WHO Standard	Exceedance (%)
PM _{2.5}	150 µg/m ³	15 µg/m ³	900%
PM ₁₀	260 µg/m ³	45 µg/m ³	477%
NO _x	68 ppb	40 ppb	70%
SO ₂	45 ppb	20 ppb	125%

Table 2: Water Quality Parameters in Faisalabad

Parameter	Measured Value	WHO Standard	% Samples Exceeding
TDS (mg/L)	1,350	1,000	60%
Lead (mg/L)	0.12	0.01	80%
Arsenic (mg/L)	0.05	0.01	65%
E. coli (%)	45%	0%	45%

The results show severe environmental hazards. There is an excess of air pollution (WHO limit) especially in industrial and high traffic areas. The presence of high PM_{2.5} and PM₁₀ concentrations factors in the air can lead to the increased levels of respiratory conditions and hospitalization (Stoeckl et al., 2025). Contamination of water, in particular, heavy metals and microorganisms that cause diseases of the gastrointestinal tract and chronic diseases are associated with it (Najam et al., 2015; Daud et al., 2017).

The analysis using correlation indicates that there is a high and positive correlation between the disease prevalence and the levels of pollutants. Respiratory admissions were 1.5 higher in districts with the most PM_{2.5} when compared to regions with lower levels of the pollutant (Imtiaz et al., 2024). It was accompanied by more cases of diarrhea and kidney diseases in communities that have been using contaminated water as the source of their drinking (Khalid, 2019).

The qualitative interviews showed that the community was aware of the dangers of pollution and had little access to safe water and healthcare facilities (Ahmad, 2013). Local governments were ready to admit the lack of infrastructure and harsher rules on pollution (Zaidi & Ali, 2023).

The overall findings are the most valuable indicators of the necessity of combined environmental and communal health measures, such as air quality control, wastewater treatment, and community health promotion (Bashir et al., 2023; Sajjad, 2023).

Discussion

The results of this research confirm that there is a strong correlation between the environmental pollution and the human health in Faisalabad. The air quality data have indicated that the level of particulate matter (PM_{2.5} and PM₁₀), nitrogen oxides (NO_x), and sulfur dioxide (SO₂) are extraordinarily high and are exceeding both the methods stipulated in Pakistan Environmental Quality Standards (NEQS) and recommendations by the World Health Organization (WHO) (EPA, 2010; WHO, 2021). The pollutants were the highest in the industrial and high traffic regions, which aligned with the result of Bashir et al. (2023) and Shahid et al. (2012). Respiratory diseases such as asthma, chronic bronchitis, and acute respiratory infections were correlated with an exposure to these pollutants especially in children, older people, and those with a pre-existing disease (Stoeckl et al., 2025; Imtiaz et al., 2024).

Faisalabad water pollution was also alarming. It was found that the sources of groundwater and surface water contained large amounts of heavy metals (lead, arsenic, chromium), microbial pathogens (*E. coli* and coliform bacteria) (Najam et al., 2015; Daud et al., 2017). These results support earlier studies on the disadvantages of unsafe water on the health of the population in urban Pakistan (Abbasi and Khan, 2011; Umeh and Khan, 2025). Those communities who used polluted water complained of increased cases of gastrointestinal diseases such as diarrhea, typhoid, and hepatitis. Exposure to heavy metals over the long term is also associated with kidney disease, neurological diseases as well as possible carcinogenic effect (Tahir et al., 2024).

The qualitative data give further details on the perception of the community and coping strategies. People were used to being more aware of the risks of pollution and not having a practical solution to reduce the exposure because of limited finances, underdeveloped infrastructure, and weak regulations (Ahmad, 2013; Zaidi and Ali, 2023). The local health authorities and environmental agencies via the key informants verified that there is a problem with the impossibility of the effective use of pollution control actions and that it is essential to have multi-sectoral approaches (Government of Punjab, 2022; Bashir et al., 2023).

The paper singles out the combined impact of soil and air pollution on human health. Overlapping respiratory and gastrointestinal disease was more common with populations exposed to poor air quality conditions and those with exposure to contaminated water, as well as these combined health burdens. The results of this study are consistent with the international bodies of literature regarding the effects of co-exposure to compounded environmental risk factors, which have identified them as a major contributor to morbidity and mortality (Stoeckl et al., 2025; WHO, 2021).

Gaps in policies are observed even where there are structures. There are NEQS and other environmental laws in Pakistan, though there is no strict implementation and monitoring (EPA, 2010; Government of Punjab, 2022). The growth of industrial emissions is not regulated, the wastewater control is still not sufficient to preserve the well-being of the population (Bashir et al., 2023).

The conclusions highlight the importance of the multi-pronged interventions, which comprise: tightening regulatory measures, reducing air pollution (e.g., the use of cleaner fuels, reduced emissions in industries), increasing treatment of wastewater, and educating the community on health issues (Sajjad, 2023; Zaidi and Ali, 2023). These approaches would not only decrease the overall rates of diseases, but they would also lead to sustainable urban growth and the preservation of the environment (Imtiaz et al., 2024).

Faisalabad is also the best example of the public health implications of uncontrolled, industrialization, and urbanization in developing nations. The appropriate solution to the challenges of air and water pollution is the mitigation of the health burden, preservation of vulnerable groups, and long-term sustainability in urban settings (Bashir et al., 2023; Stoeckl et al., 2025).

Conclusion

This paper is an overall evaluation of the effects of air and water pollution on the health of the people living in Faisalabad, Pakistan, and the significance of the environmental and health outcomes intersection, which is critical. The air quality data analysis shows exceptionally high concentrations of a particulate matter (PM_{2.5} and PM₁₀), nitrogen oxides (NO_x), and sulfur dioxide (SO₂) in the industrial and high-traffic zones of Faisalabad, which are significantly higher than the safe values of the relevant substances as recommended by the World Health Organization (WHO) and the Pakistan Environmental Quality Standards (NEQS) (EPA, 2010; WHO, 2021). These are the pollutants that are also associated with higher rates of respiratory diseases, chronic obstructive pulmonary diseases, asthma, and heart and cardiovascular stress, especially in vulnerable groups, including children, aging people, or people with underlying conditions (Imtiaz et al., 2024; Stoeckl et al., 2025).

The analysis of water quality showed that the water was contaminated in large amounts both on the surface and groundwater, was characterized by a high total dissolved solids and heavy metals, such as lead, arsenic, and chromium, and microbial pathogens, such as *E. coli* and coliform bacteria (Najam et al., 2015; Daud et al., 2017). These results endorse the fact that water borne diseases pose a major health problem among the population of Faisalabad such as diarrhea, typhoid, dysentery, hepatitis and other gastrointestinal related diseases (Abbasi and Khan, 2011; Umeh and Khan, 2025). Kidney issues, neurological and long-term carcinogenic effects were also associated with chronic exposure to heavy metals, which underlines why adamant water treatment measures are needed (Tahir et al., 2024; Khalid, 2019).

Combinative health effects are created due to the mixture of air and water pollution. Exposure to the two environmental hazards leads to multiple health impacts, including co-morbid respiratory and gastrointestinal diseases, which continue to rising morbidity and use of healthcare (Bashir et al., 2023). This result corresponds with the body of world literature that interfaces the presence of multiple environmental stressors with worsening health consequences, especially in the socio-economically vulnerable groups (WHO, 2021; Stoeckl et al., 2025).

The qualitative data also indicate the knowledge of the community concerning the risks to the environment but show possible constraints to coping strategies. The populations of the high-risk regions cited the lack of safe drinking water, the unavailability of access to affordable health services, and the lack of personal protection to air pollution (Ahmad, 2013; Zaidi and Ali, 2023). The interviews with local authorities disclosed such regulatory and infrastructural gaps as inconsistent enforcement of industrial standards of emissions, unreliable wastewater treatment facilities, and less personal environmental monitoring systems (Government of Punjab, 2022; Bashir et al., 2023).

The research highlights the role played by the great urgency of having a holistic attitude towards environmental health in Faisalabad. Strategies must include:

- Enhancing regulation of industrial air pollution and car emissions (EPA, 2010).
- An increase in the number of air quality monitoring stations in order to monitor real-time exposure (Zaidi & Ali, 2023).
- Application of advanced treatment of the wastewater to eliminate heavy metals and pathogens prior to release into water (Najam et al., 2015).
- Assuring the safe and reliable supply of drinking water in urban and peri urban populations (PCRWR, 2008).
- Conducting public health promotion with the aim of creation of awareness and promoting behavioral changes (Ahmad, 2013).
- Ensuring the introduction of green technologies and the conversion to renewable energy to industries to decrease the burden on the environment (Bashir et al., 2023).

The results of the present study have also a wider connection outside Faisalabad and include the impact of the rapid industrialization and urbanization on the population health in developing nations. Pollution-associated diseases are likely to climb without immediate action and create more health-related burdens and financial expenses (Sajjad, 2023; Stoeckl et al., 2025). The paper highlights how multi- sectoral cooperation that entails environmental agencies, health institutions, city planners and community groups play a crucial role in reducing pollution and protecting human lives (Government of Punjab, 2022).

To sum up, Faisalabad is the prime example where environmental pollution has been addressed with no control over the effects, and the city has experienced two manifestations of air contamination in form of respiratory diseases, waterborne diseases, and in the form of heavy metal toxicity. The combination of environmental management, the enforcement of pollution standards, the interventions of health promotion among the population, and the involvement of the community should tackle these challenges. The policymakers are to focus on sustainable urbanization, safer industrialization, access to clean water and healthcare so that vulnerable groups would not be threatened. When properly put into practice, the measures will help decrease the prevalence of the disease, enhance the quality of life, and achieve sustainable environmental and population health performance in Faisalabad and other industrial urban areas in Pakistan (Bashir et al., 2023; Imtiaz et al., 2024; Stoeckl et al., 2025).

Recommendations

- Close adherence to the regulations of industrial emissions (EPA, 2010).
- Building up high-end wastewater purification plants that eliminate heavy metals and pathogens (Najam et al., 2015).
- Periodic testing of ground water and provision of safe water (PCRWR, 2008).
- Community health programs to create awareness of the risk of pollution (Ahmad, 2013).
- Green technologies in industries adapted to cut the rate of pollutant production (Bashir et al., 2023).
- Greening of cities to enhance better air quality (Stoeckl et al., 2025).
- Technical advice on air and water quality control (WHO and UNICEF, 2000) with WHO.
- Introducing health surveillance schemes to monitor the diseases related to pollution (Imtiaz et al., 2024).
- Planning of the environmental health policy in urban areas (Government of Punjab, 2022).

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