Designing the Smart Oasis of Tomorrow: A Project-Based Approach to Climate Resiliency and AI Literacy in Riyadh

Nurturing Architects of the Future through "Design Empathy"

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This quantitative assessment investigates the impact of "Design Empathy" Summer-Autumn Program on 34 high school students in Riyadh. This project-based course tasked students with prototyping smart resilient towns aligned with Sustainable Development Goals (SDGs), supported by emerging technologies such as Artificial Intelligence (AI). Survey results from 31 respondents indicate significant gains in knowledge levels and positive attitude shifts, with no noticeable gender-based differences. Findings corroborate with existing literature on the pedagogical soundness of project-based learning. Learner support and academic-industry partnership also account for the program's success in harnessing students' socioemotional and vocational development. Exemplifying Student-AI Collaboration (SAC) through the use of AI-powered software VillageOS™, the synthesis of climate education and hands-on AI interactions provides a unique venue for data model visualization and machine learning techniques. Insights from the preliminary outcomes can inform future practitioners technological integration in teaching climate science. It is also imperative that policymakers and institutional stakeholders continuously broaden the access to similar educational initiatives for all students, thereby galvanizing youth's boundless potential in innovation and environmental stewardship. "Design Empathy" underscores climate resiliency and digital literacy, demonstrating equitable benefits across genders for its inclusive and versatile design. Future iterations will explore multisite implementations, sample diversification, deepened AI integration, and longitudinal studies.

CCS CONCEPTS • Artificial Intelligence • Interactive Systems and Tools • Visualization • Computer-assisted instruction

Additional Keywords and Phrases: Education for Sustainable Development, Smart Urban Planning, Design Thinking

1 INTRODUCTION

Against the backdrop of the United Nations Sustainable Development Goals (UN SDGs), countries worldwide have been racing towards the benchmarks set by the year 2030. Access to renewable energy, clean water, sustainable food supply chains, and climate resiliency are recurring themes in SDGs discourses [12]. Most recently, urban regeneration has emerged as the focal point in SDGs localization [39]. This tactic proposes an integrated planning strategy focusing on "social equity, human health, carbon emissions, infrastructure improvement, [livability], and housing" [39] in urban spaces. Leveraging data-driven tools and participatory decision-making, urban regeneration blazes a new trail in fulfilling the SDGs benchmarks in the next decade.

Saudi Arabia localizes SDGs by aligning its national development agenda, Vision 2030, with the 17 goals. With regard to SDG 4 "Quality Education," the Saudi government has established policy incentives for expanding climate literacy and building value-added digital skills central to the Vision 2030 ambition [12, 18]. The country's capital city, Riyadh, also excels in experimenting with urban regeneration with the Central Riyadh Regeneration (CRR) project, paving the way for urban vibrancy, cultural prosperity, digital transformation, and knowledge economy [39].

What drives this research is Saudi Arabia's prominent position in SDGs localization, along with the converging interest in advanced technological solutions to climate challenges through Artificial Intelligence (AI), machine learning, and robotics [16]. The current study aims to evaluate the impact of the "Design Empathy" Program on a group of high school students from MISK Schools based in Riyadh. Jointly led by higher education institutions and education technology enterprises, this project-based program introduces students to smart and sustainable urban planning. The evaluation focuses on students' overall climate literacy and tendency to pursue related courses and careers in the future. Using metrics-based surveys before and after the program, this study examines changes in students' knowledge level in climate resiliency and digital technologies. Regarding cognitive development, the surveys address students' interest in climate education, their attitudes towards SDGs, their comfort with learning about smart urban design, and their preparedness in pursuing relevant careers. Additionally, this research considers gender differences in these measures. This impact assessment sets out to explore the under-addressed field of interdisciplinary climate and AI education for K-12 learners in the Saudi Arabian context.

2 PURPOSES & RESEARCH QUESTIONS

The purpose of the current study is trifold:

- To explore the impact of a project-based intervention program about sustainable development and smart city design on a cohort of young students in Riyadh, Saudi Arabia;
- To enrich current knowledge in interdisciplinary and participatory approaches to climate education with digital enrichments;
- To examine the demographic factors such as gender on students' learning experiences, academic outcomes, and personal development.

2.1 Research Questions

This study henceforth proposes the following research questions:

- **RQ1:** Does the participation in the intervention program impact students' a) Knowledge Level; b) Academic Interest; c) Attitudes towards Sustainable Development; d) Comfort with Learning; and e) Career Preparedness?
- **RQ2:** Does gender differentiate the program's impact on the 5 constructs?

3 LITERATURE REVIEW

3.1 Smart & Sustainable Urban Planning

Smart cities refer to an emerging model of urban planning and residence characterized by digitization and high tech-driven infrastructures. Commonly used digital tools include AI, big data, 3D modeling tools, and online interfaces [1, 2, 7]. Smart cities have gained momentum in post-pandemic years [1]. Its manifestations in the Gulf exemplify the promising outcomes of smart urban planning and governance. As in NEOM and Riyadh, emerging technologies such as AI, Digital Twins, and the Internet of Things (IoT) have facilitated intercity connectivity, fast transportation, and real-time monitoring. These design choices are tailored to local landscapes, lifestyles, and developmental goals with greater precision [22, 30]. Smart cities can also fortify the overall resilience of urban space. In the case of Makkah, smartified protocols with AI robotics and simulators helped curb the spread of the pandemic [1]. Smart infrastructures delineate a new normal in urban dwelling, augmenting efficiency, efficacy, and security of urban dwellers [1].

Sustainability ties synergistically with smart city design [10]. Recent studies recognized the benefits of digitization in making better informed decisions about sustainable practices, at the same time stimulating cross-sectoral communication to facilitate whole-society efforts towards environmental soundness [1, 10]. Examples of Riyadh, Graz, and NEOM feature green infrastructure and accessible public transport [1, 10, 22, 30]. These inquiries have shed light on environmentally conscious smart urban design, prioritizing the ecological, economic, and social expectations in the SDGs.

Digitally and environmentally literate human capital is the backbone of building smarter and more sustainable cities [5]. Talent acquisition in sustainable development and smart urban design can encourage more environmental consciousness, which in turn advances sustainable business practices and everyday lifestyles [5]. Climate and digital education, therefore, plays an indispensable role in the collaborative social network.

3.2 Climate Education in Saudi Arabia

Saudi Arabia is strengthening climate education among young students and professionals. One action research with college engineering students yielded a significant increase in students' knowledge of science-based facts about climate change [35]. The course also strengthened students' willingness to devise solutions to environmental degradation. Similarly, a more recent study revealed the positive correlation between secondary and tertiary climate awareness and improved environmental quality [20]. Climate literacy remained a necessary component of Saudi Arabia's knowledge economy [20].

Climate education cultivates students' capacity to start green businesses [21]. Such an opportunity also hones students' soft skills through socioemotional development: traits like optimism, self-efficacy, and resilience [21] provide students with the psychological capital to combat climate change. Another study looked into how student-driven climate education could bolster community cohesion [6]. Climate education can thus nurture the invaluable human capital [5] that builds "a more diversified, resilient, and sustainable economy" [17].

3.3 Project-Based Learning (PBL)

Project-based learning (PBL) is widely used in AI and climate education. Basic components of PBL involve hands-on experiences, individual or team research projects, and reflective iterations [4, 24, 25, 29]. PBL lessons are empirically proven to promote knowledge acquisition. In one interdisciplinary program, students partook in group projects on sustainable urban design, with themes of urban orchids, electricity-saving lighting systems, and solar panels [36]. Students' understanding of sustainable development doubled after the program, and the use of interactive robotics correlated to students' strengthened willingness to learn about sustainability-related topics [37]. Another PBL lesson engaged students in green projects related to water conservation, waste management, and energy efficiency, cultivating sophisticated climate literacy and incentivizing climate actions [25]. In essence, PBL engages students in experiential learning throughout the course, thereby deepening their understanding of the subject matter.

PBL develops the intangible assets that stimulate students' academic and career pursuits [24, 29]. PBL lessons emphasize curiosity, exploration, and a sense of achievement. These socioemotional benefits tie to students' positive attitudes towards the subject [29]. The participatory and experiential elements in PBL can also enhance students' community engagement, building tighter bonds with the work sites and landscapes [24]. Rooted in free-choice and student-centeredness [24], PBL lessons allow students to enjoy the process of creating their own deliverables, thus cultivating skilled and emotionally intelligent learners [29].

3.4 Gaps & Opportunities

Existing literature has underscored the necessity of sustainable smart city designs and high quality climate education. Resiliency and digitization through smart cities will continue to redefine and revolutionize urban planning and living. Climate education cultivates the human capital crucial for sustainable practices, green entrepreneurship, and environmentally conscious infrastructure. "Design Empathy" synthesizes these crucial elements in its course design and implementation to deepen the insights at the intersection of smart urban planning and climate education.

Multistakeholder partnership is one of the defining factors of the success in smart urban planning and education initiatives. Interdisciplinary lesson plans that integrate climate science, technology, and humanity can also foster well-rounded students capable of hard skills like digital and environmental literacy and soft skills like communication, problem-solving, and critical thinking. The "Design Empathy" program embodies both paradigms with its course design and organization, driving forward innovative learning and cross-sectoral partnerships.

This study can contribute to the current canon in smart urban planning and sustainability education in two ways. First and foremost, the reviewed literature that simultaneously addresses both fields remains largely conceptual. There is a lack of on-the-ground evidence and its assessment at this intersection. The nature of "Design Empathy" as an educational intervention will mitigate this gap in literature by offering evaluative data gleaned from direct actions. Second, current studies related to climate literacy largely concern higher or tertiary education, lacking focus on younger participants. This research can contribute to the understudied area of K-12 climate education with an intersection in digital skills and urban planning. These areas of contribution establish the significance of the current inquiry.

4 PROGRAM OVERVIEW

4.1 Context

The "Design Empathy" Summer-Autumn Program was an intensive, project-based certificate course, jointly led by higher education institutes and education technology industry leaders. 34 students aged 12-17 enrolled in the course on a voluntary basis. 8 instructors (4 women and 4 men) monitored and facilitated the program. The program aimed to deepen students' knowledge in regenerative principles, compassionate sustainability, and autonomous solutions to climate change; cultivate career-ready transferable skills such as technical fluency, design thinking, collaboration and creativity; and inspire students to envision and design future innovations that integrate AI, machine learning, and digital processes.

The one-week course invited students to role-play as local government agents commissioned to envisage a virtual masterplan of a hypothetical "Resilient and Smart Town" adjacent to their campus. Students initially worked in a gender-separated lecture hall where they formed into 3-4 teams with 4-5 members in each section. Then, the small cohorts formed into one boys team and one girls team for the Smart and Resilient Town design activity. Each team formulated their respective proposals through communication and compromise. After further refinements and cooperation, the two teams synthesized their designs into one cohesive final masterplan. This funneling process established teamwork foundations necessary for their goal achievements in the subsequent design challenges. Figure 1 presents the timeline and content of the program.

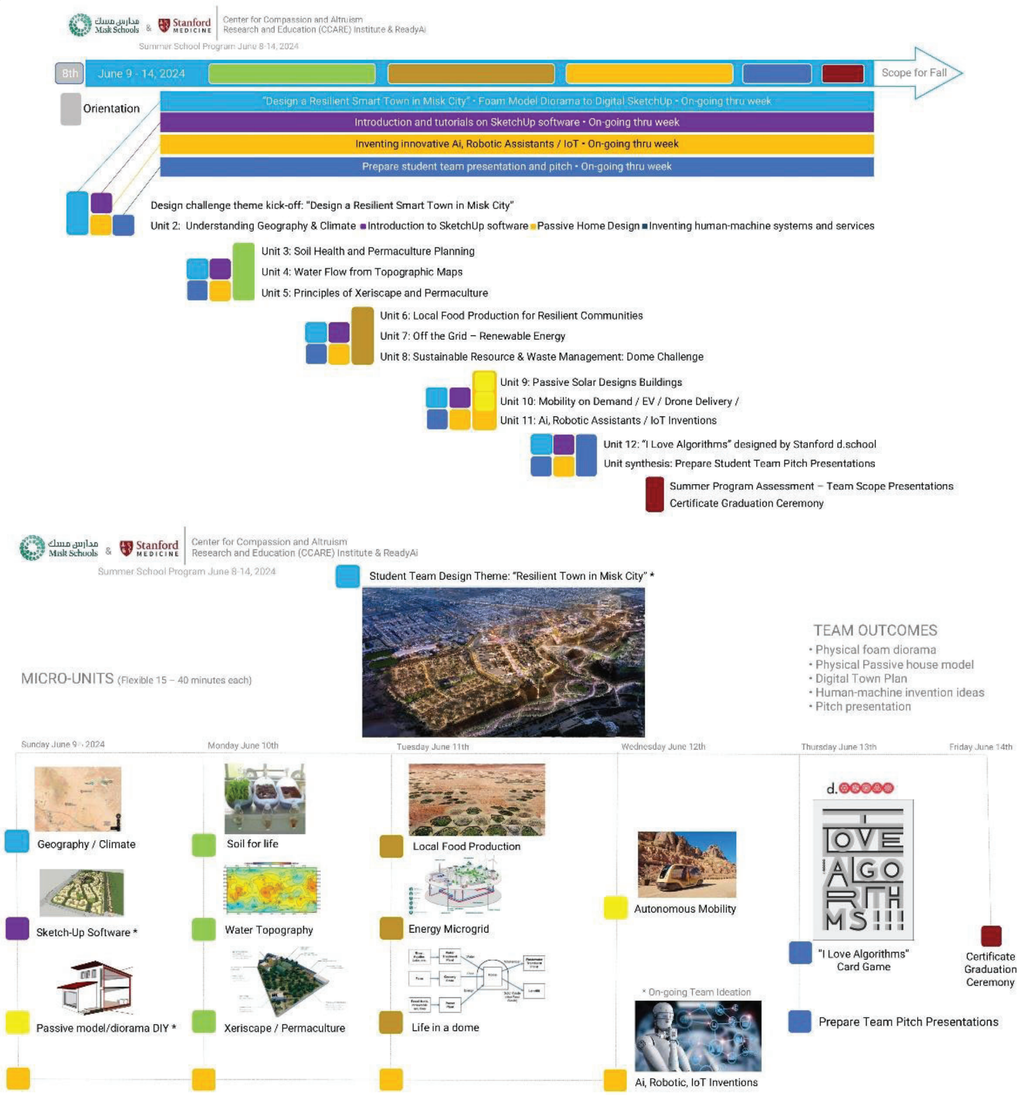

Figure 1: "Design Empathy" Summer Course Timeline

The overarching principles of "Design Empathy" derived from regeneration and circularity – essentially, the interconnected whole-system planning for operational capacity and resource self-reliance [16]. The course revolved around the innovative deployment of proven technology in built-environment energy positive communities with renewable powers and large-scale sustainable food supplies [16]. Students would address local challenges regarding soil health, water conservation, waste management, and energy efficiency in their self-reliant and hyper-local neighborhoods [16].

Besides tackling climate and technical challenges, students were also engaged in mindfulness exercises and team-building activities. Every morning, students joined remotely with a neuroscience expert in a series of guided meditation practices manifesting bodily and spiritual wellness. Mindfulness sessions also enhanced altruism amongst students, as opposed to self-centeredness [14]. Later in the program, students collectively planted a courtyard tree, furthering their connection with nature and with each other, thus harnessing the culture of compassion and empathy.

4.2 Summer Portion (June, 2024)

In the opening activity, the student teams collaborated on designing and crafting a shoebox-sized prototype of a passive home. During this design challenge, students applied the criteria of passive solar design and energy efficiency to formulate their models. They constructed their model homes and placed the artifacts outside for 48 hours to gather climate data such as outdoor temperature and humidity using embedded sensors. They then compared the data to evaluate the robustness and resiliency of their passive home designs. Flexible mini-workshop sessions (15-40 minutes each) helped the teams to refine their town design based on more sophisticated climate concepts and technological support. Passive home design kickstarted the introductory phase of the workshop, preparing students for the main task of developing smart resilient towns.

Covering interdisciplinary themes of geography, ecology, urban planning, and information technology, the second phase consisted of experiential units to brainstorm and prototype the comprehensive smart town plans in both physical and digital formats. Student teams applied design thinking and regenerative principles to collectively imagine – and co-create via foam core cutouts – what their ideal towns would look like. Their designs encompassed residential, recreational, ritual, business, and cultural districts. Modular hands-on units (15-40 minutes each) introduced students to permaculture, soil types, waste-to-resource systems, and renewable energy microgrids, all of which vitalized the climate resiliency of the plans.

Building onto ecological and geographical fundamentals, students looked for innovative ways that sensors, digital devices, robotics, and AI-enhanced processes could lead to residential betterment. A set of daily sub-units incorporated basic digital literacy in AI, machine learning, and emerging technologies. Students learned about how data information was collected, processed, and (re)produced. Lightning talk lectures on robotics, IoT, and AI introduced students to the building blocks of future-ready urban hubs with enhanced connectivity and efficiency. Given the current trends in robotics and autonomous residential interventions, students were encouraged to invent their own automated or digital solutions to incorporate in their final smart resilient town design. Running concurrently during the week, students leveraged SketchUp software platform, an accessible digital tool, to envision their smart city prototypes. SketchUp training was reinforced each day so that students could fledge out and configure their physical diorama layouts into 3-dimensional digital models. After SketchUp smart rendering, students worked with Twinmotion, an animation software, to delineate higher fidelity rendering, shading, texture mapping and animation sequences. The deliverables presented fly-through town plan animations, including sun-path simulations throughout the day and year. Physical and digital deliverables from boys' and girls' teams are presented in Appendix A.1.

4.3 Autumn Portion (September - November, 2024)

In lieu of time during the summer portion, students had yet to delve deeper into the features and functionalities of Twinmotion. Nevertheless, entering the autumn term, students continued to bring their models to life. A subset of 7 students (4 male students and 3 female students) in the autumn semester voluntarily enrolled in the continued portion. They merged into one workgroup to polish their consolidated town plans based on the respective proposals in the summer portion. Through comparative analysis and critical inquiries, students collaborated with each other to unify the design. They synthesized key community amenities, housing systems, road infrastructure, and knowledge hubs. Each week, students briefly proposed their ideas for group discussions to reach consensus that built towards the final integration.

During the autumn session, students engaged more with data analytics and AI or machine learning software. In a shared spreadsheet, they collected and compiled data on natural capacity, resource flows, and demographics, which informed them of the optimal housing population with maximized comfort and resiliency measures. For inspiration, students took photos or searched for images of town layouts, mobility solutions, building types, and public areas to further substantiate their ideas. Figure 2 presents a snippet of the data model that students co-constructed. The sample spreadsheet presented the amounts of energy and water consumption, along with construction costs and land prices, disaggregated by land usage purposes.

data types	#
amounts towers	20
amounts atrium	20
amounts townhouse	20
amounts single family	20
amounts malls	1
energy consumption	energy consumption kwh/c*a
residential	10,000
comercial small	45,000
comercial medium	60,000
commerical big	900,000
water consumption	water consumption m3 per capita per year
residential	120
comercial small	75
comercial medium	100
commerical big	1,000
construction costs	$/m2 new construction
residential	1,600
comercial small	850
comercial medium	2,500
commerical big	3,000
sales prices	$/m2 sales prize
residential	2,200

Figure 2: Student Data Model (inputs)

Additional lightning talks took place during the weekly sessions, including more in-depth climate and weather modeling, demographic information, and a talk from a Stanford real estate professional on how financial feasibility aspects are measured for mixed use residential/commercial real estate developments. Through lively discourse and brainstorming, students built a consistent and structured data model to further inform their placements of design components in their digital plan.

In addition to Twinmotion, students upgraded their digital rendering through VillageOS™, an AI-powered software for dynamic and predicative model renditions [15]. This smart system connects neighborhood infrastructures with local terrains and ecosystem, aiming for maximized inhabitant welfare and minimized environmental hurdle [15]. VillageOS™ enabled students to program and reify complex town designs based on real-time climate and typological analysis. During the rendition phase, students categorized their data models into several domains: location-based climate analysis for infrastructure connectivity, water and aquaculture resiliency, land-informed agriculture for nutrition, renewable energy, and extreme weather-proof mechanisms. The input dataset was then translated into animated outputs simulating time of year, weather patterns, rainfall and fluid dynamic models. Alongside the visualized town plan, a metrics-driven dashboard displayed SDGs and climate indexes, evaluating the overall performance of the design against these crucial UN benchmarks (see Figure 3). Upon commencement, student teams completed their physical diorama town models, finalized their digital blueprints (see Appendix A.2), and refined their high-fidelity animated simulation that they later presented as part of the conclusion of the summer-autumn program at the Cityscape Global Congress (see Appendix A.3). Showcasing the students' professionalism and remarkable teamwork, the conference presentation marked the culmination of "Design Empathy."

Figure 3: VillageOS™ Rendering with SDG Dashboard

Looking ahead, "Design Empathy" aspires to anchor itself in the larger, more systematic educational structure in Saudi Arabia. The current program is a standalone intervention. Provided its immediate positive impact, the initiative aims for the seamless integration within the regular school curriculum across all grade bands and measure its enduring impact. The upscaling of "Design Empathy" strives to better harness environmental stewardship and AI for environmental good among students of Saudi Arabia and beyond.

5 METHODOLOGY

31 respondents were assessed through surveys (see Appendix B), administered before and after the summer portion of the course. Knowledge level survey was conducted separately using multiple-choice questions regarding AI and SDG content knowledge. For the other 4 measures, each construct was measured on a Likert linear scale of 1 to 7, with 1 being “Strongly Disagree” and 7 being “Strongly Agree.” The pre-course assessments established baseline data, while the post-course assessments evaluated the course's impact on the 5 aforementioned measures. Students were asked to select the number that best described them. A repeated measures ANOVA was performed to gauge the extent of change over time, as well as the between-group differences by gender.

6 FINDINGS

6.1 Descriptive Statistics

Table 1 lists the descriptive statistics disaggregated by gender, including mean scores and standard deviations before and after the course.

Table 1: Descriptive Statistics for Pre-Course and Post-Course Measures

Measure	Pre-Course Mean (SD)	Post-Course Mean (SD)
Knowledge Level (Females)	11.85 (1.72)	14.62 (0.65)
Knowledge Level (Males)	10.33 (2.85)	14.56 (0.62)
Interest in Learning (Females)	52.42 (4.99)	61.52 (1.39)
Interest in Learning (Males)	55.43 (10.51)	62.36 (1.75)
Attitude towards Sustainability (Females)	8.89 (3.50)	13.26 (1.14)
Attitude towards Sustainability (Males)	8.29 (3.74)	13.79 (1.14)
Comfort with Learning (Females)	16.11 (3.15)	20.04 (1.93)
Comfort with Learning (Males)	17.07 (3.01)	20.79 (0.98)
Career Preparedness (Females)	16.52 (3.33)	20.00 (1.47)
Career Preparedness (Males)	17.43 (4.15)	21.21 (0.93)

Before the program, female students acquired a slightly higher knowledge level than their male counterparts. Their attitudes towards sustainability and environmental awareness were also stronger. This observation supports past findings that female-identifying individuals tend to have more prior knowledge in climate-related topics and more attentiveness to sustainable development [31].

On the other hand, before the program, female students demonstrated lower interest, comfort, and career preparedness than their male counterparts. This is consistent with the literature in the emotional perceptions on climate change where male-identifying individuals tend to feel less anxious about climate-related topics [31]. Furthermore, the lower interest and preparedness among female students could be explained by their general inadequacy in access to educational and economic resources [8].

The levels across the 5 constructs are approximately evened between both groups, although female students only outperformed male students in terms of knowledge level. This observation is in line with the general consensus on climate literacy [31, 40].

6.2 Within-Group Differences

Table 2 shows the change across all 5 measures among female students, as visualized in Figure 4.

Table 2: Within-Group Differences among Female Students

Measure	M (Pre)	SD (Pre)	M (Post)	SD (Post)	t	p
Knowledge Level	11.85	1.72	14.62	0.65	-5.448	< .001*
Interest in Learning	52.42	4.99	61.52	1.39	-4.444	< .001*
Attitudes	8.89	3.50	13.26	1.14	-5.944	< .001*
Comfort	16.11	3.15	20.04	1.93	-5.964	< .001*
Career Preparedness	16.52	3.33	20.00	1.47	-3.909	< .001*

Note. *M* = Mean; *SD* = Standard Deviation; *t* = t-statistic; *p* = p-value. *p* < .001 indicates statistical significance.

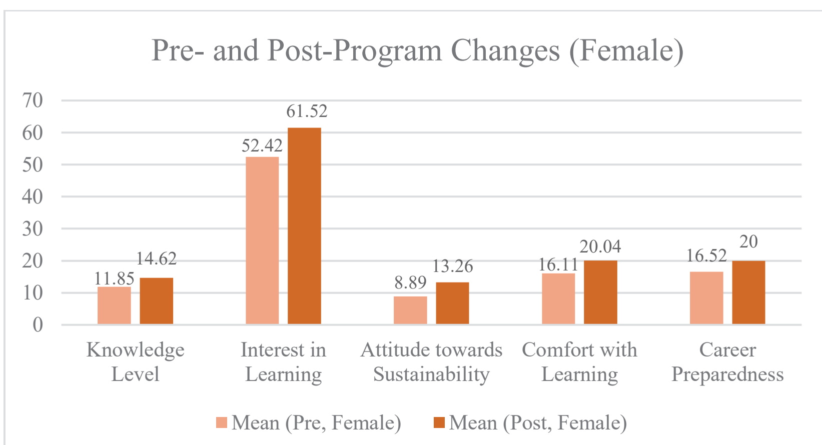

Figure 4: Pre- & Post-Program Changes across All Constructs (Female)

Table 3 shows the change in all 5 measures before and after the intervention among male students, as visualized in Figure 5.

Table 3: Within-Group Differences Among Male Students

Measure	M (Pre)	SD (Pre)	M (Post)	SD (Post)	t	p
Knowledge Level	10.33	2.85	14.56	0.62	-5.614	< .001*
Interest in Learning	55.43	10.51	62.36	1.75	-3.818	< .001*
Attitudes	8.29	3.74	13.79	1.14	-7.501	< .001*
Comfort	17.07	3.01	20.79	0.98	-7.283	< .001*
Career Preparedness	17.43	4.15	21.21	0.93	-4.050	< .001*

Note. *M* = Mean; *SD* = Standard Deviation; *t* = t-statistic; *p* = p-value. *p* < .001 indicates statistical significance.

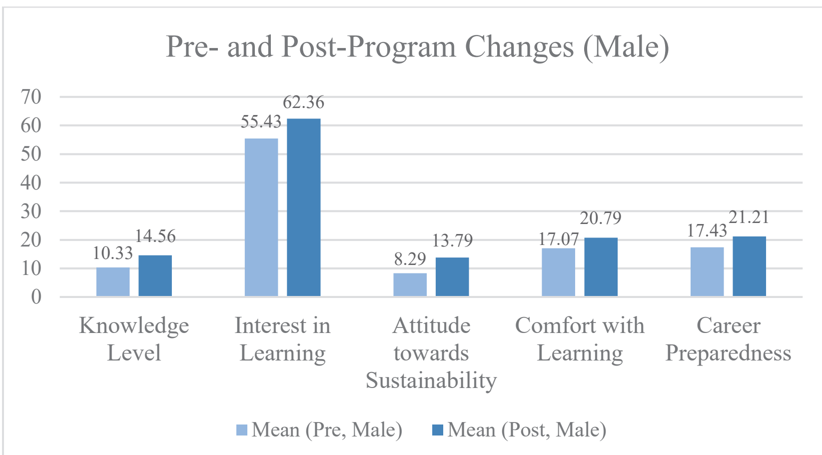

Figure 5: Pre- & Post-Program Changes across All Constructs (Male)

Significant increases are present across all constructs, indicating that both female and male students gained positive learning outcomes after the program. All students deepened their understanding of climate resilience and smart cities. They excelled in digital literacy in data science and AI. Students became more interest in attending similar courses. They perceived climate knowledge and smart urban planning as less intimidating. Students started to consider career pathways in SDGs, smart city design, and digital transformation.

6.3 Between-Group Differences (Gender)

Table 4 presents the between-group analysis regarding gender.

Table 4: Gender Differences in the Impact of the Sustainability Summer Course

Measure	Gender	t	p
Knowledge Level	Female	-5.448	0.00015*
	Male	-5.614	3.10e-05**
	Difference	-1.472	0.152
Interest in Learning	Female	-4.444	0.00080*
	Male	-3.818	0.00138*
	Difference	-0.216	0.830
Attitude towards Sustainability	Female	-5.944	6.77e-05**
	Male	-7.501	8.67e-07**
	Difference	-0.095	0.925
Comfort with Learning	Female	-5.964	6.57e-05**
	Male	-7.283	1.28e-06**
	Difference	-1.664	0.107
Career Preparedness	Female	-3.909	0.00208*
	Male	-4.050	0.00083*
	Difference	0.777	0.444

Note. t = t-statistic; p = p-value. $p < .001$ indicates statistical significance, marked by asterisks (*).

The between-group gender analysis reveals no significant difference in female and male students' changes after the program. This indicates that gender is not a definitive factor that separates the participants' educational outcomes.

7 DISCUSSION

The noticeable improvements in students sustainability awareness and AI literacy not only reemphasizes the pedagogical soundness of PBL [11, 24, 29], but also suggests the potential of hands-on technological enrichment in climate education. The results affirmed existing inquiries into AI integration in raising climate awareness, through providing learners with an efficient and user-friendly tool to quickly take in relevant information [28]. Conventional and emerging technologies alike could make climate knowledge more accessible and the learning process more interactive [28]. Besides, the direct interaction with AI software could familiarize students with the technology, espousing the learning-by-doing principle in developing AI literacy [23]. Human-technology interaction has been proven to develop students' keen sense of innovation and technical application [41]. The intentional deployment of SketchUp, Twinmotion, and VillageOS™ not only fine-tuned students' final deliverables, but also exemplified the correlation between technological augmentation and sustainable urbanization. Students of "Design Empathy" were able to tackle real-world problems using digital tools, resonating with findings from similar studies in digital design challenges [34]. Crafting authentic artifacts for problem-solving could leave a deep imprint on students' technical fluency that channels smart digital prototypes for environmental wellness [34]. As a result, "Design Empathy" could exemplify the synthesis of emerging technologies in teaching climate change.

The deployment of AI-powered software (VillageOS™) as an integral component in students' final deliverable demonstrates the applicability of the student-AI collaboration (SAC) model. SAC envisions a pedagogically underpinned usage of emerging technologies to augment students' knowledge acquisition [26, 27]. The framework is embodied through 3 interconnected modalities: cognitive, socioemotional, and artifact-mediated interactions [26]. Students are the active learning agents in the loop, mediated by the confluence of the 3 interactions. The dynamic human-AI interaction enables students to work on domain-specific tasks where AI acts as the copilot to facilitate learning or as an interface of knowledge exchange [26]. Within a participatory classroom setting as in "Design Empathy," the additional student-machine interactions have enriched the collaborative synergy in addition to interpersonal encounters, guiding students in complex problem-solving spaces through personalized instructional methods [27]. Most notably, the introduction of AI-driven tools supplemented – instead of supplanted – students' knowledge uptake and skill-building [26]. Before the digital rendering, students worked with locally sourced data to construct their models according to unique project needs. Self-driven hands-on practices forged students' computational thinking. VillageOS™ translated numeric information into vivid interactive animations through AI-enhanced gamification [19]. The software not only streamlined in-class activities, smoothening students' workflow towards the final deliverables; but it also engendered a "more effective, relevant, and engagement learning experience" [19]. Photorealistic visualizations and immersive simulations rendered dense data models more intuitive [26]. With SAC and gamification, "Design Empathy" diversified the modalities of knowledge representation regarding AI and climate science, thereby accelerating students' enduring understanding of the topics.

The crucial roles of learner support could also shape the positive results. Throughout the entire program, students worked closely in groups coupled with teachers' facilitation. This collaborative class structure enabled deep peer interactions and personalized learning experiences [6]. Interpersonal support built up a healthy, constructive classroom culture fostering greater ease of learning. The other indispensable factor is students' active roles as co-designers [34, 38] of their smart and resilient towns. The introduction of simulative role plays – as students took on the tasks of urban planners for regional development projects – reinforced the cooperative and immersive learning environment. The cumulative design processes kept the problem space flexible [38] for students to maximize their creativity through customization and digital representations. It is also worth mentioning the meaningfulness of morning meditations and team-building activities. Wellness rituals and tree-planting deconstructed in-group power imbalances and thus created space for mutual understanding [38]. In this hopeful and optimistic atmosphere [21], students managed to reclaim their agency and achieve mutually beneficial goals [14]. These strategies have made "Design Empathy" more than a place to learn but also a space to thrive, which could explain the positive attitude shift after participation. Greater comfort and motivation, in return, could further drive students' continuous inquiry in AI and climate change.

This initial growth in career tendency supports the academic-to-industry pipeline proven to accelerate smart governance and achievements in SDGs [5]. Academia-industry partnerships could help students navigate their career pathways by introducing them to experts and professionals in climate change and advanced technologies [33]. On top of honing practical skills, students gained networking opportunities that could expose them to myriad career openings [33]. Students could receive invaluable mentorship experience as they audited keynote speeches from prestigious instructors. The immediate uptake in career tendency could align “Design Empathy” with the desired outcomes of smart green education [35]. This framework promotes career-ready skills centering eco-friendly technologies via machine learning, addressing the inadequacy of age-appropriate lessons [35]. Responding to this concern, insights from “Design Empathy” could empirically support the successful realization of the framework. Through the advanced cultivation of vocational preparedness and entrepreneurship, programs like this one could tap into the resourceful talent pools of young changemakers [17].

The observations of gendered impact, though not significant, reveal the complexity in the demographic influence on the results of climate- and tech-focused courses. The current study’s finding partially aligns with one previous study where all students had gained more knowledge in climate-related topics [13]; however, female students in saw a more pronounced improvement in [13], as opposed to the findings here. A plausible explanation would be that, over the course of the past decade, female students have had more access to climate knowledge and educational initiatives [9]. In this regard, female students’ knowledge background and academic achievements are tantamount to, if not higher than, those of their male counterparts [9]. Similarly regarding science and technology education, a recent study pointed out that the gender gap in science-related subjects would start to diminish among high achievers [32]. Whether gender is a defining factor in educational outcomes remains ambiguous, as it can co-variate with other demographic, social, and cultural influences. The closing of access and thus achievement gaps may eclipse gender differences in self-efficacy and academic interest [9]. In other words, boys and girls are likely to have equitable capacity of mastering climate and digital literacy through state-of-the-art lessons. Consequently, the model of “Design Empathy” can have broad applicability that transcends gender divisions.

8 CONCLUSION

In the light of the growing imperativeness of smart and sustainable cities in SDGs and national development, “Design Empathy” is steering the cultivation of climate awareness and AI-enhanced solutions through quality education for youth. The repeated measures ANOVA results have demonstrated the program's immediate effectiveness. All of the 31 students assessed have seen significant enhancements in their learning outcomes and personal development.

Although gender does not drastically distinguish the learning outcomes in this study, it could be because students’ prior knowledge, academic performance, and social backgrounds have played a more salient role [32]. Another noted attribute could be the gender-segregated arrangement during the summer portion which this study mainly assessed. It remains an open area of inquiry whether the impact of gender would become more visible in an integrated cohort where students of all genders work together. Nonetheless, this finding alludes to the program's broad applicability and inclusivity, meaning all students, regardless of gender, can gain equally from such educational initiatives. In essence, the implementation of “Design Empathy” reiterates the empowering nature of well-crafted climate literacy and digital education for Saudi Arabian students [9].

This study provides scholarly and practical contributions to sustainability education and digital literacy. It is one of the few recent studies to delve into an under-researched domain of K-12 climate and AI education in Saudi Arabia. This study offers empirical evidence for early adoption of climate and digital literacy in line with localized SDG benchmarks. Provided its imminent benefits, “Design Empathy” can serve as the point of reference for subsequent initiatives and inquiries. Practically, this study can inform educators about innovative and active learning strategies. It points to the next direction in professional development, training qualified teachers to implement similar programs under participatory frameworks and with cutting-edge technologies. For school leaders and policymakers, more needs to be done to remove obstacles for female students as they transition from schools to careers [9]. This study reemphasizes the continuous providence of equitable access to quality education initiatives. “Design Empathy” has channeled a new course in redefining Saudi Arabia’s climate education. Students of such initiatives will stride towards a greener, smarter, and more resilient tomorrow.

8.1 Limitations & Future Directions

The current study is not without (de)limitations. For one, given the program capacity during the implementation phase, the program was constrained to 34 students in one school. A larger number of participants from more sites could enhance the representativeness of the sample, thereby strengthening the quantitative data. Secondly, the summer iteration lasted within a week. To reveal continuous effectiveness, a longitudinal study is needed. Lastly, the current study did not include a control group for reference. This was in lieu of the sampling process and ethical consideration: students were recruited on a voluntary basis; and the intentional exclusion of students from an educational opportunity is deemed unethical.

The current study could benefit from multisite implementations across Saudi Arabia with a more diverse student body, such as those from various demographic backgrounds and academic placements. Detailed subgroup analyses – including age, socioeconomic background, prior knowledge levels, and learning styles – can uncover specific impact areas and complicate the inquiries into between-group differences in educational outcomes.

Longitudinal studies can attest to students’ long-term retention in knowledge level and overall interest. Future iterations can build up from this one-off summer workshop, extending to a formal semester-long course. Documentations of enrollment, retention, and completion rates will elaborate on the integrity of the course. Quarterly recurring follow-up assessments after the course will gauge the extent of sustainable impacts post-program.

Future studies may adopt a mixed-methods approach combining quantitative methods (e.g. metrics-based surveys and quizzes) with qualitative methods (e.g. interviews, classroom observations, and focus groups). This approach will encapsulate a more precise understanding of the program's merits via numerical statistics and anecdotal evidence. The latter complements the former in measuring intangible socioemotional attributes. Both quantitative and qualitative instruments can also be applied to teachers and school administrators, besides the participants. The triangulation of information sources can paint a more holistic picture of the program’s effectiveness and reception.

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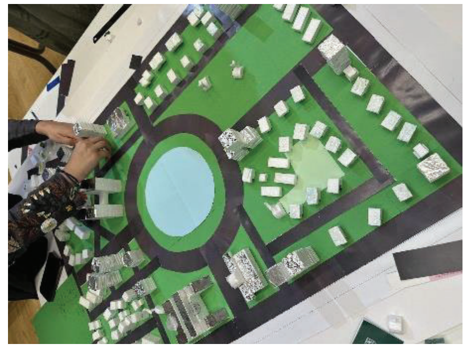
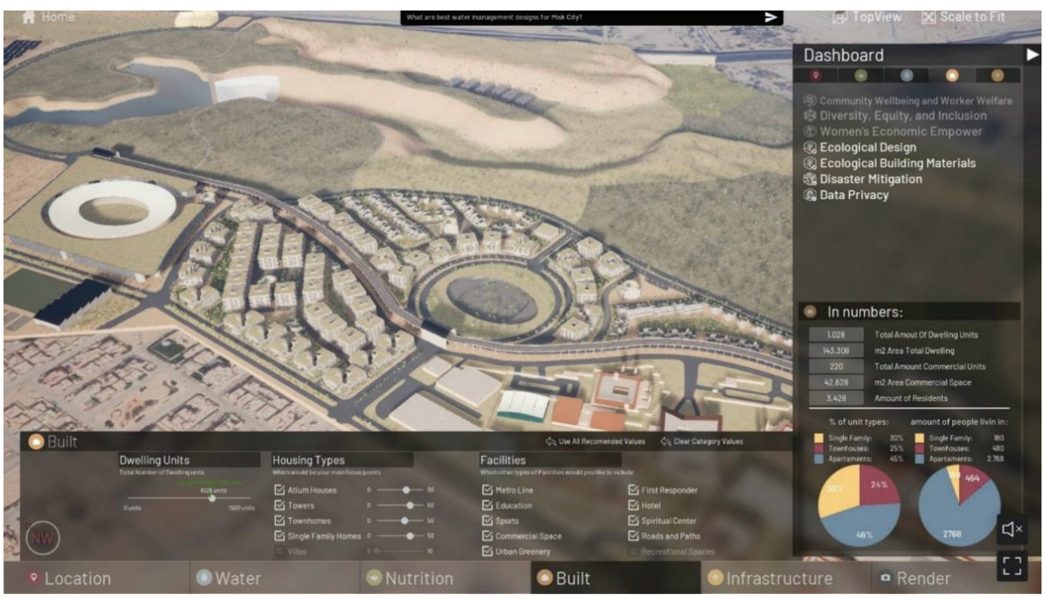
APPENDICES

A. “Design Empathy” Course Artifacts

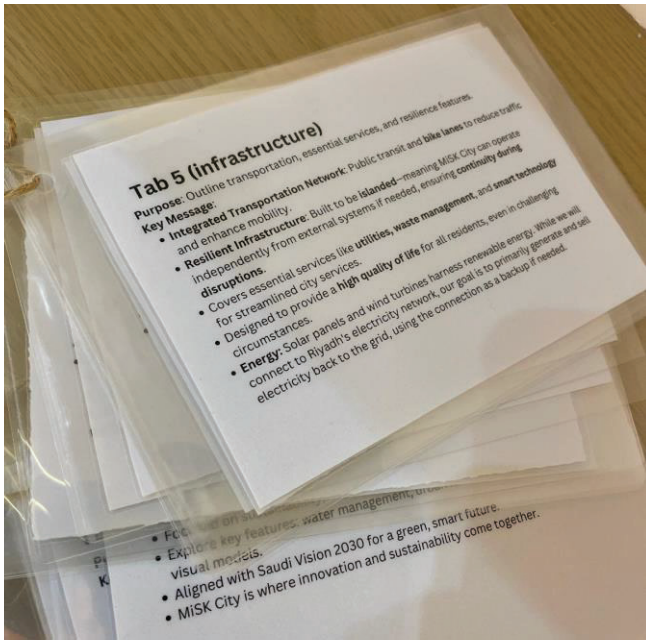
A.1. Physical Prototypes and Digital Renderings of Boys’ and Girls’ Town Plans



A.2 VillageOS™ Final Rendering



A.3. Laminated Index Cards Used for Cityscape Global Congress



B. Pre- and Post-Survey

Summer Program - Designing a Self-Sustaining Town: Survey

Demographic Information:

- Name Initials: ______
- Age: _____
- Gender (M/F): _____
- Grade Level: _____

On a scale of 1-7, with 1 being "Strongly Disagree" and 7 being "Strongly Agree," indicate the number that best describes you for the following statements.

Interest in Learning:

- I understand what sustainability is and its importance to my life.
- I would like to learn about sustainability and what it means for our future.
- I understand what Artificial Intelligence (AI) is and its importance to my life.
- I would like to learn more about how AI (artificial intelligence) can make a difference in sustainability.
- I'm interested in how technology can help make the world more sustainable.
- I know how AI can be used to make things more sustainable.
- I want to design green and sustainable communities using AI and technology.
- I think technology can help me live a more sustainable life.
- I believe AI can help me live more sustainably.

Attitude towards Sustainability:

- I often think about how technology and AI can make Riyadh a more sustainable city.
- I worry about how technology and AI might harm Riyadh's environment.

Comfort in Learning:

- I feel confident that I can learn to use AI and technology to create sustainable cities.
- I know about the different ways technology is used in Riyadh.
- I know about the different ways Riyadh uses AI.

Career Preparedness:

- Jobs that focus on AI, technology, and sustainability sound exciting.
- I would like to learn more about career opportunities regarding sustainability, AI and technology.
- I think I can positively impact my community through sustainability, technology, and AI.