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Cultivating Bionic skills for Empowering Digital Learning Innovators at King Abdulaziz University as future Entrepreneurs leadership

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Abstract. In response to the accelerating challenges posed by rapid technological advancement, the knowledge-based economy, and globalization, this study explores the implementation of an innovation-driven training model aimed at cultivating bionic skills among digital learning innovators at King Abdulaziz University. Recognizing individuals as vital assets, the development of human capital is positioned as a strategic imperative for sustainable growth and entrepreneurial leadership in the digital age. The study involved 92 University students from various disciplines who participated in a structured innovation program grounded in human-centered design methodology. Participants were grouped into collaborative teams to develop final digital product prototypes. A pre- and post-assessment approach was used to measure changes in performance indicators and the expected return on investment (ROI) derived from their innovative outputs. Findings revealed statistically significant improvements in bionic entrepreneurial skills, team performance, and perceived value creation. The results affirm the effectiveness of the applied training model in enhancing future-ready competencies and fostering entrepreneurial mindsets aligned with digital transformation goals in higher education. The study recommends institutional adoption of innovation-based training frameworks to empower students as leaders of digital entrepreneurship and to embed bionic skill development into academic innovation strategies.
Keywords: Bionic Skills; Digital Learning Innovators; future Entrepreneurs leadership.

1. Introduction

In the face of accelerating global change, organizational development, human capital development, innovation management, and sustainable business development have emerged as interdependent pillars essential for maintaining long-term competitiveness in contemporary institutions (del Pilar

Barrera et al., 2025). Organizational development focuses on optimizing internal processes, structures, and cultural dynamics to enhance adaptability and continuous improvement (Keller, 2024). Simultaneously, human capital development emphasizes strategic investment in individuals' skills, knowledge, and potential—positioning human resources as catalysts for innovation and transformative change (Meena & Santhanalakshmi, 2025). Innovation management plays a critical role in translating creative ideas into value-driven solutions, enabling organizations to proactively respond to evolving market dynamics (Shen et al., 2025). When these pillars are integrated within a sustainable development framework, they collectively promote a balance between economic growth, environmental responsibility, and social equity (Mezentseva et al., 2024). This holistic approach not only strengthens organizational resilience but also positions institutions as visionary leaders in an increasingly complex, sustainability-oriented global landscape (Ahsan & Khawaja, 2024).

Entrepreneurship is increasingly viewed as an incremental, dynamic process of value creation and wealth generation, driven by individuals or collaborative systems within organizational settings (Schenk, 2025). This process begins with the development of innovative ideas and extends to the establishment of sustainable business models, requiring significant investment of time, effort, and resources—including financial, psychological, and social capital (Martínez-Falcó et al., 2025). University students, especially in the digital era, are expected to embody an entrepreneurial mindset characterized by innovation, adaptability, and the capacity to manage uncertainty and risk (Garg, 2025). The entrepreneurial spirit empowers students to design and execute strategies that enhance productivity and address global challenges. Entrepreneurial competence among students comprises four essential abilities: the capacity for creative innovation, the ability to recognize and act upon emerging opportunities, a willingness to engage in risk-taking, and the skill to build and sustain collaborative networks (Gracia-Zomeño et al., 2025). These attributes are especially vital for students preparing to enter future workforces shaped by rapid technological, environmental, and social shifts. The importance of embedding entrepreneurship within higher education programs lies in its potential to empower students to develop their own ventures, thereby fostering independence and reducing reliance on traditional employment pathways (Drakaki, 2025). This calls for the integration of entrepreneurship and sustainability-focused curricula, alongside mentorship from experienced innovators, to enhance students' practical skills, cultivate leadership potential, and improve their overall competitiveness in the knowledge-based economy.

This integrated perspective is particularly significant for the nonprofit sector, especially within the fields of education and training. Nonprofit organizations frequently operate under constraints such as limited funding, human resource shortages, and infrastructural gaps—conditions that necessitate creative, cost-effective, and sustainable solutions (Cipriano & Za, 2025). Within this context, innovation is no longer merely a supportive tool but a strategic imperative for amplifying impact, improving operational efficiency, and maximizing social value. A compelling example of this strategic shift is the Non-Profit Sector Forum in Education and Training, organized by the Ministry of Education in Saudi Arabia. As reported by the Ministry (2025), the forum functioned as a national platform designed to foster strategic partnerships and generate sustainable, scalable solutions aligned with the

broader educational and training ecosystem. In alignment with Saudi Vision 2030, the forum aimed to empower nonprofit educational institutions, enhance their organizational capacities, and align their outputs with national development priorities. Key themes addressed during the forum included the presentation of successful nonprofit models, future foresight, educational innovation, and institutional transformation—illustrating the vital role of innovation in responding to both persistent and emerging challenges in the nonprofit education landscape.

Innovation, in this context, is not merely the generation of new ideas but a strategic mindset—one that reimagines limitations as opportunities for transformation and continuous renewal. It involves reframing problems, challenging existing assumptions, and unlocking creative, value-driven solutions that align with broader societal and economic goals (by Typografia et al.). For university students poised to lead in an increasingly digitized world, innovation is both a cognitive and practical skillset that underpins entrepreneurial capacity (Kwapisz et al., 2024). True innovation fosters the ability to navigate uncertainty, make informed decisions, and explore alternative futures through experimentation and adaptive learning (Blevins & Sabatino, 2025). Achieving sustained growth requires more than incremental improvements; it demands disruptive innovations that address the unmet needs of underserved populations—an approach that strongly aligns with educational contexts seeking to empower diverse learners (Christensen & Raynor, 2013) .Furthermore, the "Jobs to Be Done" theory emphasizes that individuals adopt innovations to fulfill specific objectives in their lives, positioning educational innovation as a deeply human-centered endeavor (Breyer et al., 2024). Within this framework, cultivating bionic skills becomes a vehicle to engage purposefully with emerging technologies, lead innovation within and beyond academic institutions, and contribute meaningfully to sustainable economic and social development (Staley & Endicott, 2023). When supported by a systemic culture of experimentation, critical thinking, and institutional alignment, innovation and entrepreneurship together serve as the dual engines that drive the transformation of higher education—and prepare students not just for the jobs of the future, but for shaping that future themselves (Christiansen, 2025).

In the era of accelerating digital transformation and shifting global labor dynamics, bionic skills have emerged as a strategic response to the demands of the future workforce (Chandratreya, 2025). These skills are conceptualized as a new generation of competencies that transcend traditional digital literacy by merging technological fluency with uniquely human capabilities such as adaptability, ethical reasoning, and creative problem-solving (Honke & Becker-Genschow, 2025). Rather than emphasizing technical mastery alone, bionic skills highlight the symbiotic relationship between human potential and emerging technologies, framing innovation as a human-centered endeavor (Saha, 2025). The concept of bionic itself, first introduced between 1955 and 1960, originates from the fusion of biology and electronics, and has evolved as an interdisciplinary field applying functional biological systems to solve technological challenges (Shi & Liu, 2025). bionic skills represent modern human–machine proficiencies that enhance human performance beyond natural limitations through innovations such as wearable technologies (Ahmad et al., 2025).

As digital transformation reshapes the nature of work, the concept of the bionic worker has emerged as a central illustration of how these skills manifest in practice (Fu & Li, 2025). The notion of the

bionic worker reflects this shift, describing professionals who leverage advanced tools—including artificial intelligence, data-driven systems, and immersive digital platforms—to enhance productivity, efficiency, and output quality. Preparing such workers for complex responsibilities requires significant upskilling, with a bionic skillset encompassing four interrelated dimensions: working effectively with new technologies, mastering digital communication, collaborating across disciplinary and cultural boundaries, and preserving well-being in technology-intensive environments (see Figure 1) (Human Capability Development Program, 2024). Building on this foundation, it becomes evident that bionic skills are not only abstract competencies but also practical enablers of future-ready performance (Pekarcikova et al., 2025).

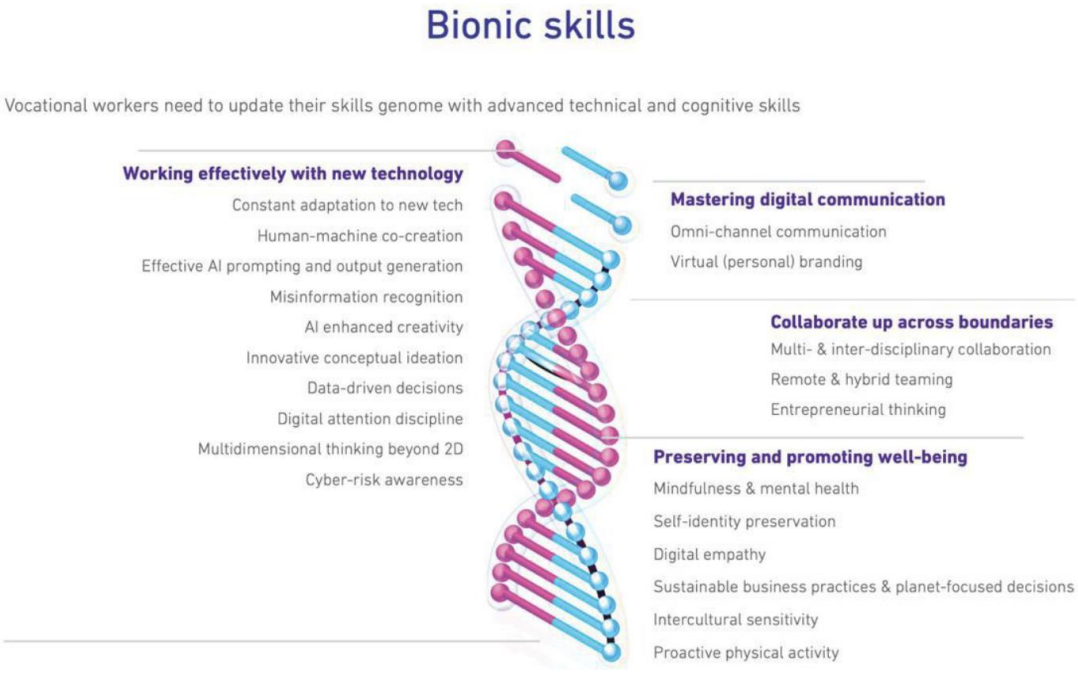

Figure (1): Bionic Skills. (Human Capability Development Program, 2024)

Bionic skills represent hybrid competencies that merge human intelligence with emerging technologies, enabling individuals to thrive in complex, technology-driven environments (Mohan et al., 2024). At their core lies the ability to work effectively with advanced digital tools through continuous adaptation, human–machine co-creation, and purposeful use of artificial intelligence for enhanced creativity, data-driven decision-making, and misinformation detection (Ramaswamy, 2025). These skills also encompass cultivating digital attention discipline, multidimensional thinking, and cyber-risk awareness, which together foster resilience in digital problem-solving (Babu et al., 2025). Beyond technical proficiencies, bionic skills require mastery of digital communication—through omni-channel interaction and strategic personal branding—alongside effective collaboration across multi- and interdisciplinary teams in increasingly hybrid and remote settings (Neubauer et al., 2024). Im-

portantly, they also integrate well-being, mindfulness, identity preservation, digital empathy, and sustainable practices, ensuring ethical and holistic engagement with innovation (Fasnacht, 2024). This comprehensive view resonates with the Human Capability Initiative (HCI) 2025, which positioned bionic skills as foundational to future workforce readiness, recommending their integration into education and training systems, the promotion of lifelong learning, cross-disciplinary collaboration, and resilience-building as key enablers of sustainable human capital development (Lampela, 2023).

Building upon the strategic imperative of cultivating bionic skills as foundational to future workforce readiness, fostering a culture of innovation emerges as a critical driver of entrepreneurial success. As Stiller notes in the MIT Sloan Management Review, organizations that actively empower individuals to ask challenging questions report a 25% increase in idea generation compared to those that do not—underscoring the transformative potential of inquiry-driven environments in fueling innovation and adaptive growth (Stiller, 2025). Similarly, research featured in the Harvard Business Review found that companies fostering a culture of inquiry and questioning the status quo achieve a 34% higher return on investment (ROI) than their counterparts (Gruenewald & Mueller, 2025). Furthermore, insights from Gallup reveal that teams regularly engaging in difficult conversations and challenging conventional thinking are 15% more productive and generate 21% higher profits (Smallman & Parry, 2025). These findings highlight the significant organizational benefits of cultivating a culture of curiosity and critical inquiry. In the innovation-driven ecosystems of Silicon Valley, even seemingly naïve questions are not dismissed but rather protected and celebrated. Over years of experience, these companies have discovered that such questions often lead to breakthrough insights and novel solutions (Duan, 2024). This underscores the pressing need for organizations to train and empower employees not only to follow rules and procedures but also to ask meaningful questions—questions that challenge assumptions, provoke reflection, and ultimately spark innovation.

Building upon culture of inquiry and innovation, social entrepreneurship emerges as a transformative paradigm that channels such critical engagement toward solving complex societal and economic challenges through equitable, sustainable, and inclusive practices (ODESANMI et al., 2024). Social entrepreneurship bridges the traditional divide between the for-profit and nonprofit sectors by embedding justice, inclusion, and shared value into innovation processes. Its practices are evident across fields such as education, healthcare, environmental conservation, and economic empowerment of marginalized populations (Deepalakshmi & Lakshmi, 2024). These initiatives not only strengthen social capital but also enable communities to address complex systemic issues through collaborative and context-aware interventions. Social entrepreneurship is grounded in design thinking, impact-oriented planning, and multi-stakeholder partnerships that yield solutions with both economic viability and social significance (Carè et al., 2025). It is increasingly recognized as a catalyst for sustainable development, civic engagement, and the creation of purpose-driven business models (Pardo-Jaramillo et al., 2025).

Building on the established role of social entrepreneurship as a catalyst for societal transformation, effective implementation requires the adoption of structured innovation frameworks. One of the most

recognized approaches is the Nesta Spiral Model, which conceptualizes social innovation as an iterative, non-linear progression through stages such as exploration, prototyping, scaling, and systemic change (Pei, 2025). Complementing this is the SCI-Project methodology developed by the Young Foundation, which operationalizes these stages through community-anchored interventions. It consists of four interconnected phases—Prepare (team formation, capacity building, challenge identification), Co-define (insight gathering, pattern recognition, problem framing), Co-create (participatory workshops and prototyping), and Implement (refinement, scale-up, and institutional embedding). Together, these methodologies emphasize the importance of inclusive participation, iterative learning, and evidence-based innovation in generating sustainable, scalable solutions (Nascimento et al., 2025). These structured approaches highlight the importance of inclusive participation, iterative learning, and evidence-based innovation in generating impactful and scalable solutions.

Accordingly, this study aims to bridge the gap between theoretical frameworks and practical application by designing, implementing, and empirically evaluating a structured, innovation-driven training model that cultivates bionic skills within higher education. Anchored in human-centered design and interdisciplinary collaboration, the model targets the development of future-ready entrepreneurial competencies among undergraduate digital learning innovators. The research contributes to the growing body of knowledge on innovation-based education by providing actionable insights into how bionic skills can be systematically developed and aligned with national and institutional goals related to digital transformation, sustainable development, and workforce readiness. Ultimately, the study seeks to inform educational policy and practice by offering a scalable, evidence-based model that empowers students to become proactive, resilient leaders in the digital economy.

2. Materials and Methods

2.1. Methodology and Approach

This study adopted an action research methodology grounded in Kurt Lewin's three-phase model of organizational change—Unfreezing, Changing, and Refreezing—to systematically guide the design, implementation, and evaluation of an innovation-driven training program aimed at developing bionic skills among digital learning innovators. Action research, by nature, provides a participatory and reflective framework that actively engages stakeholders in a cyclical process of diagnosing problems, implementing solutions, and evaluating outcomes in real-time educational settings. Lewin's model offered a dynamic structure through which the research progressed:

Unfreezing Phase (Input): This initial phase involves identifying the current state through a preliminary diagnosis, collecting baseline data, analyzing existing challenges, and conducting collaborative planning sessions with stakeholders (students, faculty, and digital learning specialists). This step aims to increase awareness of the need for change and prepare the environment for intervention.

Changing Phase (Transformation): During this phase, the co-designed training model is implemented. It includes interdisciplinary learning experiences, hands-on innovation projects, and action steps de-

veloped with participants. The emphasis is on capacity-building and activating creative, human-centered problem-solving processes that allow learners to co-create digital solutions and entrepreneurial ideas.

Refreezing Phase (Output): This final phase focuses on evaluating the outcomes of the intervention. It involves measuring behavioral and skill-based changes, conducting post-training data collection, and assessing the sustainability and scalability of the acquired competencies. The aim is to embed the new practices into institutional culture and ensure lasting impact.

Throughout the three phases, feedback loops (A, B, and C) are used to connect planning, action, and results, allowing for continuous refinement based on data and participant input. This cyclical and adaptive nature of the model aligns with the values of human-centered design and the goals of empowering learners as digital changemakers within both educational and nonprofit contexts.

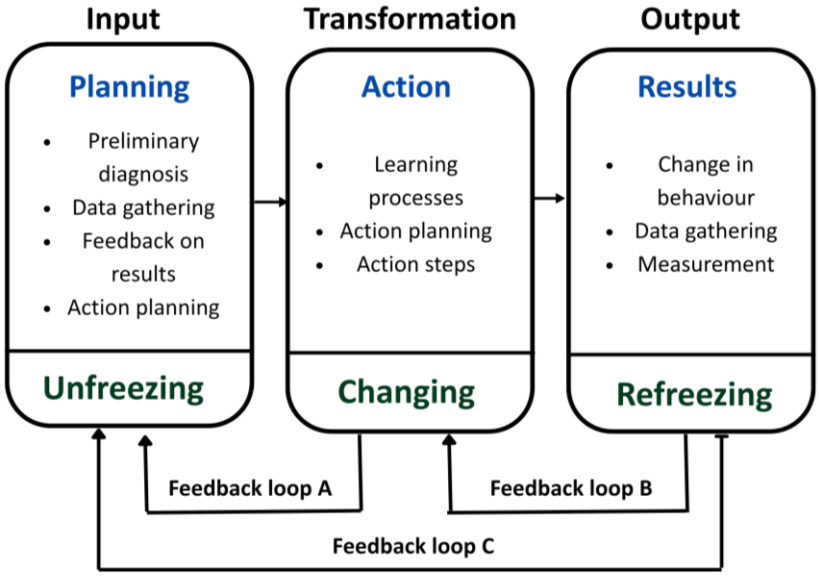

Figure 2. Kurt Lewin's Change Model

2.2. Participants' Information

A statistical power analysis was conducted using G*Power software (version 3.1) to determine the minimum required sample size. The analysis aimed to ensure a statistical power of 90%, with a medium effect size of 0.15 and a significance level of $\alpha = 0.05$. According to Hair et al. (2017), the recommended sample size for such studies ranges between 156 and 225 participants. However, considering the applied nature of this research and contextual constraints, a random sample of 92 university students from King Abdulaziz University was selected. The participants represented a variety of academic disciplines, including education, engineering, computing, and business, which enriched the interdisciplinary learning dynamics within the intervention activities. Prior to the main data collec-

tion, a pilot study was conducted with a separate sample of 15 students to assess the clarity, readability, and conceptual validity of the instrument. The responses from this pilot group were excluded from the final analysis.

The primary data collection tool was the Bionic Skills Scale for Future Workforce Readiness (BSS-FWR)—a scientifically validated instrument developed based on internationally recognized competency frameworks and adapted for the context of digital learning in higher education. It measures students' proficiency in bionic skills essential for future workforce readiness in the era of digital transformation. All participants signed informed consent forms, ensuring their voluntary participation, the right to withdraw at any time, and the assurance of data confidentiality and anonymity. Demographic variables such as age, gender, and work experience were collected and used as control variables in the statistical analysis, given their potential influence on the dependent variable—Innovative Work Behavior (IWB), Table 1 presents the results of demographic characteristics of participants derived from the data collected:

Table 1. Demographic of the 92 Digital Learning Innovators respondents.

Demographic Variable	Category	Frequency (n = 92)	Percentage
Gender	Male	22	23.91%
	Female	70	76.09%
Age	18–20 years	34	36.96%
	21–23 years	56	60.87%
	≥ 24 years	2	2.17%
Academic Majors	Computing and Information Technology	53	57.61%
	Economics and Administration	14	15.22%
	Science	11	11.96%
	Law	5	5.43%
	Human Sciences and Design	2	2.17%
	Arts and Humanities	3	3.26%
	Nursing	1	1.09%
	Engineering	1	1.09%
	Earth Sciences	1	1.09%
	Education	1	1.09%

2.3. Implementation of the Innovation-Driven Training Program

The participants were engaged across three thematic tracks, each designed to cultivate specific dimensions of innovation in digital learning. The first track, Enjoyment, aimed at making learning an engaging and stimulating experience by integrating games and interactive technologies that increase motivation and learner involvement. The second track, Empowerment, focused on developing smart and inclusive solutions that expand learning opportunities for all, with particular attention to supporting individuals with disabilities and underserved groups. The third track, Enhancement, emphasized

creating methods and technologies that improve the quality, accessibility, and efficiency of digital learning environments.

Building on these tracks, a structured training program was implemented, grounded in an innovation model of five progressive stages that guided participants from problem identification to solution development and final presentation. The Exploration stage centered on analyzing the nature of digital learning, identifying its challenges, and recognizing the role of innovation in addressing emerging issues. In the Design stage, participants generated creative solutions, applied artificial intelligence tools, and developed initial prototypes that translated abstract ideas into practical outputs. The building stage emphasized testing and refining these prototypes through iterative feedback while integrating tools for designing and testing social business models tailored to the nonprofit sector. This enabled participants to align their solutions with community needs, define social value propositions, and anticipate measurable social impact through both short- and long-term outcomes. As a result, they produced functional models supported by compelling success narratives. The Preparation stage equipped participants with essential presentation and pitching skills, enabling them to design effective strategies for communicating their solutions to stakeholders, including educators, investors, and institutional decision-makers. Finally, the Launch stage culminated in the formal presentation of completed projects, evaluated against transparent criteria, and reinforced by discussions and mentorship to ensure readiness for real-world application.

2.4. Instruments and Data Collection

To assess the development of bionic entrepreneurial skills, a pre- and post-assessment was conducted using a validated instrument: the Bionic Skills Scale for Future Workforce Readiness (BSS-FWR) was created based on globally recognized competency models and specifically adapted to the context of digital learning innovation. This scientific instrument is intended to measure individuals' proficiency in bionic skills, which are considered essential for meeting the evolving demands of the future labor market amid rapid digital transformation. The scale consists of 21 indicators that provide a comprehensive assessment of these skills. Responses are rated using a 5-point Likert scale to determine the level of mastery: 5 = Very High, 4 = High, 3 = Medium, 2 = Low, 1 = Very Low. The indicators are grouped into four core dimensions, each encompassing a distinct set of sub-skills, including:

1. Working effectively with new technology.
2. Mastering digital communication.
3. Collaborating across Digital boundaries.
4. Preserving and promoting well-being.

The expected Return on Investment (ROI) was calculated using a customized value-creation matrix developed for this study. Within the context of this research, the Innovation Score serves as a critical evaluation component in the Return on Investment (ROI) matrix for the bionic skills training program. It focuses on assessing the originality and applicability of the digital solutions developed by participants. Although this indicator carries a relatively lower weight (10%) compared to other dimensions, it holds strategic significance in evaluating transformative creativity and its relevance to real-world

contexts. The innovation score is measured through an expert judging panel, ensuring objectivity in the assessment process. Its classification as a "low" contributor to overall ROI reflects its role as a complementary metric that enriches the understanding of value creation, without serving as the sole determinant of the program's impact.

3. Results

The findings of this study revealed that the innovation process followed by participants was structured around the four interconnected phases of the Double Diamond model: Discover, Define, Develop, and Deliver. In the Discover phase, learners engaged in generating ideas, drawing inspiration from leadership and collective inputs, while systematically analyzing user needs to frame the problem context. The Define phase focused on narrowing the scope of identified challenges through user research and the development of a Minimal Viable Prototype (MVP), which provided a concrete baseline for subsequent iterations. The Develop phase emphasized iterative cycles of task setting, design, construction, and testing, ensuring that the proposed solutions were continuously refined to meet user requirements and delivered within the defined timeframe. Finally, the Deliver phase enabled participants to present their solutions through demonstrable prototypes, disseminate key learnings, and collaborate with stakeholders to translate innovations into scalable products or services. This structured and iterative approach underscores the value of integrating design-thinking methodologies within educational contexts, as it fosters problem-solving, creativity, and the translation of conceptual ideas into impactful, real-world applications.

The analysis of the finalist teams in the Innovators of Digital Learning revealed a balanced distribution across the three thematic tracks: Empowerment, Enjoyment, and Enhancement. As shown in Table 2, a total of 24 teams participated, representing 92 students from diverse academic backgrounds. The Empowerment track included seven teams with 22 participants, while the Enjoyment track also comprised seven teams, but with a slightly higher number of participants (n = 29). The Enhancement track demonstrated the largest representation, with 10 teams and 41 participants, reflecting its prominence in addressing quality improvement and efficiency in digital learning environments. Gender distribution indicated that 19 of the finalist teams were female-led, compared to five male-led teams, highlighting the significant engagement of female students in digital learning innovation. Collectively, these results emphasize the diversity and inclusivity of participation while underscoring the growing interest in developing innovative solutions aligned with the three key tracks of empowerment, enjoyment, and enhancement.

Table 2. Distribution of Finalist Teams in the Innovators of Digital Learning (n = 24 teams, 92 participants).

Track	Teams (n)	Team Names	Participants (n)	Female Teams	Male Teams
Empowerment	7	Mobser, EduHelper, Spark Lab, Aoun, ZeroOne, SignPath, Ara	22	6	1
Enjoyment	7	Khata Team, EDU PLAY by AR, Tadribon, MindVenture Team, Project Anomaly, Madarek, Sanad	29	5	2
Enhancement	10	Nasiq Team, Wamdh Team, Tech-Geeks, Art Team, SJF, InnoPower (Tatthbeet), Tatweel, Techance, Al-Mulhamoon Team	41	8	2
Total	**24**		**92**	**19**	**5**

As part of the preliminary evaluation process, all 24 qualified projects were assessed by panels of expert judges, with three specialized reviewers assigned to each track—Empowerment, Enjoyment, and Enhancement. The evaluation criteria focused on the originality of the entrepreneurial ideas and their potential for generating a meaningful social return on investment (SROI). Based on this assessment, the top three projects from each track were shortlisted for the final round, representing distinctive and creative approaches that underscored the transformative potential of digital learning innovations. In the Empowerment track, the selected projects were Mobser, ZeroOne, and EduHelper. For the Enhancement track, the finalists included Tatthbeet, SJF, and Techance. Meanwhile, the Enjoyment track featured Project Anomaly, MindVenture, and EDU PLAY by AR. These finalist teams advanced to present their innovative solutions before the final judging committee, which was tasked with identifying the most impactful project in each track.

Among the finalist teams, three projects stood out for their originality, entrepreneurial orientation, and potential to shape the future of digital learning innovation. In the Empowerment track, Team ZeroOne's project Taallum introduced an integrated educational platform that combines Saudi curricula with advanced artificial intelligence tools to ensure inclusivity. Its distinctive features—such as an interactive chatbot for instant support, a virtual tutor capable of translating content into sign language, and an intelligent narrator for visually impaired learners—demonstrated a strong commitment to accessibility and equity in education. In the Enhancement track, Team Tatthbeet developed Tatthbeet, a smart system that analyzes real-time classroom interaction data using machine learning to improve knowledge retention and transform lecture-based teaching into dynamic, student-centered learning experiences. In the Enjoyment track, EDU Play applied augmented reality (AR) to transform abstract educational concepts into immersive and enjoyable experiences, offering teachers powerful

tools to enrich instruction while ensuring that students, including those with visual and hearing impairments, benefit equally. Collectively, these three projects exemplify the creative and entrepreneurial potential of future digital learning innovators, showcasing scalable solutions that align with the goals of inclusive, engaging, and impactful education.

This study further demonstrated that the participating digital learning innovators successfully acquired bionic skills through the structured training intervention, highlighting their potential as future leaders and entrepreneurs in education. This section presents the statistical findings derived from the pre- and post-test analysis conducted to evaluate the program's impact on the development of these skills among university students. The analysis focused on four core dimensions—Working Effectively with New Technology, Mastering Digital Communication, Collaborating Across Digital Boundaries, and Preserving and Promoting Well-Being—each comprising a set of sub-skills aligned with future workforce readiness. Descriptive statistics (mean scores) and inferential analyses (paired-sample t-tests and Cohen's d effect sizes) were employed to assess both the magnitude and the significance of change across the 21 indicators. The results revealed consistent and statistically significant improvements across all dimensions, confirming the effectiveness of the intervention in enhancing students' proficiency in bionic skills. Table 3 summarizes the detailed outcomes for each skill dimension before and after the training intervention.

Table 3. Effects of the Intervention on Bionic Skills: A Pre–Post Analysis

Category	Item	Mean (Pre)	Mean (Post)	t-statistic	p-Value	Cohne's d
Working effectively with new technology	Constant adaptation to new tech	3.37	4.46	19.575	0.0	0.859
	Human-machine co-creation	2.92	4.19	19.709	0.0	2.074
	Effective AI prompting and output generation	2.81	4.13	23.514	0.0	2.471
	Misinformation recognition	2.89	4.22	22.696	0.0	2.387
	AI enhanced creativity	2.96	4.21	19.082	0.0	2.008
	Innovative conceptual ideation	2.79	4.15	25.695	0.0	2.693
	Data-driven decisions	2.63	4.01	24.005	0.0	2.503
	Digital attention discipline	2.37	3.92	22.285	0.0	2.323
	Multidimensional thinking beyond 2D	2.27	3.88	26.913	0.0	2.806
	Cyber-risk awareness	3.09	4.35	20.478	0.0	2.135

Mastering digital communication	Omni-channel communication	2.37	4.01	32.31	0.0	3.387
	Virtual "personal" branding	2.85	4.68	18.282	0.0	1.916
Collaborating across Digital boundaries	Multi- & inter-disciplinary teams	2.46	3.98	26.547	0.0	2.783
	Remote & hybrid teaming	2.77	4.16	23.276	0.0	2.427
	Entrepreneurial thinking	2.25	3.81	29.832	0.0	3.11
Preserving and promoting well-being	Mindfulness & mental health	2.11	3.8	34.785	0.0	3.646
	Self-identity preservation	2.4	3.98	30.424	0.0	3.172
	Digital empathy	2.36	3.97	31.444	0.0	3.278
	Sustainable business practices & planet-focused decisions	2.12	3.79	34.063	0.0	3.551
	Intercultural sensitivity	2.15	3.83	34.063	0.0	3.551
	Proactive physical activity	1.98	3.78	43.389	0.0	4.524

The analysis of the first dimension, Working Effectively with New Technology, revealed a statistically significant improvement across all nine indicators following the intervention. The pre-test means ranged from 2.27 (Multidimensional thinking beyond 2D) to 3.37 (Constant adaptation to new tech), while post-test means increased notably, ranging from 3.88 to 4.46. Paired-sample t-tests confirmed that these improvements were highly significant ($p < 0.001$) for all items. The most substantial gains were observed in Multidimensional thinking beyond 2D ($M_{pre} = 2.27$, $M_{post} = 3.88$, $t = 26.913$, Cohen's $d = 2.806$), Innovative conceptual ideation ($M_{pre} = 2.79$, $M_{post} = 4.15$, $t = 25.695$, $d = 2.693$), and Data-driven decisions ($M_{pre} = 2.63$, $M_{post} = 4.01$, $t = 24.005$, $d = 2.503$), indicating a profound transformation in students' higher-order thinking and decision-making capabilities. Other indicators also showed large effect sizes, such as Effective AI prompting and output generation ($d = 2.471$), Misinformation recognition ($d = 2.387$), and Digital attention discipline ($d = 2.323$). Even foundational skills like Human-machine co-creation and AI-enhanced creativity registered strong improvements with Cohen's d values of 2.074 and 2.008 respectively. These findings underscore the effectiveness of the intervention in enhancing students' readiness to navigate complex digital ecosystems and engage in adaptive, data-informed, and innovative practices essential for the future workforce.

The results related to the dimension Mastering Digital Communication reveal a substantial improvement in participants' self-reported proficiency following the training intervention. Specifically, the skill of Omni-channel communication increased from a pre-test mean of 2.37 to a post-test mean of

4.01, with a highly significant t-statistic of 32.31 ($p < 0.001$), and a large effect size (Cohen's d = 3.387), indicating a very strong impact of the training on this skill. Similarly, the skill of Virtual "personal" branding improved from a mean of 2.85 to 4.68, with a t-statistic of 18.282 and a Cohen's d of 1.916, also representing a large effect size. These findings emphasize the effectiveness of the intervention in enhancing participants' abilities to communicate effectively across diverse digital platforms and establish a strong professional presence in virtual environments—both of which are crucial competencies for future workforce readiness in the digital era.

The results for the dimension Collaborating across Digital Boundaries revealed a significant enhancement in all associated skills following the intervention. The mean score for working in multi- and inter-disciplinary teams increased from 2.46 (pre-test) to 3.98 (post-test), with a t-statistic of 26.547 ($p < 0.001$) and a large effect size (Cohen's d = 2.783). Similarly, the mean for remote and hybrid teaming rose from 2.77 to 4.16, yielding a t-statistic of 23.276 and an effect size of 2.427. The most substantial improvement was observed in entrepreneurial thinking, where the mean increased from 2.25 to 3.81, accompanied by a t-statistic of 29.832 and a very large effect size (Cohen's d = 3.11). These findings confirm the program's strong impact on enhancing participants' collaborative competencies in diverse digital contexts—skills that are critical for navigating dynamic, distributed, and innovation-driven work environments.

The results for the Preserving and Promoting Well-Being dimension demonstrated remarkable improvements across all associated indicators. The mean score for mindfulness and mental health rose from 2.11 (pre-test) to 3.80 (post-test), with a t-statistic of 34.785 ($p < 0.001$) and a large effect size (Cohen's d = 3.646), indicating a substantial impact. Similarly, self-identity preservation improved from 2.40 to 3.98 ($t = 30.424$, $p < 0.001$, $d = 3.172$), while digital empathy increased from 2.36 to 3.97 ($t = 31.444$, $p < 0.001$, $d = 3.278$). Notably, both sustainable business practices and planet-focused decisions and intercultural sensitivity reported identical statistical outcomes ($t = 34.063$, $p < 0.001$, $d = 3.551$), confirming consistent enhancement in socially responsible and globally aware behaviors. The most pronounced change was found in proactive physical activity, which increased from a mean of 1.98 to 3.78, with an exceptionally high t-statistic of 43.389 and a Cohen's d of 4.524—reflecting a very strong practical effect. Collectively, these findings highlight the training program's significant contribution to enhancing students' digital-age well-being, resilience, and responsible engagement.

Figure 1 presents a comprehensive comparison of pre-, and post-test mean scores across all items within the four bionic skills dimensions. The results reveal a consistent and substantial improvement in participants' performance following the intervention. Each skill area demonstrated a noticeable increase in mean scores post-training, highlighting the efficacy of the immersive learning experience in fostering future workforce readiness. The most pronounced gains were observed in skills related to advanced digital competencies, collaborative practices, and well-being in the digital age. These findings collectively underscore the success of the intervention in equipping students with multidimensional capabilities essential for thriving in complex, technology-driven environments. The visual

disparity between pre- and post-assessment outcomes affirms the significant pedagogical impact of the program on enhancing bionic skill development in a higher education context.

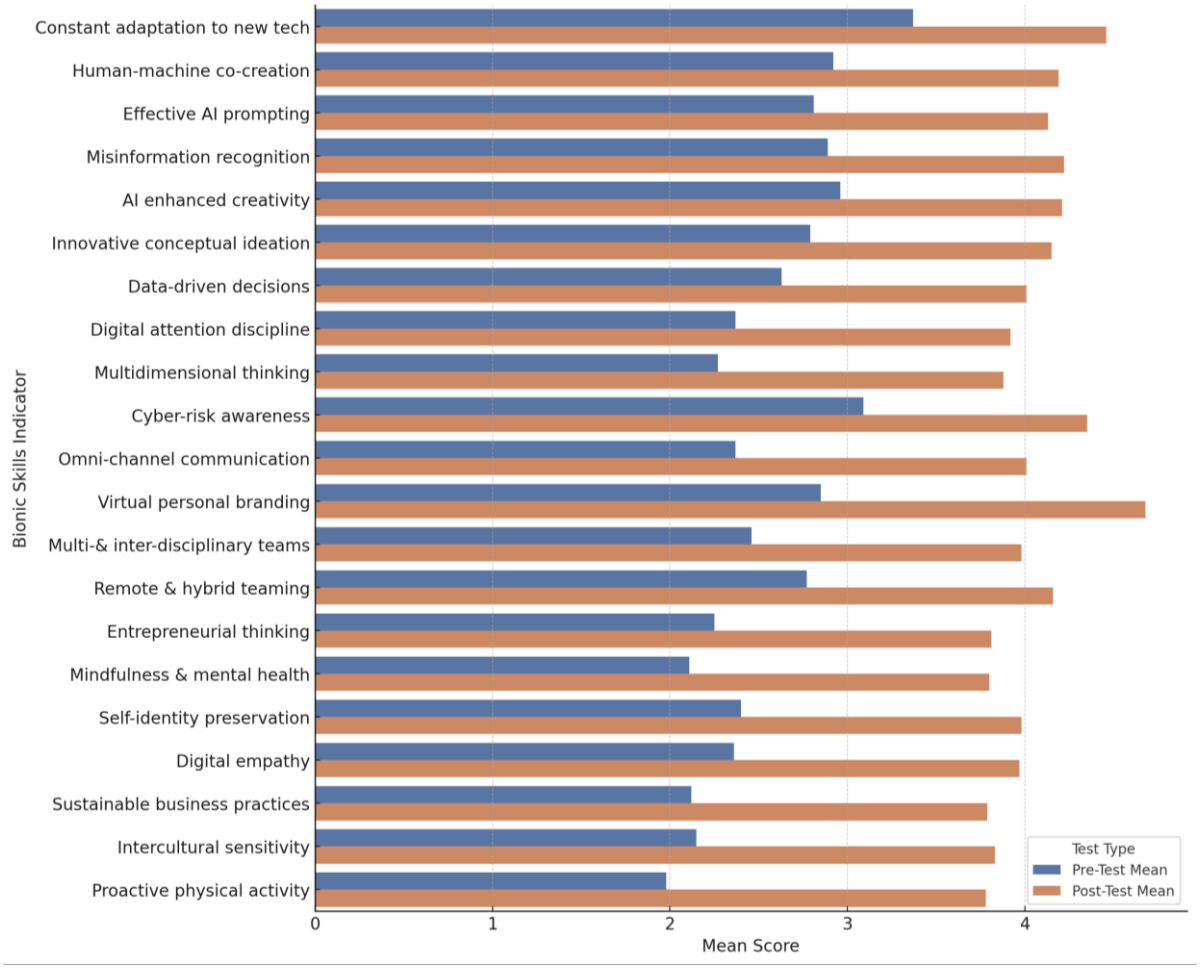

Figure 3. Pre- And Post-Test Comparison of Bionic Skills Indicators

4. Discussion

The findings of this study offer robust empirical evidence supporting the effectiveness of an innovation-driven training model in cultivating bionic skills among undergraduate students. The significant improvements observed across all four core dimensions—working effectively with new technology, mastering digital communication, collaborating across digital boundaries, and preserving and promoting well-being—affirm the strategic value of embedding structured, human-centered innovation frameworks into higher education. These results align with prior research emphasizing the transformative potential of interdisciplinary learning and participatory design approaches in enhancing students' readiness for the digital economy (Staley & Endicott, 2023; Ramaswamy, 2025).

From a theoretical perspective, the study validates the application of Kurt Lewin's change model within educational interventions. The observed pre–post differences, reflected in consistently large effect sizes (Cohen's $d > 2.0$ for most indicators), suggest that the unfreezing–changing–refreezing sequence effectively facilitated behavioral and cognitive shifts essential for developing complex, fu-

ture-oriented competencies. This process was particularly impactful in fostering higher-order thinking skills such as data-driven decision-making, innovative ideation, and multidimensional digital reasoning—skills that are increasingly required in AI-enhanced work environments (Babu et al., 2025). Furthermore, the significant advancements in well-being-related competencies underscore the importance of addressing mental health, empathy, and intercultural awareness in digital skill development. These results mirror the recommendations of the Human Capability Initiative (HCI, 2025), which call for a holistic approach to workforce readiness that integrates psychological resilience and ethical digital engagement. The unprecedented improvement in proactive physical activity ($d = 4.524$) highlights how immersive learning experiences can also influence behavioral health outcomes, reinforcing the interplay between cognitive, emotional, and physical dimensions in digital-age education. Comparatively, this study extends the literature on entrepreneurial education by demonstrating that fostering bionic skills is not limited to technical or digital domains but also supports entrepreneurial mindsets. The notable improvement in entrepreneurial thinking ($d = 3.11$) resonates with Schenk's (2025) conceptualization of entrepreneurship as a dynamic process that interlinks creativity, opportunity recognition, and collaborative problem-solving. These competencies are essential for preparing students to navigate uncertain and volatile labor markets and to initiate purpose-driven innovation within both for-profit and nonprofit sectors.

Importantly, the results support national policy directions such as Saudi Vision 2030, which emphasize innovation, partnership, and youth empowerment as strategic levers for transformation. The alignment of this study's findings with the objectives of the Nonprofit Sector Forum in Education and Training reinforces the institutional relevance of integrating bionic skills into academic programs. It also suggests the feasibility of scaling such interventions through institutional incubators, innovation hubs, and cross-sectoral collaborations.

Despite the promising results, the study acknowledges certain limitations, including the sample size and the context-specific nature of the intervention. Future research should aim to replicate the model across diverse institutional and cultural settings to enhance generalizability. Longitudinal studies are also warranted to assess the sustainability of skill development over time and its impact on students' career trajectories.

In conclusion, this study contributes to the evolving discourse on future workforce readiness by offering a validated, replicable framework for cultivating bionic skills through immersive, interdisciplinary, and student-centered innovation experiences. It calls upon educational institutions, policymakers, and nonprofit actors to jointly institutionalize such frameworks and to invest in the development of future-ready, socially responsible entrepreneurial leaders capable of shaping inclusive and sustainable futures.

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