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Education and society: New approaches for new challenges

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Education and society: New approaches for new challenges

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Table of contents

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Editorial: Education and society: new approaches for new challenges

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Editorial on the Research Topic
Education and society: new approaches for new challenges

The requirements of the Fourth Industrial Revolution exert intense pressure on the educational community to create what is currently called Education 4.0: a driver for the twin transformation -digital and green- of society, capable of facing challenges with flexible strategies with personalized offers for lifelong learning, the development of Global Citizenship, and an unwavering commitment to Diversity, Inclusion, and Equality. Research in Socially-Oriented Education (SOE) currently represents one of the best strategies for the sustainable solution to humanity's most pressing problems: poverty reduction, coordinated response to natural disasters provoked by climate change, and ensuring peace by providing clean water and energy to the most vulnerable communities.

This Research Topic contains an exciting selection of studies on SOE innovative initiatives, related not only to successful experiences of pedagogical approaches for Higher Education (HE) but also to proposals for upskilling and reskilling strategies to improve employability within the framework of Industry 4.0. and beyond. To what extent can education be a pivotal instrument to confront society's disruptive challenges? How can educational institutions leverage the COVID-19 response experience to reduce the social, environmental, and economic impacts of unforeseen Global Risks? These were some questions that we, as Guest Editors, asked the STEM academic community. The Research Topic was good enough to relate the concepts of education applied to urban development, the social accountability of dentistry and medical sciences education, and even the use of education as a tool for social transformation.

Social Accountability (SA) is a new paradigm in dental and medical education and must be addressed in the relationship between society, culture, and education. Interestingly, this Research Topic had two contributions related to this matter: on the one hand, Masud et al. evaluated the perception of SA among students at King Saud bin Abdulaziz University for Health Sciences (KSAU-HS), in Riyadh campus, Saudi Arabia. The study concluded that medical students exhibited profoundly different perceptions of SA, depending on whether they were in the preclinical year or the last year; on the other hand, Imani et al. delved into the SA process in the Iranian dental education system. The results indicated that the SA process has essential and practical requirements in the antecedent, mechanism, and result stages and performs well in meeting the current needs of society for dental services.

Berliner and Hecla presented a complete study on nuclear engineering and physics history, development, and particularities. The authors explain the origins of the nuclear field and the scientific and political implications, aiming to demystify and uncover the falsehoods that usually accompany teaching courses related to nuclear sciences in university programs.

Sankaran and Saad analyzed how the academic training programs for educators in Malaysia should be modified by bringing the trainers of the Faculty of Education closer to social training that can bring them closer to society.

Campos, Hidrogo et al. suggest that using virtual reality (VR) in classes can improve the cognitive process of abstract concepts, placing VR as an essential element to increase the acquisition of complex ideas in STEM careers. The study includes a comprehensive literature review on cutting-edge innovations in educational technology and provides numerous details of the methodology, instruments used, and data analysis. The detailed description of the methods and the results make this study a valuable source for replicating the experiment.

Ponce-Lopez et al. reflect that education is society's primary driver of innovation. The authors highlight the importance of sustainable cities having spaces designated as Innovation Districts since jobs are created in these spaces, and they promote new markets specialized in products and services with high added value. In this way, cities in rapidly industrializing developing countries can maximize their chances of success by fostering explicit collaboration between industry and educational institutions.

Ventura Roque-Hernández stated the importance of inter- and trans-disciplinarity in the promotion of a culture of peace, and they presented some examples of initiatives that aimed at cultivating a culture of peace from different areas of knowledge, education, and research, regardless of discipline.

Márquez Cañizares et al. studied the importance of the idea-generation process in HE, specifically in engineering programs. The authors explain the application of the Ideation, Categorization, Regrouping, Ideation (ICRI) method and the importance of its implementation during the years 2020 and 2021 when COVID-19 forced HE students to take all courses virtually. The ICRI method allowed students to gather and develop creative proposals in virtual contexts to solve problems systematically. The findings showed a positive evaluation by the students, which is why it is considered that the ICRI method could be implemented in other virtual collaboration contexts, for example, in international research teams.

Hadi et al. proposed to study the attitudes related to the spirituality of students and their psychological and cognitive inclinations. The findings showed the importance of spirituality as a driver of the physical and mental wellbeing of the students. One of the study's main findings was that college students who actively participated in spiritual rituals tended to reinforce habits and attitudes related to entrepreneurship skills. The results of this study may be inspirational for business education programs and business incubators that the Indonesian government proposes to implement in the future.

Ramaditya et al. conducted a detailed study of the performance indicators of various private HE institutions in Southeast Asia. The authors analyzed why universities perform poorly in the QS World University Ranking despite government initiatives and funding programs. The study's results indicate that the talent shortage originates from poor talent management. This article offers guidelines for improvements in organizational transformation to maximize the performance of graduates to create a competitive advantage.

There were also some reflections on the impact of COVID-19 on education and society: Moser-Mercer et al. developed a method for evaluating the EdTech platform, taking into account the authors' experience during the COVID-19 pandemic and explaining how this educational tool was crucial for remote teaching during the closure of schools and universities. The authors describe the humanitarian actions in Jordan and the methodology used—Participatory Action Research (PAR)—to create community educational experiences among young refugees; Dickson et al. mainly analyzed how it affected the work of teachers and the development of learning processes in children and adolescents. The authors examined the impact on the professional performance of those academics who had to exercise parenting responsibilities alongside their academic role, the difficult challenge of working from home without a dedicated academic career, and how this affected their performance in research processes and dissemination of results in scientific journals. Campos, Daruich et al. analyzed a Student Teaching Assessment (SET) survey conducted at their institution during and after the COVID-19 pandemic. The results showed that the COVID-19 pandemic didn't affect the assessment scores, which allowed them to identify the most assertive strategies most accepted by the students.

The improvement in the relationships between educational institutions and society represents an imperative of the 21st century: universal and globalized education that helps citizens solve the world's problems responsibly and sustainably. The potential link between education and society shows that the challenges for the future of educational programs have to be designed for a social transformation that improves the understanding of nature to transform it. The international experts who shared their studies and opinions on this Research Topic showed us that Higher Education can potentially become an agent of change for a more diverse, equitable, and egalitarian Society.

Author contributions

PC: Conceptualization, Funding acquisition, Supervision, Writing—original draft. JM-H: Conceptualization, Supervision, Writing—review and editing. GZ: Conceptualization, Supervision, Writing—review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Social Accountability in Medical Education: Students' Perspective

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Background: Globally, there is a rising interest in the concept of social accountability (SA). The literature evaluating SA of medical schools is limited; however, some international studies have revealed a lack of understanding of SA by medical students. This study evaluated the perception of SA among medical students at a governmental university in Saudi Arabia.

Method: A cross-sectional study with 336 currently enrolled medical students was conducted from September 2020 to May 2021. The data were collected using an electronic survey comprised of the THEnet questionnaire that included 12 items to assess the perception of SA and some demographic variables. The total score was categorized into four groups and compared with the demographic profile of students.

Results: Out of the 336 participants, the mean age was 21.26 ± 0.5 years, with most students in the 19–21 age group (n = 154, 46%), and 189 (56.3%) were males. In addition, preclinical and clinical students had similar representation: 170 (51%) and 166 (49%), respectively. Most participants (173, 52%) scored in the 18–36 range, reflecting good perceived SA. The demographic profile of students (i.e., age, GPA, and year of study) was significantly associated with perceived SA (p = 0.003, 0.002, and < 0.001, respectively).

Conclusion: The study concludes that most medical students had a good level of perceived SA about their institution. The preclinical year students exhibited a better perception of SA. The final-year students were more critical about the SA of the institution compared to other students.

Keywords: medical students, medical schools, social accountability, social responsibility, medical education

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INTRODUCTION

The concept of social accountability (SA) has attained a growing interest worldwide (Emadzadeh et al., 2016). SA includes citizen-led efforts to hold public officials, lawmakers, and service providers accountable for their acts and performance in providing services, enhancing people's welfare, and preserving their rights (Beck et al., 2007). In 1995, the World Health Organization (WHO) adapted this concept in medical schools (Boelen et al., 1995). The WHO defines SA in the context of medical education as the responsibility to focus education, research, and service activities on tackling

the most pressing health issues in the communities, regions, and countries they are intended to serve (Boelen et al., 1995). As SA is considered the foundation of both medical practice and medical schools, four values were introduced by WHO, namely, quality, equity, relevance, and cost-effectiveness, to evaluate the progress of medical schools in addressing SA (Boelen et al., 1995). This implies that SA should emphasize meeting professional standards and satisfying community expectations through providing equal opportunities for healthcare to everyone, addressing locally relevant problems, and ensuring the cost-effectiveness of healthcare service delivery.

The main challenge for medical schools in the twenty-first century resides in the responsibility for achieving community-based medical education that is relevant to the community health needs to produce competent graduates who can provide optimal healthcare status. With the global shift toward anticipating the individual and societal health needs and tailoring curriculum to best meet priority health concerns of a nation, SA was integrated into some medical schools' educational programs (Boelen et al., 1995; GCSAMS, 2010). Canadian medical schools were the earliest schools that officially adapted the concept of SA to ensure a highly valued Canadian healthcare system (Social Accountability | The Association of Faculties of Medicine of Canada [AFMC], 2022). Furthermore, other countries like Sudan, Saudi Arabia, and Egypt have also taken initiatives toward achieving community-based, socially accountable medical education. A study that assessed the SA of the Faculty of Medicine at the University of Gezira (FMUG), Sudan, concluded their educational program as socially responsible and socially accountable only in certain aspects (Ahmed et al., 2020). Hosny et al. (2015) suggested using the conceptualization production usability (CPU) model to assess SA in medical institutions. The study emphasized compliance with parameters of CPU domains for an institution to be recognized as a proactive, socially accountable medical school (Hosny et al., 2015).

Furthermore, a recent study conducted in Saudi Arabia used the SA grid issued by the WHO as a basis for assessing SA. The study concluded that the educational aspect had the highest compliance for SA. Nevertheless, there is a need for more studies to explore how to achieve accountable social status (Alrebish et al., 2020). Some locally conducted studies in Saudi Arabia have focused on developing an integrated curriculum that is more community-orientated for a new medical college. It was noted that the traditional curriculum was insufficient to graduate doctors, consequently providing lower quality services to their community (El-Naggar et al., 2017). They started formulating the new curriculum by interviewing experts and doing a literature survey/search to gather the needed information (El-Naggar et al., 2017). The study ended up formulating a program that consists of three phases "pre-med (year 1), organ/system, and clinical clerkship to be followed by a year of internship." The Jazan Faculty of Medicine has adopted this program to improve the outcomes of medical staff (El-Naggar et al., 2017). Both studies have locally provided evidence that some medical schools in Saudi Arabia are socially accountable, although the extent is unknown, and more studies are needed to evaluate SA in the other medical schools.

Although the importance of SA is widely agreed upon, the concept of SA is less familiar among the medical students who are the end product of a medical college. A study conducted at Makerere College of Health Sciences exploring the perceptions of senior medical educators and students discovered that SA was an unfamiliar concept to many of the respondents. Many students are not even aware of this term (Galukande et al., 2012). Another international study conducted in the United Kingdom to assess the concept of SA in a medical school illustrated that students could not express a well-understanding of SA meaning. However, they admitted that the curricula revealed a few core principles around SA (McCrea and Murdoch-Eaton, 2014). A study by Social Accountability in Health Professional Education (SAHPE) showed that the associated supervisors in the hospital rated SAHPE medical workforce higher overall than traditional medical school graduates in socially accountable competencies and the overall performance and clinical skills (Woolley et al., 2019).

The perception of SA among students varies among different institutions across the world. Due to the limited reports on SA in Saudi Arabia, the study aimed to assess the perceived SA of medical students currently studying at the governmental institution following problem-based learning. Also, we wanted to assess whether the concept of SA was clearer among students across different years in medical school.

MATERIALS AND METHODS

Study Design and Setting

A cross-sectional questionnaire-based survey was conducted in Riyadh campus between September 2020 and May 2021 at King Saud bin Abdulaziz University for Health Sciences (KSAU-HS). KSAU-HS is a governmental university first established in Riyadh in 2005, making it the first specialized university in health sciences in Saudi Arabia and the whole region (College Of Medicine Riyadh-Home, 2022). Subsequently, other campuses were established later in Jeddah and Al-Ahsa. It has 14 colleges in various health-related specialties on all these three campuses. The College of Medicine (COM) only exists in Riyadh and Jeddah, graduating almost 500 doctors every year.

The KSAU-HS mission is to deliver high-quality medical education, medical research, and community services that enhance society's health. To achieve that, KSAU-HS adapts a problem-based, community-based, student-centered, and outcome-oriented program for the specialty of medicine and surgery in collaboration with Sydney University, Australia (College Of Medicine Riyadh-Home, 2022). Given the sizeable global shift toward competency-based medical education and its dominance over traditional learning approaches, the spectrum of educational interventions, including learning resources allocation, educational methods, teaching faculty, and Students' performance assessment, should be shaped to best meet priority healthy needs (GCSAMS, 2010). Therefore, the Saudi Medical Education Directives Framework (SaudiMEDs framework)

competencies were integrated into the KSAU-HS curriculum (Tekian and Al Ahwal, 2015; Ten Cate, 2017). It was adopted to ensure the implementation of six key competencies, namely, scientific method in practice, patient-centered care, community-based practice, professionalism, research, and scholarship. This would ensure a more efficiently delivered educational infrastructure and facilitate the graduation of competent healthcare providers capable of providing optimal healthcare services (Tekian and Al Ahwal, 2015).

Study Participants

The target population was all medical students studying preclinical and clinical phases from 2020 to 2021 at the Riyadh campus. Including both male and female campuses, both stream I, students who recently graduated from high school, and stream II, students who already have a bachelor's degree in science, applied medical science or pharmacy, and currently studying medicine as a second major, from third to the sixth year. However, we excluded pre-medical students since they were new to the college during the data collection. The final sample was 336 students currently enrolled at the college of medicine. The non-probability quota sampling was used to include proper representation across different years of students and gender and avoid under or overpresenting the student groups. The approximate number of male and female students in each batch was 300 and 150, respectively. Therefore, the sample was divided into 50 and 34 participants from each male and female batch.

TABLE 1 | Profile of participants (n = 336).

Variable	Category	N	Percentage
Age categories	19–21 years	154	46%
	22–25	152	45%
	26 and above	30	9%
Gender	Female	147	44%
	Male	189	56%
Year of study	Third year	91	27%
	Fourth year	79	24%
	Fifth year	86	26%
	Final year	80	24%
Phase of study	Pre-clinical	170	51%
	Clinical	166	49%
Entry level	School entrant	293	87%
	Graduate entrant	43	13%
Education level	High school	293	87%
	Bachelor	43	13%
GPA	3–3.5	5	2%
	3.6–4	37	11%
	4.1–4.5	109	32%
	>4.6	185	55%
Teaching faculty	Non-Saudi faculty	96	29%
	Saudi faculty	240	71%
Parents background	No healthcare background	265	79%
	Have healthcare background	71	21%
Sibling background	No healthcare background	165	49%
	Have healthcare background	171	51%

Data Collection Tool and Process

A validated questionnaire created by a collaboration between the International Federation of Medical Students Association (IFMSA) and the Training for Health Equity Network (THEnet) (Dijk et al., 2017) was used and distributed among students as an electronic survey available on Google Docs online platform. The link of the survey was distributed with the help of focal person who were the batch leaders from preclinical and clinical years. No prior pretesting was done before the data collection, and the questionnaire was adopted in its original form. The survey was accessible only to the target population. Due to unforeseen COVID-19 restrictions, the teaching model was shifted to online. Therefore, the mode of data collection was changed from self-administered hardcopy to online survey. Students had the right not to participate; filling out the questionnaire and submitting it was considered consent for participation (see **Supplementary Appendix 1**).

The main sections of the questionnaire were adapted from the original created by IFMSA; therefore, no prior pilot testing was done before formal data collection (Dijk et al., 2017). The questionnaire consisted of three sections. The first part displayed an introductory paragraph of the study's aims and participation request along with consent form. The second section included questions related to demographic profile, including current year of study, clinical phase, stream, educational level, whether any family member belongs to healthcare background, and campus. The third section included the IFMSA and THEnet 12-item questionnaire to evaluate the medical colleges' SA based on Students' perceptions. The items were assessed on a four-point Likert scale (no = 0, somewhat = 1, good = 2, excellent = 3), with the lowest and highest score of 0–36 for the 12 items, respectively.

Statistical Analysis

A Microsoft Excel sheet was initially used for data entry and coding. The data were checked for correctness and missing information. After data cleaning, it was transferred for statistical analysis to Statistical Package for the Social Sciences software version 24. The overall Cronbach's alpha for the 12 items on SA was 0.80 showing good internal reliability of the questionnaire in our sample. The descriptive statistics were reported for all the variables, and the means standard deviations (SDs) were reported for 12 items and other numerical variables, while the categorical data were presented as percentages. The total score for the 12 items on SA was computed first and presented as mean $\pm$ SD for the individual item. The total score was later categorized into four groups, namely, weak foundation in SA (score: 0–8), some SA (score: 9–17), look for areas of improvement (score: 18–26), and strong foundation in SA (score: 27–36). The percentages for each of the SA categories were also presented. To assess the association of SA categories with the profile of the students, chi-square and Fisher's exact tests were applied as applicable. Additionally, a new variable was computed using the scores of SA items, and the cutoff score for acceptable SA was $\geq$ 18, and low SA was $\leq$ 17. Statistical significance was set at p-values < 0.05 for all the tests applied.

Ethical approval was given by the Institutional Review Board of King Abdullah International Medical Research Center, with ref No. IRBC/1413/20. All collected data were coded and kept under lock and key. Confidentiality and anonymity were always maintained during all the stages of the research.

RESULTS

Demographic Characteristics

A total of 336 students with a mean age of 21.26 ± 0.5 years completed the survey distributed among medical students currently studying in KSAU-HS. Students aged < 25 years comprised the majority, with the 19–21-year-olds accounting for 46% (n = 154) of the students. Male participants represented 189 (56.3%) of the sample, with fourth-year students lowest in number 79 (24%). Similar percentages of medical students in their preclinical and clinical years were included in the study, 170 (51%) and 166 (49%), respectively. However, most enrolled students were school entrants, while only 43 (13%) were graduate entrants. On a GPA score of 5, the self-reported GPA for most students was >4.6. Furthermore, most students stated that they were taught by Saudi teaching faculty (**Table 1**).

Descriptive Summary of 12 Items Determining Social Accountability

Out of the 12 items determining the perceived SA, items 5 and 12 had the highest mean scores. Item 5, which evaluated the presence of the populations intended to be served by medical students at places where students are practicing medicine, had a mean of 2.08 ± 0.88. Furthermore, item 12 assessed the school's positive impact on the community and had a mean of 2.07 ± 0.88. In addition, regarding the community-based research provided by the school, the mean score of item 10 was 1.9 ± 0.99, which was reasonable based on the scoring scale used in the study. Item 11, in contrast, assessed to what extent the school encouraged the students to undertake generalist specialties and had the least mean score of 1.18 ± 1.01. Items 6, 3, and 4 also had lower mean scores than the other items. Item 6 assessed if the community-based learning was one of the school's learning objectives and had a mean score of 1.3 ± 1.04. Item 3 assessed whether the school's curriculum considers other cultures and other social circumstances in a medical context, item 4, and had a mean of 1.39 ± 0.89. Items 1, 2, 7, 8, and 9 had an average assessment score between 1.6 ± 1.0 and 1.8 ± 0.87. Although the community's needs are addressed by the school's curriculum or not, which was evaluated by item 2, had a mean score of 1.87 ± 0.87. Furthermore, regarding the similarities of sociodemographic characteristics between the reference population and medical students, reference population, and teaching faculty, items 7 and 8 had mean scores of 1.71 ± 0.82 and 1.64 ± 0.88, respectively. Finally, item 9, which was related to the learning experience at the college allowing the students to play an active role in serving their community, had a mean score of 1.62 ± 1.00 (**Table 2**).

Social Accountability Status Based on Categorized Scores

Out of the 336 participants, 48 (14%) students perceived the SA of COM as very good and scored between 27 and 36, implying that the college has a strong foundation in SA and advocate for continued growth and leadership in SA. Whereas most of the students 173 (52%) scored between 18 and 26 and perceived that the school is doing well, there are weak areas and ways to improve SA. Furthermore, 98 (29%) students scored between 9 and 17 and perceived that the college has some SA strategies, and there is a need to build on these existing strategies. The rest of the students [17 (5%)] scored between 0 and 8, implying that the school has no SA and that there is a need to begin building up SA (**Figure 1**).

Association of Participants' Profiles With Social Accountability

The demographic variables, age, year, phase of the study, and GPA were significantly associated with medical Students' perception of SA. Most students scored highest in the 18–26 range, reflecting a good SA level. Within this scoring range, younger students were more likely to have better perception as the 19–21-year-old group had the highest score of 95 (62%), followed by the 22–25-year-old group (70, 46%) (χ^2 = 19.6, p = 0.003). The preclinical year students (103, 61%), particularly fourth-year students [52 (66%)], were also significantly reporting the perceived SA within this range compared to clinical year students (χ^2 = 40.4, p = 0.002) (χ^2 = 49.8, p < 0.001), respectively. Moreover, 59 (54%) students who reported a GPA between 4.1 and 4.5 scored between 18 and 26 compared to other groups (χ^2 = 22.1, p-value = 0.002). Other variables, including gender, education level, teaching faculty, and the presence of parents or sibling healthcare background, had no significant association with the perceived SA of medical students (**Table 3**).

Each of the 12-item assessing SA was checked with the year of study to measure associations. It was found that 9 out of 12 items were significantly associated with the year of study. Item 5 had the highest reported good SA among year 5- and final-year students: 81 (94%) and 63 (79%) (χ^2 = 18.9, p < 0.001). Moreover, item 9 revealed that third-year students scored the highest in the category of good SA [58 (64%)], whereas final-year students scored the lowest [34 (43%)] (χ^2 = 9.8, p = 0.02). For item 10, students in their final year reported the lowest perceived SA (40, 50%), while the other years reported better perception of their school SA with a similar response rate (χ^2 = 15.8, p < 0.001). Finally, item 12 showed that both third- and fourth-year students scored the highest in the good perception of the school SA [80 (88%) and 68 (86%)], respectively (χ^2 = 37.4, p < 0.001) (**Table 4**).

DISCUSSION

The research was conducted to understand the SA from the Students' perspective. Additionally, the association of gender and year of the study with the perceived SA was considered during the research. Results showed that the KSAU-HS medical students

TABLE 2 | Descriptive summary of the items determining social accountability (n = 336).

Item no	Items	No N (%)	Sometime N (%)	Good N (%)	Excellent N (%)	Mean score Mean ± SD
1	Does your institution have a clear social mission (statement) around the communities that they serve?	31 (9%)	98 (29%)	134 (40%)	73 (22%)	1.74 ± 0.90
2	Does your curriculum reflect the needs of the population you serve?	20 (6%)	91 (27%)	139 (41%)	86 (26%)	1.87 ± 0.87
3	Does your school have community partners and stakeholders who shape your school?	63 (19%)	125 (37%)	116 (35%)	32 (10%)	1.35 ± 0.89
4	Do you learn about other cultures and other social circumstances in medical context in your curriculum?	58 (17%)	123 (37%)	121 (63%)	34 (10%)	1.39 ± 0.89
5	Do the places/locations you learn at in practice include the presence of the populations that you will serve?	24 (7%)	46 (14%)	144 (43%)	122 (36%)	2.08 ± 0.88
6	Are you required to do community-based learning (opposed to only elective opportunities?	92 (27%)	102 (30%)	90 (27%)	52 (16%)	1.3 ± 1.04
7	Does your class reflect the socio—demographic characteristics of your reference population?	17 (5%)	124 (37%)	134 (40%)	61 (18%)	1.71 ± 0.82
8	Do your teachers reflect the socio—demographic characteristics of your reference population?	30 (9%)	121 (36%)	125 (37%)	60 (18%)	1.64 ± 0.88
9	Does your learning experience also provide an active service to your community?	50 (15%)	105 (31%)	102 (30%)	79 (24%)	1.62 ± 1
10	Does your school have community-based research?	37 (11%)	71 (21%)	117 (35%)	111 (33%)	1.9 ± 0.9
11	Does your school encourage you to undertake generalist specialties (e.g., family medicine, general practice)?	105 (31%)	107 (32%)	83 (25%)	41 (12%)	1.18 ± 1
12	Does your school have a positive impact on the community?	17 (5%)	67 (20%)	127 (38%)	125 (37%)	2.07 ± 0.8

All percentages have been rounded to the nearest tenth; the total might not add up to 100%.

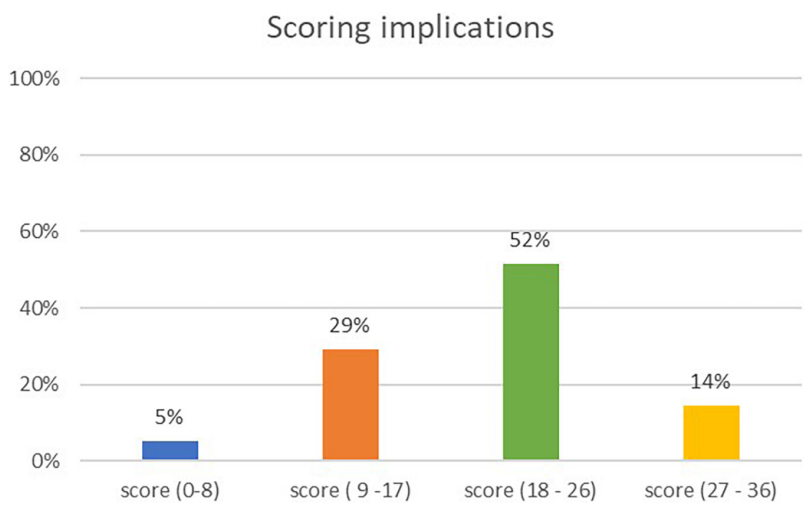

FIGURE 1 | Social accountability status based on the categorized scores. (0–8) Start a conversation with your classmates and school to begin to build SA at your school (9–17), your school has some SA strategies, look for ways to advocate to build on these existing strategies (18–26), your school is doing well, look for areas of weakness and ways to advocate to improve SA (27–36), your school has a strong foundation in SA, advocate for continued growth and leadership in SA.

perceived their institution as a good, socially accountable institution. No statistically significant differences were noted among male and female students who study at two separate campuses within the same institution. The variation across different years of study with the acceptability of the institution's SA was also noted.

In Saudi Arabia, almost all medical colleges have segregated male and female campuses. The teaching staff at male campuses is predominantly male and *vice versa* at the female campus. Yet, in our study, no such differences across gender were noted with the perceived SA. The role of the teaching staff is crucial in developing SA among students. The presence of socially responsible teaching faculty has a significant impact on medical programs progressing toward being fully socially accountable with community-oriented health services. This also ensures higher deployment and consistent retention of healthcare workers in rural or remote areas (Elsanousi et al., 2016). Similarly, the role of gender is also considered an important variable affecting the perception of SA (Alghamdi, 2014).

TABLE 3 | Association of the profile of participants with SA of the institution (n = 336).

Variables	Categories	SA categories				
		Score (0–8)N (%)	Score (9–17)N (%)	Score (18–26) N (%)	Score (27–36)N (%)	*p*-value
Age categories	19–21 years	4 (3%)	34 (22%)	95 (62%)	21 (14%)	0.003*
	22–25	9 (6%)	52 (34%)	70 (46%)	21 (14%)	
	26 and above	4 (13%)	12 (40%)	8 (27%)	6 (20%)	
Gender	Female	8 (5%)	43 (29%)	75 (51%)	21 (14%)	0.99
	Male	9 (5%)	55 (29%)	98 (52%)	27 (14%)	
Year of study	Third year	4 (4%)	20 (22%)	51 (56%)	16 (18%)	<0.001*
	Fourth year	0 (0%)	20 (25%)	52 (66%)	7 (9%)	
	Fifth year	0 (0%)	24 (28%)	46 (54%)	16 (19%)	
	Final year	13 (16%)	34 (43%)	24 (30%)	9 (11%)	
Phase of study	Pre-clinical	4 (2%)	40 (24%)	103 (61%)	23 (14%)	0.002*
	Clinical	13 (8%)	58 (35%)	70 (42%)	25 (15%)	
Entry level	School entrant	13 (4%)	82 (28%)	157 (54%)	41 (14%)	0.17
	Graduate entrant	4 (9%)	16 (37%)	16 (37%)	7 (16%)	
Education level	High school	13 (4%)	82 (28%)	157 (54%)	41 (14%)	0.17
	Bachelor	4 (9%)	16 (37%)	16 (37%)	7 (16%)	
GPA	3–4	8 (19%)	11 (26%)	19 (45%)	4 (10%)	0.002*
	4.1–4.5	5 (5%)	31 (28%)	59 (54%)	14 (13%)	
	>4.6	4 (2%)	56 (30%)	95 (51%)	30 (16%)	
Teaching faculty	Non-Saudi	4 (4%)	23 (24%)	55 (57%)	14 (15%)	0.50
	Saudi	13 (5%)	75 (31%)	118 (49%)	34 (14%)	
Parents background	No healthcare background	16 (6%)	79 (30%)	132 (50%)	38 (14%)	0.35
	Have healthcare background	1 (1%)	19 (27%)	41 (58%)	10 (14%)	
Sibling background	No healthcare background	9 (6%)	48 (29%)	87 (53%)	21 (13%)	0.86
	Have healthcare background	8 (5%)	50 (29%)	86 (50%)	27 (16%)	

**Chi-square test/Fisher's exact test significant at < 0.05. All percentages have been rounded to the nearest tenth; the total might not add up to 100%.*

One of the notable findings of the study was the highest mean score associated with the item evaluating the location of the medical practice and the future posting preference of medical students. The result can be associated with the core of KSAU-HS mission, which is to graduate qualified physicians for community services and promote the concept of SA (Mission Vision and Strategic Goals, 2022). COM offers volunteering opportunities at multiple levels to meet this goal, such as volunteering in the Saudi red crescent authority, the Hajj volunteer program, and a mandatory summer elective course. Hence, allowing the students to be engaged and familiarized with the intended population and well-equipped for serving the community. Dharamsi et al. (2010) also support the effect of community placements in cultivating a sense of SA among students. A recent study conducted in Morocco showed similar results and reported that students who do social services perceived a better perception of SA (Sebbani et al., 2021). It is believed that engaging students in community-based learning sites representing the actual population ensure the acquisition of well-defined competencies for more efficient health service delivery and encourage medical students to feel their school impact on the community and, thereby, improve their perceived SA (Boelen, 2016; Clithero et al., 2017; Roughead et al., 2017; Woolley et al., 2019).

An interesting finding of the study was that students perceived the school did not promote general specialties, such as family medicine and general practice (GP). The finding was supported by another study conducted at KSAU-HS in which two-thirds of the medical students refrained from choosing a general specialty as a future career option (Alshammari et al., 2019). Unlike our study population, medical students from universities in the United Kingdom were more inclined toward opting for GP as a future specialty for practices (Alshammari et al., 2019; Henderson et al., 2020). The National Health System in the United Kingdom has integrated GP within the community at advanced levels, leading to higher earning potential and relatively easily manageable expertise compared to doctors working in other specialties (Henderson et al., 2020). The Saudi Commission for Health Specialties has urged medical colleges to align the curriculum with the newly implemented Saudi MED framework, focusing on the priority health needs of the Saudi population and society (Tekian and Al Ahwal, 2015). Therefore, similar strategic reforms to the United Kingdom may be instilled in Saudi medical colleges and healthcare setup to strengthen SA. Having said that, further research is required to understand the impact of other exogenous social factors such as lifestyle and luxuries on perceived SA among students. As the primary health setups are predominantly in the country's rural areas, choosing a GP position in rural areas could be a hard decision for many young practitioners (Henderson et al., 2020). Individual motivation and commitment to service is considered as one of the factors that can increase SA among students (Mohammadi et al., 2020).

TABLE 4 | Association of the 12 items determining SA with the year of study.

Items	SA category	Third year	Fourth year	Fifth year	Final year	*p*-value
		N (%)	N (%)	N (%)	N (%)	
1. Does your institution have a clear social mission (statement) around the communities that they serve?	Low	35 (39%)	21 (27%)	28 (33%)	45 (56%)	<0.001*
	Acceptable	56 (62%)	58 (73%)	58 (67%)	35 (44%)	
2. Does your curriculum reflect the needs of the population you serve?	Low	24 (26%)	23 (29%)	23 (27%)	41 (51%)	<0.001*
	Acceptable	67 (74%)	56 (71%)	63 (73%)	39 (49%)	
3. Does your school have community partners and stakeholders who shape your school?	Low	43 (47%)	35 (44%)	54 (63%)	56 (70%)	0.002*
	Acceptable	48 (53%)	44 (56%)	32 (37%)	24 (30%)	
4. Do you learn about other cultures and other social circumstances in medical context in your curriculum?	Low	47 (52%)	45 (57%)	49 (57%)	40 (50%)	0.72
	Acceptable	44 (48%)	34 (43%)	37 (43%)	40 (50%)	
5. Do the places/locations you learn at in practice include the presence of the populations that you will serve?	Low	29 (32%)	19 (24%)	5 (6%)	17 (21%)	<0.001*
	Acceptable	62 (68%)	60 (76%)	81 (94%)	63 (79%)	
6. Are you required to do community-based learning (opposed to only elective opportunities?	Low	43 (47%)	54 (68%)	40 (47%)	57 (71%)	<0.001*
	Acceptable	48 (53%)	25 (32%)	46 (54%)	23 (29%)	
7. Does your class reflect the socio-demographic characteristics of your reference population?	Low	43 (47%)	31 (39%)	28 (33%)	39 (49%)	0.11
	Acceptable	48 (53%)	48 (61%)	58 (67%)	41 (51%)	
8. Do your teachers reflect the socio-demographic characteristics of your reference population?	Low	48 (53%)	27 (34%)	30 (35%)	46 (58%)	0.002*
	Acceptable	43 (47%)	52 (66%)	56 (65%)	34 (43%)	
9. Does your learning experience also provide an active service to your community?	Low	33 (36%)	41 (52%)	35 (41%)	46 (58%)	0.020*
	Acceptable	58 (64%)	38 (48%)	51 (59%)	34 (43%)	
10. Does your school have community-based research?	Low	22 (24%)	21 (27%)	25 (29%)	40 (50%)	<0.001*
	Acceptable	69 (76%)	58 (73%)	61 (71%)	40 (50%)	
11. Does your school encourage you to undertake generalist specialties (e.g., family medicine, general practice)?	Low	56 (62%)	57 (72%)	50 (58%)	49 (61%)	0.27
	Acceptable	35 (39%)	22 (28%)	36 (42%)	31 (39%)	
12. Does your school have a positive impact on the community?	Low	11 (12%)	11 (14%)	23 (27%)	39 (49%)	<0.001*
	Acceptable	80 (88%)	68 (86%)	63 (73%)	41 (51%)	

**Test significant at < 0.05. All percentages have been rounded to the nearest tenth; the total might not add up to 100%.*

For the overall level of SA among our study, most participants scored within the range of 18–26 across all the survey questionnaires, indicating signs of weaknesses, despite the school's improved efforts. The junior students revealed better and positive perceptions about school's SA compared to final-year students. Similar findings were reported by a study at Qassim University. The higher rates of burnout syndrome and depression were associated with Students' progression through the medical school, impacting the clinical phased Students' perception of their school's SA (Alkhamees et al., 2020). Besides a higher prevalence of burnout syndrome in senior students, depression can also affect their perception of the survey items (Pacheco et al., 2017).

For most items, the academic year of study was significantly associated with the level of Students' perceptions of their school's SA. An acceptable reason behind the senior Students' high scores in the fifth item, which evaluates the presence of the targeted population to be served at Students' practice sites, is that students start their hospital rotations during fourth and final academic years. In clinical years, learning becomes more patient-oriented, unlike third and fourth years, where most of the learning takes place in the college. Item 9, which assesses whether the learning experience is providing active service to the community, is evaluated through the availability of opportunities for students to create health promotion projects supported by the university faculty that target the community. One example is the "*Yakfeek Sharraha*" campaign conducted in 2019 by students with support from the university. This project aimed to raise community awareness about motor vehicle accidents and the role of different surgical specialties in saving lives (College Of Medicine Riyadh-Home, 2022). Another awareness campaign was educating the public and correcting the common misconceptions on what to do in emergencies. Thus, community-centered initiatives and the school's contribution to the community it serves may play a pivotal role in promoting SA amongst medical students (Boelen, 2016; Boelen et al., 2016).

Item 10 of the SA questionnaire focused on evaluating the role of research in the university, whereas item 12 primarily evaluated university's impact and engagement with the community. On the research front, medical research course is mandatory during the third and fourth academic years at COM. This ensures that students take initiative to conduct research in different priority areas set by the institution on yearly basis. As the medical research course is conducted during the preclinical years, this explains the significantly lower SA acceptance among the fourth- and final-year students in the research domain. Furthermore, the community engagement of the university was assessed through two parts, namely, first, the encouragement of scientific research through the number of publications and Students' participation in conferences; and second, supporting students to adapt and engage in various community-based activities results in developing a positive landscape of the university among people. At KSAU-HS, the university Student's club encourages

students to engage in various activities to improve their skills and abilities, promote their social responsibility, and provide the maximum benefit to the community. Each college in the university has a student club, including a social team responsible for educating and raising the community's health awareness through campaigns. Prioritizing the research based on the population's needs is one of the ways that can successfully improve SA of an institution (Strasser et al., 2013; Ahmed et al., 2020).

Despite the comprehensiveness of this research for capturing the perceptions around SA in medical universities in Saudi Arabia, there were certain limitations to the study approach. The mode of data collection was altered from a face-to-face self-administered approach to an Internet-based survey approach, which may have affected the study results. Additionally, the reporting bias may have affected the overall perception of the medical students. Single-institution-based survey can also limit the generalizability of the results to other medical colleges. Notwithstanding the limitations, efforts were made during the design phase to avoid the over- or underrepresentation of the participants through quota sampling, which is one of the strengths of this study. Our study participants represent the views of students studying in a public university. The private medical universities in Saudi Arabia are only a few; therefore, the results of the study can be generalized to most of the public medical universities.

Going forward, SA is a complex phenomenon and has different aspects that need more advanced understanding. One strategy for all the studying batches of students might not be applicable in medical colleges since each year has its own specific needs. Future research is required to further explore institutional-based evaluation models to identify well-defined indicators for improving SA among students. Additionally, a qualitative research study can also provide meaningful insight into understanding SA from a Student's perspective. This may help identify the areas for improvement and reinforce the institutional strategy in meeting ideal SA principles.

To summarize, there is an urgent need to integrate SA approaches into healthcare delivery by medical schools and aid the establishment of a more relevant, equitable, high-quality, and cost-effective healthcare system at Saudi Arabia's medical schools. Additionally, with the changing global dynamics of health as witnessed in the recent pandemic, medical schools must also be ready to adapt to the rapidly changing demand of their community (Minter et al., 2021; Papapanou et al., 2021). That might require more frequent changes to the existing modes of improving SA than expected as the students move along their growth trajectory.

CONCLUSION

The study concludes that one-third of the medical students had an overall low perceived SA. It was noted that the acceptability of SA varied across different years based on the individual items among preclinical and clinical year students. Therefore, the institution needs to focus its interventions based on the needs of preclinical and clinical year students accordingly. As final-year students were more critical, it is recommended that they require more attention to improve the acceptability of SA. The university should focus specifically on the needs of the graduating final-year students to meet the aim of socially accountable institutions meeting the need of their nation. It is recommended that the graduating students be provided sufficient exposure and spend an adequate length of time in community-based placements during clinical rotations. This can be an opportunity to enhance the overall perceived level of SA of medical institutions among the community and medical students.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to institutional policies of maintaining the confidentiality of the student data.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the King Abdullah International Medical Research Centre, Riyadh, Saudi Arabia. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

NM contributed to conceptualization, proposal development, formal analysis and result interpretation, manuscript revision, and finalization for submission to the journal and general supervision as a senior member of the team. SA, OA, DAg, RA, and DAb contributed equally to proposal development and literature review, data acquisition, data cleaning and management, and manuscript writing and editing as junior research team members. SA-N contributed to study designing, data checking, result interpretation, manuscript editing, and technical revision and project management as a senior member. All authors have read and approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.868245/full#supplementary-material

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Building a Culture of Peace in Everyday Life With Inter- and Transdisciplinary Perspectives

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In this article, peace is emphasized as a vital condition for all aspects of our existence, as individuals, as a society, and in our planet. The importance of inter- and transdisciplinarity in promoting a culture of peace and peace education is presented. Some examples of initiatives aimed at cultivating a culture of peace from diverse areas of knowledge are also provided. The paper presents a current and interconnected viewpoint on peace study, as well as some ideas for combining peace with education in the everyday routine of teaching and research work, regardless of discipline.

Keywords: culture of peace, peace, peace education, higher education, interdisciplinarity, transdisciplinarity and interdisciplinarity, transdisciplinary education

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INTRODUCTION

Peace is a global concept that is more relevant than ever in today's society. It is not simply a concern for countries and governments; it is also a concern for individuals in their relationships with others and with the planet. According to Capistrano (2020), peace is linked to the harmonious coexistence of individuals in their environment, which depends on principles such as social justice, sustainability, democracy and tolerance. A culture of peace can be fostered and promoted *via* education not only in large projects but also in everyday life. As stated by Cuéllar (2009), ordinary life is a key object of philosophical reflection from which "a humanism up to the mark of our time" can be derived, and everyday life is "where we begin to forge ourselves as people, where we can completely fulfill ourselves, in terms of work, production and rest, in married and family life, in the experience of love, freedom and recognition of the other."

This article highlights the importance of promoting peace education and a culture of peace through inter- and transdisciplinarity. The paper also provides examples of initiatives aimed at fostering a culture of peace from diverse areas of knowledge. Additionally, various concepts for integrating peace with education in everyday life are given, regardless of discipline.

AN IMPERFECT AND EVERYDAY PEACE

When asked "what is peace?" we tend to define it in terms of the absence of war, warlike conflicts, or discord. Known as a negative conception of peace, this perspective has persisted since ancient times. Conversely, positive peace emphasizes the promotion of values, respect, justice, equity, communication, collaboration, empathy, collaboration, and non-violence. Positive peace desires peace and wellbeing and avoids conflict at all costs. However, this concept appears perfect, utopian, or unattainable. As a result, a new approach termed "imperfect peace" has been developed (Comins-Mingol, 2002). The reason it is imperfect is that we are perpetually reconstructing it; it is a dynamic,

continuous, and multifaceted concept. Imperfect peace admits that peace and conflicts coexist. Acosta Oidor et al. (2021) explain that peace and violence are both present in every aspect of daily life and not only in a single field such as politics. Furthermore, they quote that peace is a road and not a state. Imperfect peace alludes to the imperfect nature of every human. The concept of imperfect peace is a productive field on which we can produce from our regular work routine.

CULTURE OF PEACE

Culture of peace refers to "lifestyles, belief patterns, values, behaviors, (. . .) wellbeing, equality, equitable administration of resources, security for individuals and families, (. . .) non-violence, and harmony" (Cabello et al., 2016). Culture of peace is inclusive and complex because it incorporates knowledge, values, and communication. It also integrates physical, biological, and social aspects. Culture of peace is all-encompassing. Page (2008) defines peace education as "the process of acquiring values, knowledge, attitudes, skills, and behaviors to live in harmony with oneself, others, and the natural environment." Peace education encompasses personal, social, and planetary dimensions. Thus, can we integrate peace into every facet of our lives? Is it possible to improve coexistence between people to foster a culture of peace? Personally, I believe we may achieve both goals through our daily life activities.

RATIONALE FOR INTER- AND TRANSDISCIPLINARITY

Should we continue to foster a culture of peace by focusing on a single discipline or collaborating on several? According to Edgar Morin's complex thinking (Morin, 1994), our contemporary reality, phenomena, and problems are complex by nature. Complexity entails more than just difficulty; it also signifies that the problems are interconnected in a framework spanning several knowledge domains. Accordingly, to address problems and better comprehend our reality, they must be regarded as interconnected and inseparable in a feedback loop, that is, from a holistic and collaborative perspective of multiple disciplines. For this reason, reductionist perspectives are no longer enough for a pertinent understanding of our reality. In this context, two key elements emerge, namely the integration of diverse specialties and collaborative work, which facilitate inter and transdisciplinary work.

According to the literature, the concept of inter- and transdisciplinarity derives from an advanced and mature level of collaboration between multiple disciplines (Escobar, 2010). First, disciplinarity occurs from specialization in a single area of knowledge. Then, multidisciplinarity emerges when several fields study the same object without interacting with one another. Pluridisciplinarity is the result of uncoordinated collaboration between different areas of knowledge. Finally, inter- and transdisciplinarity are achieved when some methodologies are transferred between disciplines (the former) and when a comprehensive and holistic perspective supports collaborations between disciplines, through them, and beyond them (the latter) (Klein, 2010). In transdisciplinarity, cognitive schemes intersect disciplines. As a result of this advanced level of collaboration, disciplines often face problems, difficulties, or challenges. Transdisciplinarity itself is not an exception; the different approaches to its conceptualization have led to contradictory points of view. For Rigolot (2020), these contradictions can be surpassed, by considering transdisciplinarity both as a discipline by itself and as a way of being. As a way of being, transdisciplinarity is fully incorporated into the human life and cannot be reduced to professional activities. This vision is compatible with that of Edgar Morin, who fully integrated transdisciplinary work with his personal life experiences (Rigolot, 2020).

INTER- AND TRANSDISCIPLINARY PEACE EDUCATION

Considering the aforementioned perspectives, effective peace education should be inter- and transdisciplinary. But how can we develop peace education through these approaches? First, embracing a complex conception of reality. In other words, reality should be viewed and understood from a broad perspective to avoid self-serving simplifications that prevent us from collaborating across disciplines. Second, our education should connect key issues such as life, humanity, culture, the planet, complexity, literature, art, philosophy, sustainability, and values regardless of field of knowledge. Third, teaching-learning processes should be adaptable, allowing teachers and students to see each subject as part of a complex whole interconnected through various mediations.

Accordingly, Lappin (2009) explains that it has been well acknowledged that peacebuilding is complex; however, there is a long-standing tendency to address peacebuilding from the point of view of a single discipline. Nicolescu (2012) adds that there is a direct and inexorable link between peace and transdisciplinarity and that any fragmented way of thinking is incompatible with peace research. Hence, education and the university must evolve to welcome a new humanism and adopt transdisciplinarity in their organization and conceptions. Along the same vein, Galtung (2010) asserts that true transdisciplinarity must be present in all aspects of the human condition, as multiple restricted or skewed perspectives will not provide a clear overview or an encompassing understanding of the whole.

Cabello et al. (2016) advocate that peace should be built on "education for justice and freedom; for reconciliation and brotherhood; for critical conscience and solidarity; for integral development and democracy; for the common good and participation; for human rights, and all the values that support and enable a culture of peace." Acevedo Suárez and Báez Pimiento (2018) explain that educating for peace is inviting to act in the school microcosm and at the macro level of social structures. They conclude that peace education is a necessity that every educational institution must assume. París Albert (2019) exposes that peace education is also a primary tool to achieve

the sustainable development goals of the 2030 Agenda; this tool consists of creativity to imagine careful alternatives to face daily situations, as well as situations of injustice, social inequalities, environmental crises, and sustainable development.

Now comes the question of how we can educate for peace in our daily teaching and research work. Some guidelines (Zurbano Díaz de Cerio, 1999) include cultivating values, learning to live with others, facilitating positive experiences, educating in conflict resolution, developing critical thinking, combating violence, educating in tolerance to diversity of dialogue, and rational argumentation. Furthermore, as educators, we must remember that our example is a powerful ally in all educational processes. We can deliver beautiful and eloquent speeches, but it is our everyday example that sows the most seeds of peace in others. We are also educating for peace *via* our own actions. We, as teachers, may encourage active listening, empathy, depersonalization of conflicts, and respect for limitations and opinions. In this approach, we may take small steps toward strengthening our coexistence and promoting a culture of peace.

Peace education must also be established at all levels, for all ages, and for all people. However, peace education has a significant impact on youth. Peace education is crucial during childhood and youth because the seeds we sow in them when they are young will flourish henceforth and bear fruit in the future for the benefit of our society. For this reason, youth represents both present and future peace and play a key role in peace education.

Currently, several discourses, initiatives, and indicators from different disciplines describe peace education. Many of them, though, remain limited to inert speeches. Peace, on the contrary, requires action (Jordan et al., 2021). We can make peace education a reality in our teaching activities through inter- and transdisciplinary approaches. Teachers can have influence in everyday life by building meaningful relationships between education and research, as well as by consistently implementing curricular and extracurricular activities that foster a culture of peace through formal and non-formal training.

EXAMPLES OF PEACE-BUILDING INITIATIVES FROM INSTITUTIONS, RESEARCH, TEACHING AND PERSONAL EXPERIENCE

Initiatives aimed at fostering a culture of peace are commonly promoted by institutions, researchers or teachers. For example, the study by Jordan et al. (2021) highlights an institutional peacebuilding initiative at the University of New Mexico School of Engineering and Health Sciences Center, where summit of the World Engineering Education Forum and Global Engineering Deans Council were hosted. The theme was "Peace Engineering" with the focal point of science and engineering-based solutions to the world's transcendent challenges. The event responded to the urgent need for engineers to reflect, understand, measure, and anticipate the intended and unforeseen implications of their work in a global context. The results of these events comprised establishing academic programs, starting new areas of education, research, and innovation relating to climate change, water, healthcare, food security, ethics, transparency, resilience, sustainability, social equity and diversity, as well as face-to-face and virtual academic events addressing peace, and engineering concerns.

In the research context, the project by Del Río Fernández et al. (2019) attempts to promote peace *via* the use of plastic and visual languages. The researchers gained this interdisciplinary experience with early childhood education student teachers through photographic exhibitions and mural workshops. They focused on developing respect for the ideas and beliefs of others, improving peaceful community life, and fostering pacific conflict resolution. This project is a clear illustration of how peace can be promoted from a variety of perspectives, such as the plastic arts.

In the teaching field, Miralay (2020) found that according to teachers' perceptions, the awareness of the culture of peace by students through arts education would promote individual and social peace. They also found that families, school administrators and governmental institutions have an essential role in promoting peace. Also, it was evident that there are deficiencies in the institutions while performing this process. On the other hand, the work of Domínguez and Ordinas (2019) describes the application of a novel methodology to promote socially equitable education in university teaching in courses involving the past and present of relations between human societies and cultures on a global scale. The aim of their work is to use ludic methods instead of traditional methods of study. Their students were encouraged to have a critical, pluralistic, cooperative outlook on the meaning of peace. This pedagogical approach has enriched the way of teaching and generating historical knowledge by using cooperative games in the classroom.

I can present my personal experience with teaching software development. In the classroom I have incorporated agile approaches which recognize that software development has a strong human dimension. Thus, people take precedence over tools (Beck et al., 2021). When these approaches are used in the classroom, students not only learn to program but also to collaborate while also learning to be tolerant. The principles of Egoless Programming (Waychal and Capretz, 2018) are also addressed during the practical lessons to help students understand the importance of good interpersonal relationships when collaborating. These approaches have been incredibly helpful in software development teaching because they strengthen understanding, respect, empathy, tolerance, and collaboration among students. In addition, I have found through quantitative and mixed research approaches that collaborative programming can produce software with better attributes than those of individually developed programs. For example, pair programming has produced elevated levels of acceptance and well-structured programs in our sessions.

CONCLUSION

Peace and peace research are pertinent needs in our society. As teachers, we must promote peace education and a culture of

peace from various angles. However, this is not an exclusive duty of teachers, but also requires the enthusiastic collaboration of institutions, students, parents, families, and communities. In this process, it is important to reflect on the contributions to peace that we can make in our everyday practice. Then, let us promote collaboration, dialogue, respect, active listening, and inclusion, using a cultural vision and living example of our behavior, thereby creating a culture of peace based on values and love in our daily lives as teachers or researchers.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

RR-H: conception, research, writing, editing, revising, and final draft.

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Evaluating the Bachelor of Education Program Based on the Context, Input, Process, and Product Model

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The study aims to evaluate the Bachelor of Education (BEd) program based on the Context, Input, Process, and Product (CIPP) model. The CIPP paradigm was employed in this study, and data were collected utilizing a questionnaire, an interview guide, and related papers. A quantitative descriptive approach was used to analyze the data. The students, teachers, and top management employees of the polytechnic departments were evaluated. The study was analyzed using SPSS version 15. The descriptive statistics were used to make descriptions related to the respondents' demographic backgrounds and the effectiveness of the BEd program. The prototype verification findings in the Glickman quadrant were used to assess the success of the learning program. According to the results, the execution of the teaching program at the polytechnic is successful considering the interdependence of CIPP. Lesson plan, semester teaching plans, curriculum, infrastructure, and facilities are the limits to the implementation of teaching at the polytechnic. The study concluded that it would be beneficial to the universities in Malaysia in the long-term effort to improve the quality of the program offered and increase the performance and wisdom of the trainers.

Keywords: Bachelor of Education program (PISMP), CIPP assessment model, university–industry, Malaysia, trainers

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INTRODUCTION

The transformation of education suggested by the government through the Malaysian Education Blueprint 2013–2025 proved the concern for the development of the education system for the public (Ministry of Education, 2012). Currently, the world is entering the era of the Fourth Industrial Revolution, in which information technology (IT) has become fundamental in human life. Education plays a significant role as it is only through education that quality and capable human resources are generated or produced in today's time where knowledge and skills learned will affect the environment (Wardina et al., 2019). As an essential part of the educational system, the teaching system needs improvement and development to be carried out by the implementers or stakeholders. The areas that need attention are curriculum development, teaching methods, techniques, materials, and evaluation to yield a future-oriented teaching system (Darma, 2019). The Bachelor of Education (BEd) program at the University of Malaysia has been offered since 1997. The offer includes BEd (Business Management), BEd (Accounting), BEd (Information Technology), BEd (Moral Education), and BEd (Counseling). This university in Malaysia focuses on a continuous effort to enhance students' potential comprehensively. According to a study by Krishnasamy et al. (2015), educationists should try to make students more knowledgeable, educated, competent, impressive, and responsible citizens of the family, society, and country.

Evaluation plays a vital role in teaching. To improve the quality of education, the implementation of assessment should be considered necessary. This process is also essential for the top management (such as principals and department heads), which serves as feedback for the educational or training programs they are responsible for Sawchuk (2015). Furthermore, the evaluation process can spark interest and motivation in students, and they become more severe learners. On the other hand, teachers can improve their teaching methods and professionalism. The evaluation process does not only comprise evaluating learning achievement but also emphasizes evaluating the input and the learning process. When the evaluation of teaching programs takes place, it is expected that the quality of teaching will improve or enhance in the future, and the quality of the education system will become even better (Grissom and Bartanen, 2019).

Mertens and Wilson (2018) suggested three main features to consider while evaluating a program. A program is a systematic inquiry contributing to information about the planner or the foundation-maker. The program evaluation process should be value-oriented, and there should not be a set time to evaluate a specific program. Besides that, program evaluation needs to be done to fulfill the need of the Ministry of Education Malaysia (MOE) so that the curriculum is always inspected to ensure conformity at all times. This is supported by the study of Tractenberg et al. (2020), which states that the curriculum evaluation of any program needs to be conducted from time to time to ensure the delivery of a quality program. Society is now demanding high accountability from educational institutions. Therefore, higher education institutions urge to generate relevant graduates who satisfy the societies and the nation's needs with effective cost and guaranteed quality. These needs alternately change the sudden increase in global knowledge and advancements in science, technology, and education widespread through the electronic networks. As a dynamic institution, the educational institution needs to explore systematically, monitor, and oversee the issue related to planning and executing programs to face this challenge.

Furthermore, Aktaş and Gündoğdu (2020) suggested that learning can become exciting, meaningful, and impactful for the students if the teacher is skillful, knowledgeable, and competent. Huliatunisa et al. (2021) explained that evaluation of programs helps change the education pattern from traditional to contemporary with a change in the role of the learners who were initially only acting as receivers of information. The difference in pattern helps these learners become more active, independent, and passionate in their learning journey. This urged the education system to change the way it delivers knowledge to meet the needs of the current society and business sector.

Some previous studies have focused on the subject of curriculum evaluation using the Context, Input, Process, and Product (CIPP) model (Zhang et al., 2011; Limouei and Hoseinzadeh, 2016; Neyazi et al., 2016; Aziz et al., 2018; Lippe and Carter, 2018). Moreover, the global changes and advancements impact the human profile anticipated to be taught, leading to dramatic changes and developments in the education system, roles, aims of education, and many other sectors, including tourism. As a result, it is vital to regularly examine and improve educational curricula in response to global trends. Evaluation is an important part of education (Vo, 2018). Curriculum review is becoming an increasingly essential aspect of tourist education. The best approach to determine if education programs achieve their goals is to evaluate them (Alqahtani, 2016). However, it is challenging to offer a single approach for curriculum assessment because of diverse curriculum creation (Karatas and Fer, 2009). As a result, it is critical to understand which model to use and how to carry out the educational assessment process systematically.

The primary purpose of the evaluation is to review the conformity, relevance, and effectiveness of the BEd program at the University of Malaysia toward increasing the performance and wisdom of training trainers. This evaluation aimed to ensure that the BEd program at the University of Malaysia is managed efficiently and effectively aligned with the current needs and generate newly trained teachers to fulfill the expectation of schools. This study also aimed to examine the BEd program to ensure that the program offered has an excellent curriculum, meets learners' needs, and realizes the objectives. This study would benefit the university in the long-term effort to improve the quality of the programs offered and increase the performance and wisdom of the trainers.

LITERATURE REVIEW

Evaluation of the Bachelor of Education Program Using the Context, Input, Process, and Product Model

The CIPP evaluation model was developed by Stufflebeam (1971). This model explains that the primary purpose of the evaluation is to obtain valuable information to make decisions. The second purpose is to enable an understanding of the program's strategy. The model's approach is based on two main assumptions. The first assumption is that evaluation plays the main role in stimulating and planning changes, while the second assumption is a complementary element to general institutions' programs (James, 1993).

The CIPP Model is an evaluation model that aims to assess specific programs to enhance the programs, especially the programs offered in education and human resources. According to Nikijuluw (2020), CIPP is a model of evaluation that acts as a tool to assist in forming a customized program that could benefit the people of an organization. The model has four different areas of assessment such as contextual evaluation, input, products, and process. Using these four areas, evaluation of a program can be conducted easily. The selection of a specific evaluation area depends upon the program's goals and objectives.

Context Evaluation

Context evaluation helps to evaluate the needs and opportunities in a specific context or environment. The objective is to recognize, define, and address the needs of the target population. The different ways and methods used in this type of evaluation include surveys, data analyses, interviews, and document reviews

(Toosi et al., 2021). Below are some questions that contextual evaluation deals with:

Q1. Does the school have substantial aims or not?
Q2. Are the objectives extracted from the aims?
Q3. Are the courses being taught relevant to the aims?
Q4. Is the school able to fulfill the social needs or not?

Input Evaluation

Input evaluation focuses on the content and the issues related to the evaluation of textbooks. Stufflebeam and Shinkfield (2007) mentioned that input evaluation helps determine the project to be identified and overcome the need. Therefore, the primary approach is to identify and evaluate the current ability of the ongoing system that suggests suitable alternative strategies. The input evaluation assists researchers in planning decisions, locating available resources, finding alternative ways to be taken, planning strategies to achieve the objective, and designing the working procedure to achieve it. Warr et al. (1970) explained input evaluation as overseeing the use of resources to execute the training program. The objective of input evaluation is to provide ease in implementing the program planned in the context stage. Moreover, it focuses on specific resources such as financial resources, human resources, policies, educational strategies, limitations, and hurdles of the education system (Saif, 2019).

Process Evaluation

Evaluation of the process focuses on the teaching method and considers the involvement between the instructor and the process. Evaluation is an observation process of program execution assisting in preparing the main reference list for continuous observation. This process aims to obtain feedback on the progression and procedure of executing the program and controlling and fixing the plan. Worthen and Sanders (1987) explained that process evaluation emphasizes three objectives: detecting or predicting the procedure design or the execution of the program at the implementation level, supplying information on the result of the program, and maintaining the procedure record has been implemented.

Process evaluation covers data collection that has been decided and implemented in the program execution. Ultimately, process evaluation is done to measure the progress and determine which components need to be focused on. It refers to identifying or estimating performance problems that occur during educational activities and defining the attractiveness of the implementation process. This process discusses the effect of the educational program on the learners (Saif, 2019).

Product Evaluation

Evaluation of product is an assessment done to observe the achievement obtained from the planned execution of the program. Product evaluations identify and evaluate the result of the program as to whether it is a success or not. The objective of product evaluation is to measure, interpret, and assess the outcome with honesty. Product evaluation observes whether the need is fulfilled or needs improvisation (Stufflebeam and Shinkfield, 2007). Stufflebeam (2008) explained that product evaluation gives project directors or teachers a chance to make decisions on specific programs. Product evaluation can provide information to educators or administrators to make decisions on the effectiveness of the implemented program. Farida (2000) stated that product evaluation could assist in making decisions on obtained outcomes and long-term planning. Therefore, it can be concluded that product evaluation can see the effectiveness of any program as to whether it has achieved the main objective or otherwise. At this level, the evaluator can contribute suggestions or recommendations for improvement.

Context, Input, Process, and Product evaluation evaluates multiple education programs while preparing for better education development (Zhang et al., 2008, 2009). Felix (1979) used the CIPP model to evaluate and improve the instruction system in schools in the region of Cincinnati. The development faculty have also utilized the CIPP model to support medical students' teaching and learning professionalism in the United States (Steinert et al., 2005). An important objective of evaluation based on the CIPP model is to bring improvisation to the program's performance. The CIPP model of evaluation is a cyclical process that focuses on the process more as compared to the product, and it is regarded as a fundamental goal of the evaluation process. The purpose of it is to improve the curriculum of the educational program. Studies have shown that the CIPP evaluation model covers all the stages of reviewing an educational program. It provides the required information needed to bring about a constructive improvement in the educational programs and make informed decisions. The model not only focuses on providing answers to clear questions but also emphasizes the systematic and general determination of the competencies of an educational program (Toosi et al., 2021).

Several local researchers also used the CIPP model to evaluate the effectiveness of teaching and learning. Ahamad and Sidek (2009) researched to assess the implementation of the curriculum for the Lower Form History subject using the CIPP evaluation model. The research sample consisted of 147 teachers and 1441 students of lower forms in secondary schools. This research used a survey as the research instrument to assess input, process, and product. The study's outcome showed that teachers' perception of the constructs of knowledge pedagogy, facilities, teaching, and learning plan was moderate, while the mean score for curriculum observation was at the lowest level. With this, it can be concluded that the CIPP model is crucially needed and can become a guideline for researchers to evaluate any program. Through this model, researchers can identify the strengths and weaknesses of a program and bring significant improvements to it.

OPERATIONAL DEFINITIONS OF VARIABLES USED

Lecturer and Facilities

The variable lecturer and facilities refer to the teaching and learning competencies of the lecturer and the facilities of the BEd program provided to ease the process of teaching.

Relevance and Conformity of Bachelor of Education Program

The relevance and conformity of the BEd program refer to a program that offers an excellent curriculum, fulfills learners' demands, can realize the objectives, and has wide marketing possibilities as there is progress in the education field.

Effectiveness of the Bachelor of Education Program

The program's effectiveness refers to the effectiveness of the BEd program in the form of execution strategy, program outcome, and its impact on the organization.

MATERIALS AND METHODS

Study Design

The study has used the CIPP model to conduct evaluation research in Malaysia from 2020 to 2021.

Population and Sampling

This study has considered 520 BEd students from a Malaysian university (**Table 1**). A study by Krejcie and Morgan (1970) proposed a table Sample Size Determination. In this study, about 350 BEd students were chosen as the research sample because the increase in sample size can help to reduce error when the sample does not represent or has the characteristics of the population. Non-proportionate stratified sampling based on the program of study and simple random sampling were used to select the research sample.

Study Instrument

A survey questionnaire was used as the main instrument in this study. However, the instrument used in this study was adapted from previous research. The information was gathered using context, input, process, and product instruments having high levels of validity and reliability. The lowest degree of content validity for each instrument was 0.91, while the maximum level was 0.94.

TABLE 1 | Demographic details.

Variable	Frequency	%
Gender		
Men	42	19.2
Women	177	80.2
Program of study		
BEd (BA)	62	28.3
BEd (ACCT)	25	11.4
BEd (IT)	51	23.3
BEd (Moral Education)	36	16.4
BEd (Counseling)	45	20.5

Data Analysis

The researchers checked the responses obtained from the BEd students through the questionnaires and analyzed them using the SPSS version 15, Malaysia. In this study, descriptive statistics like percentage, mean, and frequency were used to describe the respondents' demographic backgrounds and the effectiveness of the BEd program. The collected data were quantitatively-descriptively assessed as follows: T-score = 50 + 10Z. The data from each variable's analysis result was compared to the true mean. They were then divided into five groups using the ideal normal curve theoretic norm based on their propensity, as follows:

- Very high – $Mi + 1.5\ SDi < x \leq Mi + 3SDi$
- High – $Mi + 0.5\ SDi < x \leq Mi + 1.5\ SDi$
- Medium – $Mi - 0.5\ SDi < x \leq Mi + 0.5\ SDi$
- Low – $Mi - 1.5\ SDi < x \leq Mi - 0.5\ SDi$
- Very low – $Mi - 3\ SDi < x \leq Mi - 1.5\ SDi$

The percentage of accomplishment was used to classify the efficacy of program implementation in each dimension. The categorization criteria are based on the hierarchy shown below (Ebel and Frisbie, 1972):

- Very high – A = (81–100)%
- High – B = (61–80)%
- Fair – C = (41–60)%
- Low – D = (21–40)%
- Very low – E = (0–20)%

The T-score determines each component's qualification. For instance, it is positive (+) if the T-score is >50 and negative (−) if the T-score is <50. The number of negative (−) and positive (+) scores are computed to find out the result of each component. The result is positive if the number of the positive scores is more or the same as that of the negative scores and *vice versa*.

RESULTS AND DISCUSSION

Table 2 shows that the number of female respondents is more significant (80.2%) compared to male respondents (19.2%). In terms of the programs of study, the result showed that BEd (BA) had the highest number of participants in this study and BEd (ACCT) had the lowest percentage (11.4%).

Table 3 shows the descriptive analysis of the effectiveness of the BEd program with a mean value of 4.12 and a SD of 1.03.

The T-score findings are reported in **Table 3**. According to **Table 3**, all context variables' components have positive (+) ratings. It demonstrates that the indicators covering the teaching strategy, vision and missions, and the educational experience have satisfied expectations. The difference between

TABLE 2 | Effectiveness of the Bachelor of Education program.

Variable	Mean	SD
Effectiveness of Bachelor of Education program	4.12	1.03

TABLE 3 | *T*-score analysis of the context variable component.

Component	Frequency category			Conclusion
	Σf (+)	Σf (–)	Σf (+) %	
Teaching strategy	105	55	51.53	Positive (+)
Mission and vision	78	72	50.64	Positive (+)
Educational experience	82	68	53.05	Positive (+)
Total				Positive (+) Effective

TABLE 4 | *T*-score analysis of the input variable component.

Component	Frequency category			Conclusion
	Σf (+)	Σf (–)	Σf (+) %	
Syllabus	72	78	47.16	Negative (–)
Quarterly teaching plan	71	80	46.08	Negative (–)
Infrastructure	70	81	45.40	Negative (–)
Human resource	80	71	51.21	Positive (+)
Total				Negative (–) Less effective

TABLE 5 | *T*-score analysis of the process variable component.

Component	Frequency category			Conclusion
	Σf (+)	Σf (–)	Σf (+) %	
Constituents	81	70	52.37	Positive (+)
Learning approaches	109	62	57.61	Positive (+)
Assessment	72	78	47.5	Negative (–)
Total				Positive (+) Effective enough

TABLE 6 | *T*-score analysis of the product variable component.

Component	Frequency category			Conclusion
	Σf (+)	Σf (–)	Σf (+) %	
Intellectual	135	180	42.21	Negative (–)
Non-intellectual	155	169	48.15	Negative (–)
Total				Negative (–) Ineffective

the positive (+) and negative (−) scores, the vision and missions, and the educational experience is positive (+). There is a correspondence between reality and theory. As a result, the context variable has aided in implementing the educational program. The teaching strategy, vision and missions, and the educational experience contribute considerably to the teaching program's implementation. The building model adhered to the teaching strategy's concepts, aims, and functions. The success of the teaching program execution is influenced by an adequate and effective teaching plan (Majid, 2012).

According to **Table 4**, the input components, including the syllabus, quarterly teaching plan, and infrastructure, all receive bad marks. However, human resource components receive high marks. Not all of the input variable's indications match the expectation. The syllabus components, quarterly teaching plan, and infrastructure have not exceeded expectations, although all study programs have a lesson plan for all courses. Furthermore, there is no guidance on how to construct the syllabus, and the assertions of attainment of learning accomplishment do not always relate to the statement of the graduate's standard competencies required in the national higher education standard. The quarterly teaching plans developed by the lecturers do not fulfill the national norm of higher education.

The process of evaluation includes the teaching constituents, learning approaches, and assessments. **Table 5** presents the *T*-score analysis of the process variable components (constituents, learning approaches) that yield a positive score. However, the assessment component yields a negative score. The constituents and learning approaches fulfilled expectations and helped to increase the process variable. However, the assessment component did not meet expectations and contributed less adequately to the process variable. Assessments occur apart from the instructional activities, notably in the middle and at the end of the semester. Assessment is an essential component of the educational process and should be implemented and carried out in tandem with it.

According to **Table 6**, all of the product's components receive a poor score. In general, product variables do not facilitate teaching in Malaysia. Intellectual and non-intellectual components did not meet expectations and contributed much less to the product variable. The goal of the teaching program has not been met optimally. According to Yusuf (2017), product assessment occurs at the end of an activity and is designed to measure the success of previously defined objectives based on a standard or criterion. This conclusion is backed by the idea that the final evaluation (product) links information about the end achievement to the objectives, context, input, and procedure executed before it (Warju, 2016).

One of the significant issues confronting theorists and people interested in educational systems is the assessment of educational programs. It is critical to pay attention to the quality of successful training that follows it in today's environment. The study aimed to evaluate the BEd programs through the CIPP model. The factors such as lecturer and facilities, relevance and conformity of the BEd program were handled collectively in multiple regression. The result of the analysis showed that the independent variable is the indicator and is significant to the effectiveness of the BEd program. The context and the process possess strong backing. However, products and input have poor support. It validates the findings of Gunung and Darma (2018), who concluded that the execution of the teaching program is adequate in terms of context, input, process, and output. It also supports the findings of Riptiani et al. (2015) and Kavgaoglu and Alci (2016), stating that the efficacy of each setting, input, process, and product determines the level of effectiveness of the program under consideration.

The assessment results show that the context in program evaluation might alter the implementation and achievement processes of the program's objectives. Management effectiveness focuses on the expected outcomes, objectives, and aims. A competent institution of higher education measures its success in terms of input, process, context, and result and is distinguished based on the high quality of the system constituents. The CIPP assessment approach views the program as a system. Integrating educational experience, input, and process both supports and impacts the result or output. The amount of efficacy of each component determines the program's effectiveness. The existence of limitations in each component will affect the program's effectiveness. As a result of the presence of limits in the components of context, input, and product, the degree of effectiveness of the educational program is adequate in Malaysia.

The relevance and conformity of the BEd program have a significant influence on the high coefficient value compared to lecturers and facilities. This shows that the variable of relevance and conformity of the BEd program has the most potent effect on the effectiveness of the BEd program. The outcome of the current study is in line with the study of Harun (2014), who discovered that the factor of relevance and conformity is the main factor in selecting any program. Their research outcome showed that students tend to choose courses and academic programs that have high quality and relevance to the current need and could secure jobs.

The planning of the instructional program has to be much improved. The teaching strategy serves as a reference for lecturers in creating more directed instructional activities that will proceed smoothly and effectively. Therefore, improving teaching quality may begin with the teaching plan (Dwiyogo, 2018). According to Işman (2011), designing a teaching program is important in increasing teaching quality. Its layout must be focused on active learning. A mature strategy determines the effectiveness of a teaching process. When a plan is well-crafted, half of the battle is won; the rest is in the execution.

Besides that, lecturers and facilities are the second-highest variance contributor and a significant indicator that affects the effectiveness of the BEd program. This study outcome is aligned with the outcome of the study of Ibrahim and Amin (2017), who discovered that the factor of teaching and facilities needed more attention in the offering of any academic program. They stated that the main aspect that needed to be emphasized are enhancing lecturers' quality, improving educational technology facilities, improving library facilities, and ensuring the academic curriculum is aligned with the needs of the schools. A similar study assessed the efficiency of the Ankara University Preparatory School curriculum from the viewpoints of instructors and students (Tunc, 2010). The findings suggested that adjustments in the program's physical circumstances, content, materials, and evaluation were necessary to make it more effective.

The lecturers and facilities and the relevance and appropriateness of the BEd program variables become significant predictors with the highest coefficient value. Therefore, these factors need to be emphasized in implementing the BEd program to create an effective BEd program. This outcome clearly states that the effectiveness of the BEd program depends on the factor of lecturer and facilities and the relevance and conformity of the BEd program. Both factors are interrelated and need to be taken into consideration to ensure that the BEd program has the quality and can help increase its effectiveness.

Another study used the CIPP assessment model as a complete framework to guide the development, planning, implementation, and evaluation of a revamped undergraduate medical education program (Mirzazadeh et al., 2016). The findings of this study demonstrated that the components of the CIPP assessment model could successfully handle all stages of the reform even when the new program was still in development. The present study used context and input assessment before and process and product evaluation after the new program's introduction (Mirzazadeh et al., 2016). Attempts to modify or reform various elements and a continuous examination of the program and its certification appear to be essential. The integrated curriculum is a well-known idea across the world. The goal of the study by Rooholamini et al. (2017) was to collect the data needed for the program assessment of this curriculum for undergraduate medical students utilizing the CIPP program evaluation paradigm. The fundamental benefit of reviewing an educational program using the CIPP assessment paradigm is that the program's context, input, process, and product are all seen and evaluated systematically. This will assist educational authorities in making appropriate decisions on the program's continuation, discontinuation, and adjustment based on the program's faults and strengths.

This study has shown that lecturers, facilities, and relevance and conformity of the BEd program variables become the predictors of the significance of the effectiveness of the BEd program. Both the variables have a significant and positive impact on the dependent variable. The study has also shown that the BEd program offered is relevant and suits the students' needs, equips the lecturers with expertise, and provides excellent facilities. This study outcome indicated that the offering of the BEd program with Honors meets the expectations and demands of both the private and public organizations. The offer of the BEd program is in line with the aim of the Ministry of Education Malaysia (MOE), which always demands trained teachers in the field of education. The expectation by MOE is to produce more trained teachers to handle the attitude problems of students as well as give guidance and advice on learning, career, and student development. Having sound knowledge and competent educators are needed to realize the mission, and the BEd program with Honors can become the platform to train these educators.

STUDY IMPLICATIONS

This study has several implications for the authorities based on the discussion and explanation that are involved in implementing the BEd program:

- This research proved that implementing the BEd program depends on the lecturers and facilities and the relevance and conformity of the BEd program variables. The study discovered that the variables of lecturers and facilities and

relevance and conformity of the BEd program have a significant and positive influence on the effectiveness of the BEd program. Therefore, it can be concluded that the implementation of BEd needs to focus on lecturers and facilities and the relevance and conformity of the BEd program variables as the enhancement of these variables affects the effectiveness of the BEd program.

- This research outcome has explained that the relevance and conformity of the BEd program variable significantly influence the effectiveness. The outcome has indicated that university authorities need to ensure that the BEd program implemented is relevant and suits the need of the educational undergraduates. This explains that the BEd program that is offered meets the demand of the current market and industries.
- The Ministry of Higher Education of Malaysia and the university need to pay full attention to ensuring the quality of lecturers and facilities, the relevance and conformity of the BEd program, and the effectiveness of the implementation. The ministry and the university need to form an organizational structure and come up with management principles that can overcome the change in circumstances and the need of the educational institution in the long term. It soon will help the ministry and the university improve and construct capable, knowledgeable, and competent graduates and increase the quality of the program offered.
- The decision-makers need to review the implemented curriculum, especially concerning the statement of learning achievement, and encourage the lecturers to prepare printed learning materials according to the student's learning needs.
- There is also a need to adapt strategies and activities in the teaching plan that has been written.

CONCLUSION

The study aimed to evaluate the BEd program using the CIPP model. The training program considered in this study is sufficient in terms of the interconnectedness of context, input, process, and result components. The context, input, process, and result components are the restrictions in instructional implementation. The teaching strategy is the context variable. The curriculum, quarterly teaching plan, and infrastructure are the input variables. The assessment system is the process variable. The quality of academic and non-academic learning success is the product variable. As a result, the study suggests that improving the quality of the curriculum given and increasing the performance and knowledge of the trainers will be helpful to the institutions in Malaysia in the long run.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

SS: conception, editing, analysis, correspondence, literature and methods. NS: drafting and analysis. Both authors contributed to the article and approved the submitted version.

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Reinventing talent management: How to maximize performance in higher education

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Talent management is considered a new organizational priority in managing people that both academicians and practitioners discuss. The purpose of this research was to examine the role of talent management (TM), knowledge management (KM), university transformation (UT), and academic climate (AC) in increasing the performance of private higher education institutions (PHEIs). This research applied a quantitative approach by collecting data from 382 lecturers who worked at various private universities in Indonesia. Online questionnaires were used to collect the data using a stratified random sampling method. Then these data were analyzed using Structural Equation Modeling–Partial Least Square. The findings indicated that systematic application of talent management and knowledge management, university transformation, and academic climate in PHEIs improves organizational performance. Developing a plan to transform their talent and the business process is the key to emphasizing its importance in shaping the character and quality of PHEIs. The practical implication, PHEIs must offer a conducive academic climate for talented lecturers. The study offers a value-add to the resource-based view theory, managing talent and knowledge as essential resources for organizational transformation to maximize organizational performance.

KEYWORDS

academic climate, human resource management, higher education performance, knowledge management, talent management, university transformation, strategic management

Introduction

Nobody would have expected that era of change could have created such a global change and uncertainty. According to Deschamps et al. (2020), the success of any organization depends on its ability to adapt to the changing business environment. For instance, era of change at places of work alters everything leading to the emergence of

a new team with unprecedented new talent (Diezmann, 2018). The challenge of this era of change has had a tremendous impact, especially on private higher education (*PHEIs*) because the funding for its activities comes from self-financing (Santoso, 2022). There is a decrease in the number of private universities in Indonesia which decreased from 2018 to 2020 due to several factors such as bankruptcy and mergers and acquisitions (Hidayat, 2020). The education sector is mainly concerned about technological developments and demands for the quality of graduates. However, higher education management faces challenges in planning and implementing the best strategy to sustain talents (Veiga et al., 2019). This shows the need for universities to transform by redesigning structures, systems, shared values, strategies, skills, and styles (Ravanfar, 2015).

The key to molding higher education performance involves managing two primary sources of organizational competitive advantage: knowledge and talent (Abdullah et al., 2020). Talent and knowledge management help improve rankings and profits (Hazelkorn, 2017). By utilizing organizational strategies with highly skilled employees, the talent management process is crucial to higher education institutions' long-term growth and success as an industry (Ming et al., 2016). Knowledge management is viewed as an integrated approach allowing organizations to meet the demands to increase competitiveness (Oktavia et al., 2017), which further results in high-quality educational outputs (Rambe and Mbeo, 2017). Therefore, a combination of talent and knowledge management helps transform and achieve improved academic performance and competitiveness (Kim et al., 2014).

Indonesia has been a G20 member and was seen as a rising nation in Asia with huge economic size and promise. Indonesia thus attends the G20 to represent a collection of emerging nations, Southeast Asia, and the Islamic world. In addition to having the potential to be a gift, the demographic benefit may also provide challenges. It all depends on whether people who are of working age (between the age of 28–45 years) will be productive when given access to proper training and education. Changes in higher education performance standards are required to meet workforce demand (Voet, 2014). Indonesia's higher education needs to create a transformation plan to adapt to the radical calls and attribute them to their operating environment by maximizing available resources (Abad-Segura et al., 2020). Also, higher education must recruit high-quality lecturers to help with the teaching and learning process, and innovation and provide solutions to the turbulent changes in the education environment (Farooq et al., 2017). Studies indicate that private universities strive for their financial resources, talented employees, high-quality lecturers, innovative research, good reputation, and status in national and international rankings (Sułkowski et al., 2019). As a result, these institutions must reconsider their governance and evaluate how they adapt to a quickly changing market (Vlachopoulos, 2021).

Previous studies have documented various findings on talent management in organizations (King and Vaiman, 2019; Narayanan et al., 2019; Whysall et al., 2019; Harsch and Festing, 2020). Although it is believed to have consequences on competitiveness (Kim et al., 2014; Harsch and Festing, 2020) and performance in general (Collings et al., 2019), this study covered some issues that have received less attention in the past. For instance, previous studies on talent management did not collect enough information on higher education performance (Farooq et al., 2017; Maghdomi and Keikha, 2017; Mohammed et al., 2020). Therefore, this study adds to the contribution of talent management in universities to prepare for higher performance and educational rankings. Besides, it elaborates on applying systematic talent management in an organization to support policies and strategies for change in higher education (Erasmus et al., 2017).

Some studies claim a solid link between talent and knowledge management (Sparrow and Makram, 2015; Osigwelem, 2017; Miiro and Otham, 2018; Mohammed, 2018; Paisey and Paisey, 2018; Abdullah et al., 2020). However, there is a lack of studies examining the relationship between talent management, knowledge management, university transformation, and academic climate. Thus, this study uncovers talent management as a unique organizational strategy mechanism that affects knowledge management, university transformation, and the intellectual environment of higher performance education. The application of talent management and other components can predict faculty members' research performance, leadership, teaching, and educational atmosphere for university performance (Maghdomi and Keikha, 2017). This study was conducted in Southeast Asia, where most higher learning institutions cannot perform well in the QS World University Ranking due to a lack of talent. The governments provide funding programs that have been carried out as initiatives to strengthen competence and insight or industrial experience for lecturers to improve the quality of the learning process and create quality human resources. But the results have not been seen because there is no comprehensive talent management practice in place. This article aims at giving insight into how private higher education institutions can survive by improving their performance. And also offers a value addition to the resource-based view theory, managing talent, and knowledge as essential resources for organizational transformation to maximize organizational performance. **Figure 1** shows the conceptual model of the study.

Theoretical background and hypothesis development

The resource-based view theory (RBV) used in this study emphasizes the importance of resources and capabilities in creating a competitive advantage. The approach provides a new

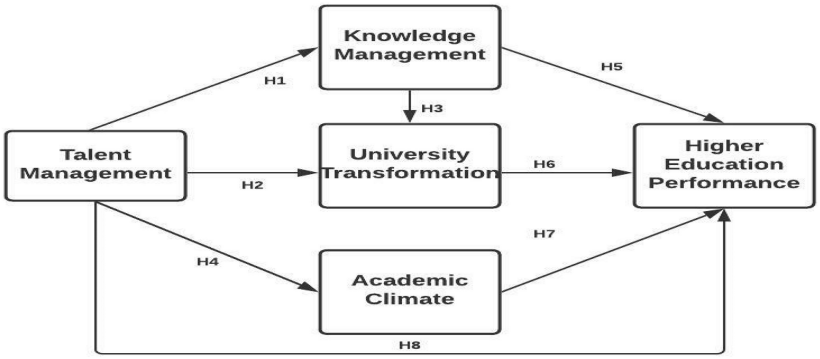

FIGURE 1
Conceptual model of the study.

explanation of talent management practice in organizations. In the 1990s, strategic organizational management shifted from an external focus to an internal focus (Wright et al., 1994). The external focus is based on the industry's strengths, weaknesses, opportunities, and threats. In contrast, the internal focus directs managerial attention to identifying assets, competencies, and capabilities to create a competitive advantage (Wright et al., 1994). Today, most of knowledge talent management methods are based on the resource-based model. Identifying and developing talent in human resource roles in organizations with several complicated positions in the global labor market provides a significant competitive advantage and increased performance (Muntean, 2014). The theory of resource-based view (RBV) is linked with talent management to create a sustainable competitive advantage, increasing customer satisfaction by showing their commitment to the organization (Al-Azzam and Al-Quraan, 2018).

Universities are knowledge-based organizations whose performance is mainly dependent on the teaching staff's expertise, competence, and excellence (Priyadarshini et al., 2016). According to the company's resource-based view, organizations must have valuable, rare, and non-replaceable resources to gain a competitive edge (Barney, 1991). Moreover, competition is growing in the higher education sector, and universities must attract and retain their valuable human resources to effectively adapt to the status of the job market (Anastasia et al., 2018). The RBV theory is essential for understanding knowledge management because it emphasizes that knowledge can represent capabilities, know-how, and organizational information. Creating and transferring this knowledge can lead to a competitive advantage (Hassan and Raziq, 2019). RBV theory enables knowledge transfer by promoting sustainable success at the individual level and across organizational units (Harzing et al., 2016). Strategy for dealing with human capital focuses on a more comprehensive approach to assist the organizations in maintaining a competitive advantage, not just on the necessity of employing, developing, and motivating employees (Suseno and Pinnington, 2017). Talented human resource is an essential factor in ensuring the success of any quality management efforts in the organization (Pantouvakis and Karakasnaki, 2017).

Talent management

Talent management is an integrated planning process, recruiting, developing, managing, and compensating employees (Sparrow and Makram, 2015). It is also defined as the process of recruiting, training, managing, developing, appraising, and maintaining the organization's most valuable talent (Polinia, 2017). Subsequently, knowledge management also contributes to organizational strategy formulation because of its vital role in decision making (Holsapple and Singh, 2001). There are three phases of decision making in complex situations; intelligence, conception, and selection processes.

The talent management process plays an important role in supporting knowledge creation strategies such as fostering knowledge creation and sharing knowledge (Whelan and Carcary, 2011). When the popularity of knowledge management in higher education increases, organizational knowledge in a higher education environment which allows it to become a learning organization can realize a competitive advantage in providing sustainable organizational performance (Karim and Majid, 2019). Successful employee knowledge needs to be transferred to improve talent management programs (Urbancová and Vnoucková, 2015).

Previous research describes the relationship between talent management practices in terms of talent identification. Therefore, talent development and talent culture seem to play an important role toward organizational knowledge transformation (Annakis et al., 2014). A study conducted on talent attraction and retention is strongly related to the degree to which organizations are accepted as having a change, quality, and technology-based culture, and is characterized

by support for creativity, open communication, effective knowledge management, and core values of respect and integrity (Kontoghiorghes, 2015). According to Mohammed (2018), the organizational strategy had a positive and significant impact on the talent and knowledge management processes in Australia's higher education sector. Talent management practices such as training and development, rewards and recognition have an effective influence on organizational performance (Kaliannan et al., 2016). Therefore, the talent management process is essential in supporting knowledge creation strategies and improved management (Whelan and Carcary, 2011; Kok and Lin, 2018). Based on the above, this leads to the following hypothesis:

> Hypothesis 1: Talent management is positively related to knowledge management.

Universities need to continually develop their talent to prepare effective knowledge management mechanisms, such as building networks to interact between individual talents to win the competition socially. Therefore, universities are interested in concentrating on talent-based knowledge management practices to gain a competitive transformation (Keat and Lin, 2017). Higher education transformation comes from the meaning of organizational transformation or change. This concept has existed since the 1970s until today. Higher education institutions must change to match the demands of technology to facilitate communication within the system itself and with the outside world (Farooq et al., 2017).

Higher education institutions need to rebrand, redesign, and restructure to suit the competitive changes in structures, systems, processes, staff, and norms (Voet, 2014). The relationship between talent management practices in talent development, talent retention, and non-financial reward plays an essential role in university transformation (Farooq et al., 2017). Therefore, we hypothesize as follows:

> Hypothesis 2: Talent management is positively related to university transformation.

Knowledge management

Knowledge management is a topic that is often in demand for research in the last 10 years (Quarchioni et al., 2020). Knowledge is a core competency, the primary source of competitive advantage and value creation for every organization worldwide (Liu et al., 2018). Knowledge management involves represented capabilities, know-how, and organizational information, creating and transferring expertise that results in competitive advantage (Hassan and Raziq, 2019).

In higher education, knowledge is generated from various activities such as teaching and learning processes, examinations, evaluations, counseling, training, research, consulting, and activity management (Dhamdhere, 2015). Organizational knowledge creates a competitive performance advantage (Karim and Majid, 2019). Many studies describe that knowledge is vital as a sustainable competitive advantage in higher education (Kanwal et al., 2019; Martins et al., 2019; Wu et al., 2019). Knowledge management involves represented capabilities, know-how, and organizational information, creating, and transferring expertise that results in competitive advantage (Hassan and Raziq, 2019). Organizational knowledge creates a competitive transformation (Karim and Majid, 2019). As a result, we come up with the following hypothesis:

> Hypothesis 3: Knowledge management is positively related to university transformation.

Academic climate

Academic climate includes atmosphere, culture, values, resources, social networks, and organizational, instructional, and interpersonal dimensions (Loukas and Murphy, 2007). Talent management aims to create sustainable organizational performance and outstanding performance following its operational and strategic objectives (Al Aina et al., 2020). Talent management has been expressed in the systematic perception of attracting, screening, and selecting suitable talent and engaging, developing, leading, and retaining talent. High-performing employees ensure a continuous flow of talent that can maintain their productivity (Thunnissen and Buttiens, 2017).

Talent management is possible in a conducive environment, and its provision is the responsibility of institutional leadership (Baporikar and Smith, 2019). On the other hand, institutional leadership refers to the top and middle management in universities who carry out management functions and inspire to realize the vision and mission of the university (Filho et al., 2020). In addition to being academics in their own right, they can inspire others by creating, supporting, and sustaining an environment for talent to thrive (Mohamed Jais et al., 2021). Consequently, we propose the following hypothesis:

> Hypothesis 4: Talent management is positively related to academic climate.

Higher education performance

The talent management strategy impacts an organization's performance (Powell et al., 2013; Miiro et al., 2016). The teaching and educational climate components have the most predictive function for university research performance (Maghdomi and Keikha, 2017). A study on talent attraction and retention presents the degree to which organizations are accepted as having support for climate, open communication, and core values (Kontoghiorghes, 2015).

Through practical knowledge management, universities can improve their processes and services such as teaching, learning, research, curriculum development, administration, and strategic planning (Ahmad et al., 2017), which in turn can improve the performance of these universities (Masa'deh et al., 2017). Several previous studies have proved the positive impact of knowledge management and organizational performance (Kianto et al., 2014; Dhamdhere, 2015; Fullwood et al., 2013; Ngah and Bontis, 2016; Shahzad et al., 2016; Rehman and Iqbal, 2020). Taking the above into account, we hypothesize:

> Hypothesis 5: Knowledge management is positively related to higher education performance.

Transformation in Universities requires organizational values, culture, structure, and routines (Spee, 2020). The results of previous studies show a positive relationship between talent management and university transformation in enhancing performance (Miiro and Otham, 2018). University transformation is the actual changing performance for higher education. Transformation is a strategy that requires a mindset, with many decisions and actions of a consistent nature directed at changing the business model and strategy of the organization's performance. The concept of university transformation mutually reinforces organizational achievement that increases performance (Azman et al., 2016). With the above review, we develop the following hypothesis:

> Hypothesis 6: University transformation is positively related to higher education performance.

A supportive environment indicates the overall support employees perceive as helping them successfully perform their job (Suifan, 2015). The relationship between the academic climate is believed to support organizational performance (Ingram, 2016; Musah et al., 2016). This study intends to contribute to the literature on student well-being and performance concerning the academic climate. Differences were observed in climate perception and academic performance in different classroom contexts. There were classes with a good climate associated with good university performance, and, conversely, students who scored low for perceived climate were associated with poor academic performance. However, strong correlations were observed between performance, well-being, and climate (Rania et al., 2014). Accordingly, we develop the following hypothesis:

> Hypothesis 7: Academic climate is positively related to higher education performance.

Talent management focusing on social capital-building practices is positively related to performance (Tatoglu et al., 2016). As proposed by prior studies, talent management has a significant association with higher education performance and is a critical source of high indicator for knowledge creation and information sharing (Whelan and Carcary, 2011; Kok and Lin, 2018). However, the impact of knowledge and talent management practices on organizational performance has not been thoroughly investigated (Kok and Lin, 2018). Previous research has also stated a positive relationship between talent management and higher education performance (Bradley, 2016; Hilman and Abubakar, 2017; Hongal and Kinange, 2020). As a consequence, we propose the following hypothesis:

> Hypothesis 8: Talent management is positively related to higher education performance.

Materials and methods

The design of this study was quantitative with descriptive and correlational explanations. Notably, Indonesia has many islands, making it impossible to collect data from the entire population due to resource and time constraints. According to Hair et al. (2010), the "10-times rule" method, which is based on the idea that the sample size should be greater than 10 times the maximum number of inner or outer model links pointing at any latent variable in the model, is a commonly used minimum sample size estimation method in PLS-SEM.

The higher education in Jakarta and its environmental area was chosen because the capital area is often a reference for the progress of higher education in Indonesia. In particular, the capital city was chosen because a lot of quality private universities are centralized in the area such as Binus University, Tarumanegara University, and Atma Jaya University that already entered QS Ranking. This research collected data from 382 lecturers who worked at various private universities. Online questionnaires were used to collect the data using a stratified random sampling method (proportional), with respondents divided into groupings of tertiary institutions in the form of universities with top tier to low accreditation as shown in **Table 1**. With a proportional or proportional distribution, the sample size for each level depends on the number of units in that level. Respondents are lecturers at the university who already have functional positions. Primary data were obtained directly from the lecturers as many as 376 respondents using the Slovin formula with a total population of 16,360, 95% confidence level, and 5% margin of error. The advantage of comparable allocation is the practicality of processing and tabulating survey results.

TABLE 1 Number of private higher education lecturers.

Institution	Accreditation	Lecture no	Calculation	Number of strata
University	A	2.613	(2.613/16.360)*376	60
University	B	12.600	(12.600/16/360)*376	289
University	C	1.147	(1.147/16.360)*376	27
Total		16.360		376
Number of respondents		376		376

Source: Human Resource Data Higher Education Service in Indonesia Capital City, 2021.

The respondents comprised 46.3% male and 53.7% female private university lecturers aged between 28 and 55 years. In addition, their level of education was Masters and Ph.D. holders with average occupation tenure of 5–10 years. Considering the time limitations, the study further used a cross-sectional design. The data were collected using a five-point Likert scale, one representing "strongly disagree" and five representing "strongly agree." A pilot study was undertaken to ensure that the questionnaire was valid for larger-scale research; we used Cronbach's alpha to establish the reliability, which is acceptable above the threshold of 0.7 (Hair, 1998; Gliem and Gliem, 2003). The questionnaire had been psychometrically validated and specifically designed for use within organizations. To ensure that the data are free from common method bias, we carry out a series of procedures to remedy it. First, we ensure that the questionnaire is anonymous to increase the objectivity of respondents' answers. Furthermore, a comprehensive collinearity test using PLS-SEM was used to investigate the common method variance (CMV) (Kock, 2017). No item has a variance inflation factor (VIF) > 3.3, according to the findings of the entire collinearity test, which demonstrates that CMV is not a severe danger to the data (Kock, 2017).

Measurement

Regarding the independent variable, a three-item scale developed by Mohammed (2018) was used to measure Talent Management (TM). In this regard, talent management was represented by several indicators, including talent development, talent retention, and non-financial rewards (Mohammed, 2018). Talent development is based on various sub-constructs such as social dominance, organizational excellence, performance management, identifying talent, and leadership development (Burnes and Cooke, 2012). Talent retention is measured through performance satisfaction, employee empowerment, and employee motivation (Mohammed, 2018).

The two constructs of knowledge transfer and knowledge sharing include knowledge management (KM) as a second dependent variable based on qualitative study (Mohammed, 2018). The university transformation questionnaire and its sub-dimensions were taken from Mehdi Ravanfar (2015) and Singh and Jain (2013). The four sub-constructs created from the above study include structure, strategy, shared values, and systems. The academic climate (AC) was adopted from Abdelmotaleb et al. (2013), representing lecture quality, curriculum, physical facilities, and managerial environment. The higher education performance (HEP) variable is a synchronized vital performance indicator by the ministry of education that has two subconstructs, namely, internal performance (input, process) and external performance (output, outcome) (Directorate General of Higher Education, 2020).

The test findings showed that all item values had a loading factor > 50, providing preliminary evidence for the measurement model's convergent validity. Composite reliability, which ranges from 0.76 to 0.96, indicates how construct indicators are expressed as part of latent variables. The results were higher than the suggested value of 0.7 (Hair et al., 2010). Subsequently, the average variance extracted (AVE) reflects the total number of variants in the indicator reflecting latent constructs; it met the recommended threshold of 0.5 in the study, indicating convergent validity (Fornell and Larcker, 1981; Hair et al., 2010). Following that, we looked at discriminant validity as proof of distinguishing between measures of distinct constructs (Hubley, 2014). **Table 2** indicates that the resulting correlation can test discriminant validity using the Fornell–Larcker criterion, which compares the AVE root value to the correlation between variables. Because the roots of AVE were all greater than the correlation between variables in the model, discriminant validity was acceptable (Hair et al., 2010).

Results

Outer model evaluation

Cronbach's alpha test results are given in **Table 1** for $TM = 0.826$; $AC = 0.845$; $KM = 0.867$; $UT = 0.92$; $AC = 0.850$. The tests incorporated in the multivariate factual examination include factor loadings, convergent validity, discriminant validity checks, and assessment of the structural equations model through evaluation of the explained variance (R^2), predictive relevance (Q^2), *t*-test (5,000 bootstrapping), and effect size (f^2) (Cohen, 1988; Hair et al., 2014). The examination was established using structural equation model–partial least

TABLE 2 Measurement variables.

Measurement		
Variable indicator		**Source**
Talent management	Talent attraction, talent development, and talent retention	Lyria et al., 2015; AlKerdawy, 2016; Nakhate, 2016; Mohammed et al., 2019
	Talent development	
	Talent retention	
Knowledge management	Knowledge transfer	Rhodes et al., 2008
	Knowledge creation	Li et al., 2009
University transformation	Structure, system, process, strategy, and foundation support	Ravanfar, 2015
Academic climate	Lecture, physical, subjects, and managerial environment	Abdelmotaleb et al., 2013
Higher education environment	Input, process, output, and outcome	BANPT, 2019

TABLE 3 Measurement model.

Construct	Item	Factor	CR	AVE	CA	Source
TM	TM1	0.935	0.923	0.801	0.874	Lyria et al., 2015; AlKerdawy, 2016; Nakhate, 2016; Mohammed et al., 2019
	TM2	0.803				
	TM3	0.940				
KM	KM1	0.935	0.937	0.882	0.867	Rhodes et al., 2008; Li et al., 2009
	KM2	0.943				
UT	UT1	0.959	0.962	0.927	0.921	Ravanfar, 2015
	UT2	0.966				
AC	AC1	0.762	0.905	0.762	0.845	Abdelmotaleb et al., 2013
	AC2	0.925				
	AC3	0.921				
HEP	HEP1	0.936	0.930	0.870	0.850	BANPT, 2019
	HEP2	0.929				

squares (Smart PLS v.3.2.8) IBM and SPSS v.21 software (Hair et al., 2017).

The convergent validity of the construct is still acceptable if the average variance retrieved is greater than 0.4 and composite reliability is higher than 0.6 (Fornell and Larcker, 1981; Lam, 2012; Hair et al., 2017). As shown in **Table 1**, all-composite reliability values are more than 0.80, indicating that all the five constructs (TM, KM, AC, UT, and HEP) are valid measurements. **Table 3** shows that when the value of T is within the range of 1.96, the link between factors is insignificant at 95%. When $T > 1.96$, the relationship between factors is substantial at the 95% confidence level. As a result, **Table 3** reveals that the relationships between all variables are significant.

Inner model evaluation and hypothesis testing

After the measurement model of PLS analysis, the structural equations model was calculated (Hair et al., 2017). As indicated in **Table 3**, the direct effect model was measured. Four criteria were used to examine both direct and indirect effects of structural equation models. (R^2) for endogenous latent variables are evaluated to determine the amount of variance in each construct, and impact size (f^2), estimate significance (Q^2), and path coefficient assessments (Hair et al., 2014). In a direct effect structural equations model, analysis was conducted to determine the impact of the 5,000 bootstrapped samples from the first 382 examples to offer point measurements of the change and estimate their significance (Hair et al., 2017).

The R^2 value describes the percentage of variation in endogenous variables that external factors may clarify (Hair et al., 2014). Although a satisfactory value of R^2 depends on the study setting (Cohen, 1988), values of 0.702, 0.744, and 0.490 express high, high, and moderate education performance, respectively. The R^2 value for an endogenous variable for the direct effect model is 0.762, implying that TM, KM, UT, and AC predict a 76.2% change in higher education performance. Moreover, in **Table 5** the R^2 for university transformation is 0.744, indicating that TM and KM explained 74.4% of the difference in university transformation. Also, a cross-validated redundancy measure (Q^2) was used to assess the research model's estimated relevance (Stone, 1974; Hair et al., 2017).

There was support for sufficient estimates significance of the direct effect model. **Figure 2** and **Table 4** show the values of Q^2 greater than zero ($Q^2 = 0.652$) for the endogenous latent variable the direct TM, KM, UT, and AC, recommending satisfactory predictive relevance of the model (Hair et al., 2017). From the **Table 6** results also support the H1, H2, H3, H4, H5,

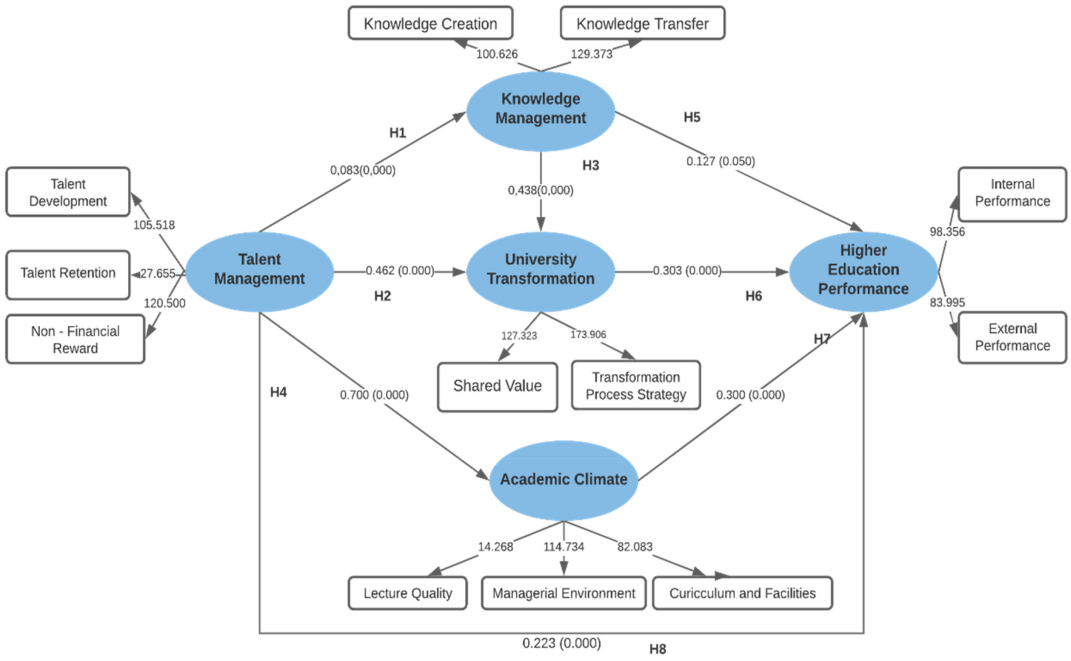

FIGURE 2
Structural equation model.

TABLE 4 Discriminant validity Fornell-Larcker criterion.

Discriminant validity Fornell-Larcker criterion

Construct	1	2	3	4	5
AC	0.873				
HEP	0.787	0.933			
KM	0.714	0.777	0.939		
TM	0.700	0.790	0.838	0.895	
UT	0.796	0.831	0.825	0.829	0.963

N = 382; items displayed in boldface represents the square root of the average variance extracted (AVE).

H6, H7, H8, and H9 the direct effect of TM to knowledge management ($b = 0.838$, $t = 34.378$, $p < 0.000$), TM to university transformation ($b = 0.462$, $t = 8.544$, $p < 0.000$), KM to university transformation ($b = 0.462$, $t = 8.544$, $p < 0.000$), TM to academic climate ($b = 0.700$, $t = 19.995$, $p < 0.000$), KM to higher education performance ($b = 0.140$, $t = 1.963$, $p < 0.050$), UT to higher education performance ($b = 0.306$, $t = 3.925$, $p < 0.000$), AC to higher education performance ($b = 0.265$, $t = 5.438$, $p < 0.000$), and TM to higher education performance ($b = 0.206$, $t = 5.438$, $p < 0.000$) all were positive and significant.

The effect size (F^2) is the direct influence of the independent (exogenous) variable on the dependent (endogenous) variable to determine how large the impact of the exogenous variable is on the endogenous variable (Cohen, 1988). Hair et al. (2017) describe (f^2) estimations with small, medium, and significant

TABLE 5 Coefficient of determination in the partial least square method.

Construct	R^2	R^2 adjusted	Q^2
Knowledge management	0.702	0.701	0.613
University transformation	0.744	0.743	0.677
Academic climate	0,490	0,489	0.357
Higher education performance	0.762	0.760	0.652

effects as 0.016, 0.050, and 0.077, respectively. Table 3 reveals that the impact size of TM on higher education performance is 0.223, 0.127 for KM, and 0.303 for university transformation to higher education performance. As a result, the exogenous constructs' impact on endogenous constructs is modest and high, respectively (Cohen, 1988).

Discussion

The primary purpose of this study was to examine the relationship between talent management, knowledge management, university transformation, and academic climate with higher education performance in the context of the private education sector in Indonesia. The results revealed through structural equation modeling that the components of development, retention by giving a non-financial reward, creating, transferring knowledge, structure, strategy, shared

TABLE 6 Results of the structural equations model.

Relationship between variables of research	SD	*T*-value	Direct effect	*p*-values	F^2
TM → KM	0,024	34,378	0.838	0,000	2,352
TM → UT	0,056	8,544	0,462	0,000	0,248
KM → UT	0,057	8,018	0,438	0,000	0,224
TM → AC	0,035	19,995	0.700	0,000	0.961
KM → HEP	0,065	1,963	0,140	0,050	0,016
UT → HEP	0,080	3,925	0,306	0,000	0,077
AC → HEP	0,058	5,438	0,265	0,000	0,134
TM → HEP	0,063	3,565	0,206	0,000	0,050

value, lecture quality, curriculum, facilities, and managerial environment helps in achieving high performance in education. It also clarifies the role of talent management in enhancing knowledge management, university transformation, and academic climate in private universities, which lead to increased higher education performance. The results also successfully justified the gap in the previous study (Bolander et al., 2017; Erasmus et al., 2017; Farooq et al., 2017; Maghdomi and Keikha, 2017; Miiro and Otham, 2018; Mohammed, 2018; Mohammed et al., 2020) by showing the significant relationship between talent management, knowledge management, university transformation, academic climate, and higher performance in education.

Hazelkorn (2017), Masa'deh et al. (2017), Rambe and Mbeo (2017), Paisey and Paisey (2018), and Karim and Majid (2019) observed the importance of managing talent and knowledge in enhancing higher education performance in the modern globalization era. The study indicated that skills and knowledge management are significant factors in achieving higher education performance. Moreover, Ravanfar (2015) and Ingram (2016) demonstrated that transforming a private university by redesigning structures, systems, shared values, and strategies, and creating academic climate styles impacting organizational performance. This study also supports previous investigations that the educational climate in higher education improves overall students' performance and satisfaction (Mcmurray et al., 2004; Musah et al., 2016). Additionally, academic climate determines the study and research environment where lecturers and students feel satisfied or dissatisfied. Since satisfaction affects employee efficiency, it is assumed that academic climate is directly related to organizational performance (Shahin et al., 2014). Thus, academic climate influences human behavior in organizations by impacting their performance, satisfaction, and attitudes.

This study has provided a theoretical implication by giving further empirical evidence on resource-based view theory, where talent and knowledge management have been hypothesized as a resource for university transformation. Similarly, the results showed that university transformation involves ongoing direction reviews, structure, systems, strategies, values, personnel competencies, and skills to adapt to the changing organizational environment to promote growth and new knowledge (Burnes and Cooke, 2012; Canterino et al., 2018). Previous studies also emphasize three main managerial drivers related to the transformation process: communication, mobilizing process strategy, and evaluating structure (Battilana et al., 2010).

Since talent and knowledge management studies, university transformation, and academic climate are limited in the RBV literature, the outcomes of this study may contribute to the literature and provide a basis for future studies. Besides, most higher education institutions in Indonesia are privately owned. Therefore, investing in employee resources for talent and knowledge management and creating university transformation is highly challenging. As indicated by the outcomes, it is proposed that private university leaders provide mechanisms in which students and lecturers receive all essential information (Acosta et al., 2018). Subsequently, private universities are recommended to support the procedure of creating and transforming information to achieve a competitive advantage and build robust structures.

Private universities must create strategies to boost significant performance growth by offering a conducive academic climate with talented lecturers. This is because talent development is a crucial strategic approach to promoting transformation and performance. The suggested private universities' development plan involves hosting recognitions and rewards, providing feedback, mentorship, and acknowledging the contribution of lecturers. Private universities also need to build innovative standards and structures to align learning to the changing students' needs. Furthermore, these universities should create a system that promotes interdepartmental collaboration to determine the best strategies for retaining lecturer talents (Narayanan et al., 2019; Mohammed et al., 2020).

Talent management requires a supportive higher education academic climate. To achieve high performance, universities should create an environment that supports their lecturers' creativity (Ingram, 2016). The superiority of universities in attracting talent depends on the climate and reputation (Abdullah et al., 2020). Hence, the academic climate can support intrinsic motivation by developing skills (Van den Broek et al., 2018). Developing a plan to transform their talent and the business process is a priority for the sustainable performance

in higher education. The role of talent management, knowledge management, and the academic climate of higher education is the key to emphasizing its importance in shaping the character and quality of higher education.

Leaders in private higher education are responsible for talent management in universities (not just the HR management department). When talent management is seen only as a HR function, then the leadership abdicates responsibility. Leaders in private universities should feel a responsibility to develop their talents, not just look at the result. One way to get started is to form a committee chaired by the chief executive who also includes the head of the human resource division. In addition, spread the urgency of talent management implementation in higher education. Because not all department heads believe that developing talent is an important part of their job.

Higher education in Indonesia needs to stop hiding potential talent. Hoarding lecturers who have great potential is an ongoing problem because leaders or heads of relevant sections are very protective of their own best talents or are not given the opportunity and also create a plan to develop future leadership skills. Smart leaders create systems for developing norms that treat high-potential talent as a potential higher education resource.

Managerial implications

This study explores the strategies including academic climate, talent management, knowledge management, and university transformation. This can be used to improve success in higher education. In talent management, it is expected that private universities can carry out talent development with programs to improve career development policies, maintain work balance, pay attention to working conditions, conduct training, improve lecturers' skills and competencies, and create development programs that utilize the skills of lecturers. Furthermore, talent retention programs need to be developed to keep qualified lecturers from leaving the organization. Several things that need to be done by private universities are to have a competitive compensation system, strive to maintain talented lecturers, and always maintain employee motivation by providing challenges to maintain the rhythm of working at the university. In addition, the role of non-financial award for talents is also needed.

Conclusion

Implementing talent management, knowledge management, university transformation, and academic climate significantly improves higher education performance. Universities can follow the strategic design in this study to achieve superior performance in higher education.

This study provides a new strategic perspective to comprehending performance, emphasizing that university leaders are in charge of managing talent and having the mindset (mindset) of the talent management implementation team in universities, mapping and developing the high potential lecturers, developing future leadership skills, and performance management of higher education talent needed to be implemented. This study also provides recommendations for maximizing the role of human resource management to increase potential and achieve higher education performance.

Limitations and future directions

The study was faced with various limitations, showing the need for further investigations. First, the sample size was limited to private universities based in Indonesia. Therefore, future studies should use a broader representation of higher education institutions in other geographic locations. Second, this study used a single data source and a cross-sectional design, leading to a common bias, and generalization between variables. Future studies, then, should use a longitudinal design to obtain data from various sources. Also, a longitudinal approach with a larger sample should be considered to improve generalizability. Future research could include interviews with a representative sample of different stakeholders (i.e., owners, customers, government, and associations) to obtain more information. Second, it focuses on a single country context, which may limit its generalizability. Exploring the same problem in a multi-country context will be interesting and important.

Data availability statement

The original contributions presented in the study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants in accordance with the national legislation and the institutional requirements.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.929697/full#supplementary-material

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Impact of virtual reality use on the teaching and learning of vectors

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The use of virtual reality in education has enabled the possibility of representing abstract concepts and virtually manipulating them, providing a suitable platform for understanding mathematical concepts and their relation with the physical world. In this contribution, we present a study that aims to evaluate the students' experience using a virtual reality (VR) tool and their learning of three-dimensional vectors in an introductory physics university course. We followed an experimental research design, with a control and an experimental group, for measuring students' performance in a pre-post 3D vectors questionnaire. We surveyed the experimental group about their perception of VR use regarding their learning objectives, their experience using VR as a learning tool during the sessions, and the value of using VR in class. We found that on the items in which visualization was important, students in the experimental group outperformed the students in the control group. Students evaluated the VR tool as having a positive impact on their course contents learning and as a valuable tool to enhance their learning experience. We identified four hierarchical categories in which students perceived the use of virtual reality helped them learn the course contents: Visualization, 3D Visualization, Identification, and Understanding. Overall, this study's findings contribute to the knowledge of using virtual reality for education at the university level. We encourage university instructors to think about incorporating VR in their classes.

KEYWORDS

stem education, virtual reality, vectors, educational innovation, higher education

Introduction

Over the last decade, several universities with the common goal of pushing educational innovation forward have invested in centers for educational innovation with a focus on emerging technologies (Hidrogo et al., 2020a). Some of the most popular emerging educational technologies are virtual reality, blockchain, internet of things,

artificial intelligence, among others. Particularly, virtual reality is in a crucial moment to be implemented massively, due to several reasons. Some characteristics of virtual reality make it a favorite candidate for its application for teaching and learning in higher education; (i) as a technological tool, it can be directly applied to the teaching-learning process. (ii) Its current technological maturity stage has allowed for the development of hardware and software that can be incorporated into the educational context. At the same time, the costs have been generally reduced, making the incorporation into the educational context more viable. (iii) It can boost curiosity among students (Hidrogo et al., 2020b); and (iv) for most students, the university is the only place where they can access this technology.

Virtual environments are becoming relevant in different areas of science education, including natural, medical and computer sciences (Chou et al., 2001; Broisin et al., 2017; Paxinou et al., 2020). Many studies about the use of VR in science education focus on students' learning outcomes, motivation, and attitude when using VR (Arici et al., 2019). The literature reports no significant differences in learning outcomes when comparing VR with other active learning experiences (Klahr et al., 2007; Moro et al., 2021), but some studies do report learning gains when comparing VR with traditional learning (Johnson-Glenberg and Megowan-Romanowicz, 2017; Liu et al., 2020). The literature on the use of VR about abilities and attitudes in science students reports improvements in students' achievement, interests and learning experience in STEM education (August et al., 2016; Al-Amri et al., 2020). The relevance of the use of VR to improve certain scientific skills, such as visualization of abstract concepts, has been highlighted by some studies (Güney, 2019; Hite et al., 2019).

The use of virtual reality in education has enabled the possibility of representing abstract concepts and virtually manipulating them, providing a suitable platform for understanding mathematical concepts and their relationship with the physical world. Many physical quantities, such as force and acceleration, are mathematically modeled with vectors for describing, computing, and predicting the physical world. Therefore, understanding and working with vectors is necessary for learning physics. The literature highlights the benefits of using VR in science learning. Different studies have reported the development of AR applications for learning vectors, their properties, and operations (Martin-Gonzalez et al., 2016; Langer et al., 2021). In this contribution, we present a study with the objective of evaluating students' learning and experience when using a virtual reality tool to learn about three-dimensional vectors in a university physics course. We first present a literature review on the basic concepts of virtuality and educational technology. We define the context of the study and present the research questions. We provide the methodology for the study, the description of the participants, instruments, data collection, and analysis. We present the quantitative and qualitative results and discuss the relations between them. Finally, we conclude the article with some recommendations for implementing educational technologies in the science classroom.

Literature review

When working with virtual reality (VR) it is essential to review the definitions of mixed reality, augmented reality, and virtual reality to portray our stand on these concepts. Mixed reality is a type of hybrid environment that blends the physical environment with virtual objects (Tang et al., 2020). It describes a linear continuum that ranges from real environments (reality) to fully virtual environments (virtuality) (Milgram and Kishino, 1994 as cited by Tang et al., 2020). In mixed reality, the real and virtual contents allow for data contextualization, they provide real-time interactivity, and the content needs to be mapped and correlated with the 3D space (Tang et al., 2020). Within this continuum, we find augmented reality, which integrates virtual objects into real-life environments, usually using devices such as smartphones or wearable smart glasses (Chuah, 2018). The real-life environment and the virtual objects interact through the augmented reality device in real-time (Dodevska and Mihic, 2018). For example, when taking a real-life picture with a camera on a smartphone, AR can attach virtual objects to the photograph (Sahin and Yilmaz, 2020). It has been found that augmented reality helps students to visualize abstract concepts, allowing them to observe phenomena that would be impossible otherwise (Sahin and Yilmaz, 2020).

At the end of the reality-virtuality continuum, we find virtual reality. VR blocks out the real world and creates a fully virtual setting to immerse the users into the virtual world (Chuah, 2018). Since VR represents only three-dimensional virtual environments generated with computers, it is necessary to use the appropriate hardware and software to experience VR (Dodevska and Mihic, 2018). VR is an experience in which the user is physically in the real world, entering a three-dimensional virtual environment using a headset and a computer or with a mobile device (Frost et al., 2020). The VR market nowadays has contributed to academic research, engineering, and education, among other areas (Tang et al., 2020).

To design and develop VR learning experiences, it is necessary to consider key educational process elements, such as effective pedagogy, considering the time for teaching and learning activities, using appropriate tools and resources, and promoting student engagement (Tang et al., 2020). Buentello-Montoya et al. (2021) highlighted the importance of having an adequate pedagogical design when implementing VR and AR in the learning of mathematics. Research has found that virtual learning environments can enhance, motivate, and stimulate learning that the traditional approach could not achieve easily (Pan et al., 2006 as cited by Tang et al., 2020). Educational technologies can improve science courses by implementing effective scientific activities and bringing students

closer to abstract situations that are difficult to recognize in real life (Sahin and Yilmaz, 2020). The development of virtual experiences in science teaching should be designed to enhance student learning and motivate positive attitudes in students.

Dodevska and Mihic (2018) highlight some advantages and disadvantages of using VR. As advantages, VR can help make decisions in complex projects, reduce time and efficiency, and provide simulations that could lower costs and improve experiences. The main disadvantages are that the initial costs of the hardware and software requirements and changing platforms may not be quite straightforward.

Virtual and augmented reality in science education

Virtual environments are becoming relevant for science education in different areas, such as computer science education (Broisin et al., 2017), nanotechnology education (Xie and Lee, 2012; Schönborn et al., 2016), biology education (Poland et al., 2003; Paxinou et al., 2020), building sciences education (Setareh et al., 2005), health science education (Chou et al., 2001), chemistry education (Miller et al., 2021), among others. Research suggests that VR can be effectively implemented as a virtual class for web-based science education (Shin, 2002). Pre-service science teachers become aware of the potential advantages and disadvantages of using virtual reality within a classroom setting after using a multi-user virtual environment (Kennedy-Clark, 2011). Cowling and Birt (2018) emphasize the need to put pedagogy before the technology to create mixed-reality simulations that satisfy students' pedagogical needs with a design-based research approach.

The trends in mixed reality studies show that most studies focus on learning achievement, motivation, and attitude and that there is a lack of qualitative research in this area (Arici et al., 2019). Most research compares students' learning outcomes when using VR to other approaches such as AR, hands-on experiences, and/or traditional education. Research suggests that VR is more effective for visual educational content, while AR is a better option for auditory learning (Huang et al., 2019).

The research has found no significant differences in learning outcomes between VR, AR and hands-on experiences. Research has shown that hands-on activities performed in virtual and physical environments are equally effective in producing significant learning outcomes regarding learners' knowledge and confidence in early science education (Klahr et al., 2007). Other studies have found that there is parity between using hands-on learning and virtual reality in learning outcomes and cognitive processes (Lamb et al., 2018). In the teaching of medical sciences, several studies have found that there is no significant difference in learning outcomes between using VR, AR or tablet-based simulations; however, using VR participants reported adverse effects, such as dizziness (Moro et al., 2017a,b, 2021).

However, when comparing the use of VR with traditional approaches, the literature reports learning gains. McElhaney and Linn (2011) found that students experiment with virtual environments as intentional, unsystematic and exhaustive experimenters, and that these students had significant learning gains on physics understanding. Collaborative embodied learning in mixed-reality environments leads to increased learning gains compared to regular instruction in science learning (Johnson-Glenberg et al., 2014; Johnson-Glenberg and Megowan-Romanowicz, 2017). Using whole-body, immersive simulations of critical ideas in physics leads to significant learning gains, high engagement, and positive attitudes toward science (Lindgren et al., 2016). Using VR in the science classroom improves academic achievement and engagement scores compared to traditional courses (Liu et al., 2020).

Several studies have found that the use of VR improves specific abilities and attitudes in science students. Implementing a 3D Virtual reality learning environment improved female students' physics achievement and motivation toward physics learning (Al-Amri et al., 2020). Scherer and Tiemann (2012) found three problem-solving abilities in virtual environments, achieving a goal state, systematic handling of variables, and solving analytical tasks. Motivation and students' learning attitudes in immersive virtual environments for science education are related through the constructs of intrinsic value and self-regulation, while students' attention and enjoyment relate to students' learning in the immersive virtual environment (Cheng and Tsai, 2020). Implementing a Virtual Engineering Science Learning Lab (VESLL) has proven to improve student interest and learning experience in STEM education (August et al., 2016).

Güney (2019) highlights the relevance of visualization and visual literacy in instructional design for implementing technology in learning environments through a literature review on visual effects, visual literacy, and the design of multimedia instruction. Using a haptic virtual model with visual and tactile sensorimotor interactions may provide students with the opportunity to construct knowledge about submicroscopic phenomena (Schönborn et al., 2011). Using VR environments and technology for science learning, it is essential to consider students' spatial acuity, since the learners' cognitive development plays an important role in students' perception of virtual reality (Hite et al., 2019). In the learning of mathematics, Schutera et al. (2021) highlighted the relevance of using AR in developing spatial visualization when learning vectors.

Definition of the study

In this experimental study, we used PC-powered VR equipment, each one with two controllers to interact with

the virtual environment. This equipment has sensors on the ceiling to enable room scale, which is the function of reflecting movements carried out in the physical world in the virtual environment. The equipment is part of the MOSTLA center, the experiential learning space for emerging technologies at Tecnologico de Monterrey. The center provides emerging technology opportunities for faculty and students at the university (Hidrogo et al., 2020b).

We used the VR commercial application Gravity Sketch, a tool for three-dimensional object design and prototyping compatible with the most popular VR systems. In this case, the VR system was HTC Vive connected to computers with Windows. For its focus on design and 3D modeling, Gravity Sketch allows the drawing and manipulating of objects through a three-dimensional grid so that it is possible to draw coordinate axes, locate the vectors in the grid, and measure the length of the vectors. It also allows drawing planes, visualizing projections of vectors in this plane, and drawing angles wherever needed. With these tools, the students could access vector models previously designed by the instructor, observe them from every angle and manipulate them to conduct measurements and computations of their dimensions, angles, and projections. Additionally, they could create their own vectors to model the physical problems they needed to solve. **Figure 1A** presents an example of the identification of vectors in Gravity Sketch and **Figure 1B** presents the students working in teams with the equipment: One student is using the VR goggles and the other students are visualizing it on the screen.

The students worked in teams of four students, assigned randomly, with preassigned activities that promoted observation of three-dimensional vectors using VR equipment. For teamwork, an external monitor is connected, which allows students outside the virtual world to watch what the student who uses the VR is watching. The students had one group session with the instructor to carry out the first activity. In this session, they learned to use the VR equipment with immediate feedback from the instructor. After the first session, the teams attended the VR lab outside of class time to complete all the activities.

For example, we provide the design of one activity, where students learn to identify the angles alpha, beta, and theta. The activity instructs students to create a Gravity Sketch file based on the Cartesian axes file (a previously designed file), and to draw a vector that begins at the origin and ends at some point of the first octant naming this vector as **A**. The activity asks students to draw the alpha, beta and theta angles for vector **A** on the virtual reality simulation. Additionally, in their worksheet, students receive the following instructions:

a. Define the vector **A** in terms of the unit vectors **i**, **j**, and **k**.
b. Calculate the magnitude of vector **A**.
c. Calculate the angle α .
d. Calculate the angle β .
e. Calculate the angle θ .
f. With the three angles that you calculated, compute: $cos^2\alpha + cos^2\beta + cos^2\theta$.

This activity has easy-to-follow and clear steps to visualize the angles in the three-dimensional virtual setting and to construct the algebraic representation of the three angles based on observations. Since this is a collaborative task, the team members can see the projection of the VR setting on the screen and write their calculations and conclusions on the worksheet. In Gravity Sketch, students were able to visualize the vectors in 3D, changing the perspective when they walked or moved their heads. They could also draw their own vectors, project them on planes and measure the dimensions of each vector, allowing them to calculate magnitudes and angles. The activity itself may take little time for experienced learners, but for most students, this course is their first approach to using VR, and they take turns using the VR equipment. The three activities follow a similar design with different objectives. The first activity helps students familiarize themselves with the equipment and define different vectors in the i, j, k unit vectors. The second activity is the example that we presented. The third activity prompts students to visualize the projection of the angles in the x-y plane and calculate the angle phi.

Research questions

Our main research question is: How does using VR impact students' learning and students' perceptions of learning three-dimensional vectors in an introductory physics course? We direct our research question to two constructs, student learning of three-dimensional vectors and students' perception of their experience using virtual reality. We identify three subordinate research questions:

- How does using VR impact students' learning of three-dimensional vectors in an introductory physics course?
- How do students perceive their learning outcomes achievement when learning three-dimensional vectors using VR in an introductory physics course?
- How do students perceive their experience using VR for learning three-dimensional vectors in an introductory physics course?

Materials and methods

We present the methodology with an experimental design. We had one control group and one experimental group, and we measured their performance in a pre-post questionnaire. We additionally surveyed the experimental group about their

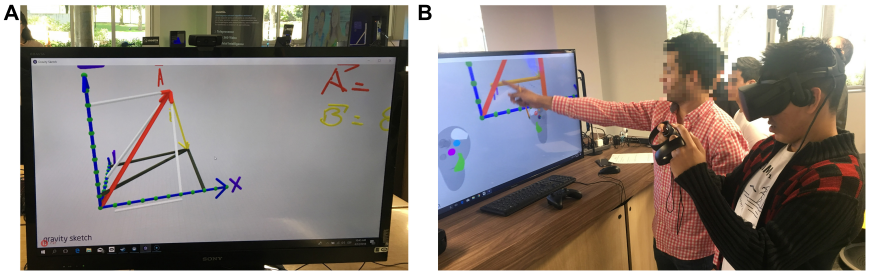

FIGURE 1
Details of implementation with Gravity Sketch. **(A)** Example of vectors in Gravity Sketch. **(B)** Students interacting through the virtual reality (VR) goggles and with the screen.

perception of the use of VR regarding their learning objectives, their experience in the VR sessions, using VR as a learning tool, and the value of using VR in class.

Participants

The participants were 94 first-year engineering students (18–20 y/o) taking the introductory physics course in a large private Mexican university. The course is a full-credit undergraduate course at the university, consisting of 3 h of class time each week for 16 weeks (48 h in total). In this course, students develop the ability to learn and apply mathematical concepts and tools to model problems in physics that are useful to them in their professional lives. The course is highly focused on the use of vector quantities for the study of engineering. The teaching approach is active learning; students work collaboratively, guided by activities designed to generate team discussions. The textbook is Introduction to university physics, which consists of three volumes: activities, problem manual, and concepts and tools (Alarcón and Zavala, 2012).

The control group (N_C = 29) took the regular introductory course at the university, benefiting from all the elements described above. The experimental group (N_S = 65) took the same course with the VR sessions instead of the guided activities related to three-dimensional vectors. The same instructor taught both courses, and the control and experimental group were assigned randomly. Students acknowledged their willingness to use the VR tools and participate in the study voluntarily and provided consent, knowing their information would be used anonymously.

Instruments

We have two instruments for this study, a pre-post 3D vector questionnaire for the control and experimental groups and a survey about students' experience with VR, which was only applied to the experimental group. The pre-post questionnaire consisted of 14 multiple-choice questions about vector magnitude, direction, and projection. Six of the fourteen questions required students to analyze the range of possible values for the angles between a vector and the axes, alpha, beta, theta, and phi. We present these six questions in **Table 1**. The remaining eight questions were dedicated to computing the magnitude or projection of a specific vector. We present these eight questions in **Appendix Table A1** for reference. In general, the questionnaire evaluates students' abilities to visualize, identify, and understand the definitions of the alpha, beta, theta, and phi angles with respect to the coordinate axes.

The survey of experience consisted of 8 qualitative questions, six open-ended and 2 yes/no questions (see **Table 2**), and 15 quantitative Likert-scale questions with five levels of agreement, ranging from strongly disagree (1) to strongly agree (5) (see **Table 3**). The open-ended questions provide information about students' perception of their achievement of learning objectives and their own experience with the VR setting. The Likert-scale questions provide information about using virtual reality as a learning tool and the value students find in virtual reality.

Data collection and analysis

The experimental design consisted of the pre-post questionnaire (**Table 1**), the implementation of the VR sessions in the experimental group, and the experience survey (**Tables 2**, **3**) to the experimental group. All the control and experimental group participants answered the pre-questionnaire before covering the topic of vectors in class. The topic of vectors was covered in 2 weeks. During these 2 weeks, the control group had regular active learning instruction. The experimental group had the first VR session with the instructor and worked on the VR activities outside of class time. After covering the topic of vectors, the students from the control group (N_C = 29) and the experimental group (N_E = 55) answered the post questionnaire. The experience survey with open-ended questions and Likert-scale items was

TABLE 1 Six items of the pre-post questionnaire with the objective of analyzing the angles alpha, beta, theta and phi of different vectors.

Item	Question	Options
Q1	Select the option that represents the range of possible values for the alpha angle of the vector A = 2.5i + 3.8j + 4.6k	a) 0° b) Greater than 0°, but smaller than 90° c) 90° d) Greater than 90°, but smaller than 180°
Q2	Select the option that represents the range of possible values for the beta angle of the vector B = 5.3i – 2.2j - 3.7k	
Q3	Select the option that represents the range of possible values for the theta angle of the vector C = 6.8i – 5.1k	
Q4	Select the option that represents the range of possible values for the theta angle of the vector B = 5.3i – 2.2j – 3.7k	a) 0° b) Greater than 0°, but smaller than 90° c) 90° d) Greater than 90°, but smaller than 180° e) 180° f) Greater than 180°, but smaller than 270° g) 270° h) Greater than 270°, but smaller than 360° i) 360°
Q5	Select the option that represents the range of possible values for the phi angle of the vector B = 5.3i – 2.2j – 3.7k	
Q6	Select the option that represents the range of possible values for the phi angle of the vector C = 6.8i – 5.1k	

implemented 2 weeks after the VR sessions for the experimental group only (N_S = 65). The control group did not answer the experience survey because they did not attend the VR sessions. The instruments were implemented through Google Forms.

The pre-post questionnaire was scored as correct/incorrect for all the questions since they were multiple-choice questions. All the questions had the same weight, and the score was calculated with the average of correct answers. We analyzed the pre-post questionnaire using the normalized learning gain (Hake, 1998). This measure analyses the differences between the pre and post-average scores and normalizes them by comparing them to the highest possible score. If the highest score is 100, then the normalized gain is calculated with: g = (%sf - %si)/(100 - %si), where g is the gain, %sf is the percentage of the final score, and %si is the percentage of the initial score. The learning gain provides evidence about the effectiveness of an educational intervention.

We analyzed quantitative data from the Likert scale questionnaire using SPSS. We performed a principal component factor analysis with an Oblimin rotation since it does not have to force the factors to be orthogonal. As with any other social scale, the factors could be correlated. The analysis divided the 15 items into two components that we called dimensions. The first dimension we call "learning tool" has 10 items related to statements describing how VR helps students learn. The second dimension, we call the "tool value," has five items related to how students value VR. Cronbach's alphas for the survey were 0.93, and the learning tool, dimension and tool value dimension were 0.94 and 0.84, respectively. We analyzed the qualitative data from the open-ended questions through coding, reaching moderate interrater reliability (Cohen's kappa = 0.71) (Donkin and Kynn, 2021).

TABLE 2 Open-ended questionnaire about students' learning objectives and experience using virtual reality (VR).

Item	Question
LO1	How was VR helpful in learning about vectors' components?
LO2	How was VR helpful in learning about vectors' angles?
LO3	What new knowledge did you learn in any of the VR sessions?
E1	The ideal VR session would be about __ minutes long.
E2	I think the most valuable of this experience was:
E3	If the sessions were not helpful, it could be because of:
E4	I had previous experience with VR in another course (yes/no).
E5	The course met my expectations (yes/no).

Results

Impact of virtual reality use on learning

We present the results for the first subordinate research question, how does using VR impact students' learning of three-dimensional vectors in an introductory physics course? The pre-post questionnaire was a 14-item questionnaire that included the six questions presented in **Table 1**, and eight more questions that asked students to calculate the magnitude or projection of a specific vector (**Appendix Table A1**). We analyzed the normalized learning gain for the complete questionnaire (14 items) and found no significant difference between the control and experimental groups (0.38 and 0.36, respectively). Both groups had a learning gain greater than 0.3, which is medium, according to Hake (1998). This implies that the control and experimental groups have similar learning. Both groups benefit from the active learning strategies implemented by the professor and the course content, regardless of the VR use.

We selected the six questions in **Table 1** because these items specifically address the ability to visualize the relations between the vectors, their components in the three-dimensional axes

TABLE 3 Likert-scale questions related to students' learning objectives and experience using virtual reality (VR).

Dimension: learning tool

Item	Statement	Levels
LT1	The VR tool definitely helped me to learn.	1–Strongly disagree 2–Disagree 3–Neutral 4–Agree 5–Strongly agree
LT2	The VR tool helped me to understand three-dimensional vectors.	
LT3	The VR tool helped me to get a better grade in the exam.	
LT4	If a friend had trouble with this course, you would recommend the use of VR.	
LT5	I think that VR has a future to help learning about vector components in 3D.	
LT6	I think that VR has a future to help learning about vector angles.	
LT7	The VR helped me to visualize or imagine mathematical problems of vectors that I needed to solve.	
LT8	The time dedicated to VR sessions was valuable for learning.	
LT9	The VR helped me to understand the location and meaning of the alpha, beta, theta and phi angles.	
LT10	I learned things that I would not have learned without the VR session.	

Dimension: tool value

Item	Statement	Levels
TV1	Learning the VR tool took little time.	1–Strongly disagree 2–Disagree 3–Neutral 4–Agree 5–Strongly agree
TV2	I would like to come to the VR lab by myself and work on preassigned material.	
TV3	The next semester, I will definitely look for some VR support.	
TV4	I would equally attend the VR sessions if they did not count toward my final grade.	
TV5	It would be great to have VR to use at home.	

and the angles between them. We aim to see whether the VR implementation helped students to improve their visualization of the relationship between vectors, components, and angles. We calculated the normalized learning gain for these six questions independently. We found that the control group had 0.14, which is a low gain in Hake's (1998) definition, while the experimental group had 0.27, which is a medium gain. As described by Hake (1998), the difference in the learning gains provides evidence that the VR implementation helped students improve their visualization ability of vectors in three-dimensional space.

Student's perception of learning outcomes achievement

We present the results for the second subordinate research question; how do students perceive their learning outcomes achievement when learning three-dimensional vectors using VR in an introductory physics course? We provide two perspectives for answering this question. We first provide the Likert scale survey results, where students evaluated the use of VR as a learning tool and its perceived tool value. We then present the results of the qualitative analysis of learning objectives.

Likert-scale survey

We present the results of the Likert scale items for the two dimensions: "Learning tool" and "Tool value," in **Figures 2**, **3**, respectively. Both figures use traffic light colors to represent the level of agreement or disagreement: The green side represents an agreement, the yellow percentage represents neutrality, and the orange and red sides represent disagreement.

In the dimension "Learning tool," students evaluated whether they agreed or disagreed with 10 statements about using VR as a learning tool. We found that over 90% of students agree that VR helped them learn, understand three-dimensional vectors, visualize mathematical problems involving vectors, and understand the location and meaning of the angles between vectors and three-dimensional axes. They also agree that the time dedicated to VR sessions was valuable for learning, and they see the future of VR as helping to learn about angles and vector components. They agree that they would recommend a friend use the VR tool for learning if they had trouble with the introductory course. The only items where students had a minor agreement (at least 80%) were about getting a better grade in the exam and learning something that they would not have learned without the VR tool.

In the dimension "Tool value," students evaluated their agreement with five statements about the worthiness of using VR for learning. More than 90% of students agree that it would be great to have VR at home. Over 80% of students agreed that they would look for courses with VR support in the future and that learning to use the VR tool took little time. More than 75% of students agreed that they would attend the VR sessions even if they did not count

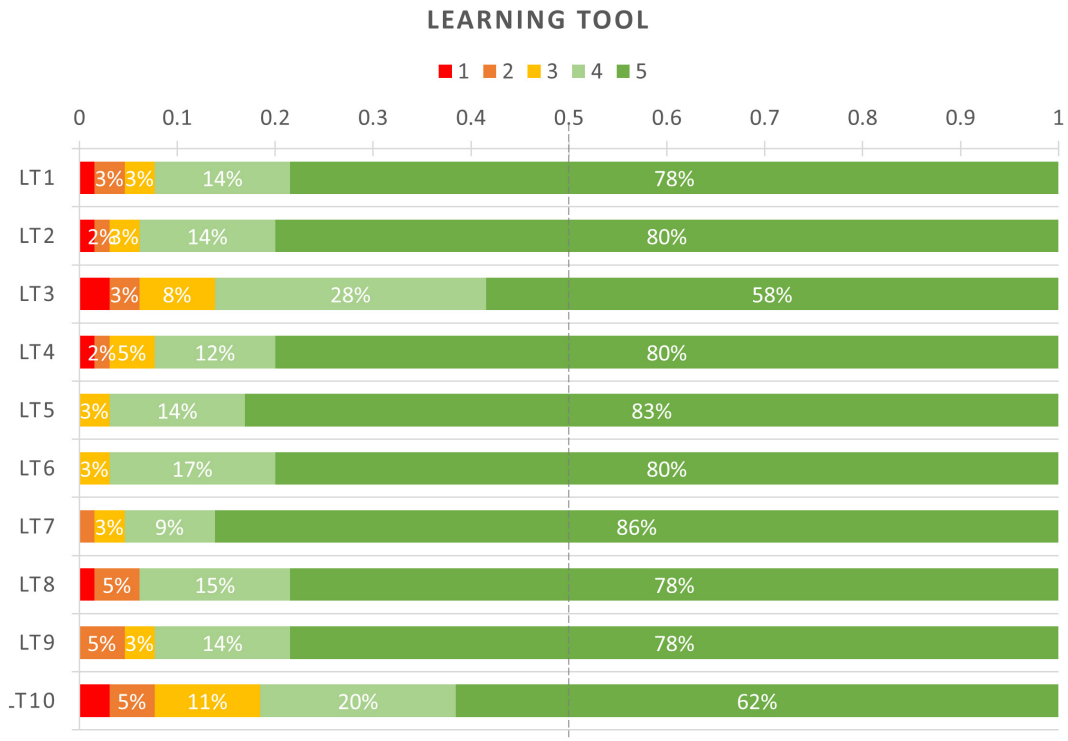

FIGURE 2
Results of Likert-scale dimension of the use of virtual reality (VR) as a learning tool.

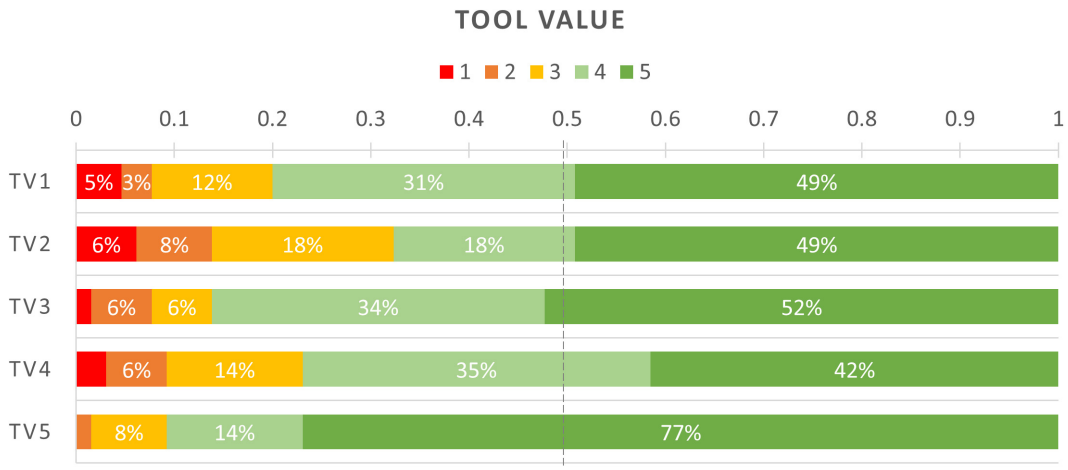

FIGURE 3
Results of Likert-scale dimension of the value of virtual reality (VR) as a tool.

toward their grades. Over 65% of students agreed that they would like to attend the VR lab by themselves to work on preassigned materials.

Qualitative analysis of learning objectives

Three open-ended questions assessed students' achievement of learning objectives. Items LO1 and LO2 referred to how the VR was helpful for students to learn about vector components and angles, respectively. Item LO3 referred to new knowledge learned while doing the VR sessions.

Since items LO1 and LO2 were similar in nature, the same four categories emerged when analyzing students' answers to these two questions: Visualization, 3D visualization, Identification, and Understanding. We describe these categories

TABLE 4 Description of categories for questions LO1 and LO2.

Category	Description	Example	Components (LO1) (%)	Angles (LO2) (%)
Understanding	Students mention that VR helped them to understand a specific topic better.	"Understanding the direction of the resulting vector if I know the components."	23	11
Identification	Students mention that VR helped them to identify or locate the components or angles.	"To locate and sketch the components of the resulting vector."	13	37
3D visualization	Students mention that VR helped them to visualize the vectors in three-dimensional space.	"To visualize the vectors in three dimensions."	34	8
Visualization	Students mention that VR helped them to visualize the vectors, components or angles.	"To visualize it! To see it! They had told me to imagine it and I had no idea of how it would look."	24	37
Other	Unclassifiable answers	"The angles."	6	7
Total			100	100

The examples are taken from question LO1.

in Table 4 and propose a pyramidal structure, as shown in Figure 4. In the hierarchical structure, we find that at the most basic level, the VR tool helps students to visualize the components and the angles of the vectors. The next level explains that the VR tool helps students to visualize in three dimensions. Some students that explain that VR helps them visualize may refer to the three-dimensional aspect of it, but they were not explicit. The third level would be an identification of the components and angles. This is higher than visualization because it not only helps students visualize but they are also able to identify and possibly relate the vectors with mathematical systems. At the highest level, we find that the VR tool helps students to understand the vectors' components and angles in a way that would have been more difficult otherwise. When students' answers reported two or more levels, we classified them as the highest.

In item LO3, students reflected on their learning achievements and answered what new learning they had during the VR sessions. Due to the openness of the possible answers, we analyzed the emerging categories differently because they do not have a hierarchical structure. We present the results in Table 5. In a few cases, students' answers could fit in more than one category, so we considered them in all the categories they could fit. We found that the most frequent category was that students learned about 3D vectors in general. This broad category was sometimes present with the categories Angles, Projections, and Components, which are all related to specific learning topics about 3D vectors. In Figure 5, we present how the categories Angles, Components, and 3D Vectors interacted; these categories were the three most frequent that pertain to the disciplinary learning of vectors. The next big category was Virtual Reality. Students categorized their learning consistently. We observe that the largest proportion of students mentioned 3D vectors which is what the tool is for. The second largest proportion is the angle in which it is the content students struggle with most in this course. The gain results of the pre and post-questionnaire are evidence that they learned better angles using VR.

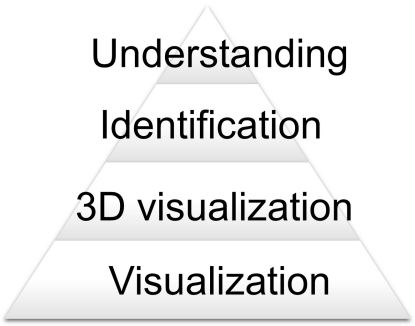

FIGURE 4
The categories that emerged in questions LO1 and LO2 have a hierarchical structure, with visualization as the most basic learning objective and understanding as the highest.

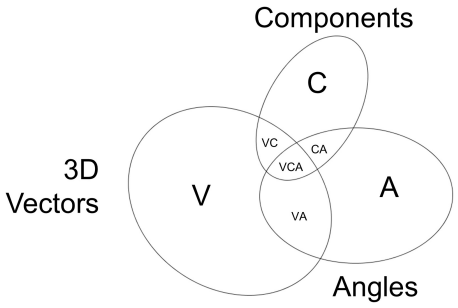

FIGURE 5
We represent the interaction between the 3D Vectors, Components, and Angles categories. We present a weighted Venn diagram generated using EulerAPE (Micallef and Rodgers, 2014).

TABLE 5 Description of categories for question LO3.

Category	Description	Example	LO3 (%)
3D Vectors	Students mention they learned about 3D vectors in general.	"How to work with 3D vectors."	31
Virtual Reality	Students specify they learned to use the VR tool.	"How to use VR."	25
Angles	Students specify they learned to obtain the angles of vectors.	"I learned to get the different angles: alpha, beta, theta and phi."	18
Components	Students specify they learned about the components of vectors.	"Helped me identify the vectors in the different quadrants, just by seeing the i, j, k components."	11
Visualization	Students specify they could visualize some aspect of vectors.	"I related the equations visually."	8
Projections	Students specify they learned about projections of vectors in planes.	"The [vectors'] shadow on the x-y plane."	6

Since more than one category may be present in the same answer, the percentages do not add up to 100%.

Qualitative analysis of students' experience

We present the results of the third subordinate research question: How do students perceive their VR experience in learning three-dimensional vectors in an introductory physics course? This section analyzes some aspects of students' experience using VR. We found that 85% of our students had not had previous experience with VR in other courses, so this was their first VR experience. It is important to describe students' experiences from two perspectives, their most valuable takeaways and the factors that could have affected their experience negatively.

In **Table 6**, we present their most valuable takeaways, which are identified in four categories: educational experience, learning, virtual reality, and visualization. In the previous section, we see that these categories are congruent with students' answers about their learning objectives. For example, we get here two categories that are related to learning outcomes: learning as a broad category that includes several aspects, and visualization, which we identified as the first level of the learning hierarchy in **Figure 4**. Furthermore, we see that 25% of students answered that they learned using the VR in **Table 5**, and 25% of students described that using VR was their most valuable takeaway from the experience in **Table 6**, so we see that for one quarter of our students the VR was a lesson in itself. These findings are supported by item E5, in which we found that using VR tools helped meet the expectations of 91% of students who answered "yes."

Table 7 presents the aspects that could affect students' VR experience. The categories that emerged when analyzing item E3 were motivational aspects, such as attention and interest, and limitations such as their poor familiarity with the VR tool, the content knowledge, and time. We think it is important to acknowledge that students have their own limitations and that implementing a new and exciting technology in class will not mitigate these limitations completely. Students recognized two motivational aspects that could affect their VR experience: attention and interest. Together, they represent 37% of the students. Also, when introducing new technologies in the classroom, there will be limitations of familiarity with the technology and the time of instruction. Analyzing item E1, we found that 75% of students prefer VR sessions of 30–60 min; More precisely, 38% think the sessions should be anywhere between 30 and 59 min, and 37% think they should be 60 min long.

Discussion

Our findings suggest that using VR in a vector course positively impacts learning three-dimension vectors and positively impacts students' perceptions of the experience of using that tool. Emerging technologies in education are becoming more common in recent years (Chou et al., 2001; Broisin et al., 2017; Paxinou et al., 2020). One of the main objectives in any use of technology, however, not the only one, is the impact technology has on learning. However, learning can be improved with the use of the tool and by motivating students to learn with a positive experience using the technology.

The 14-item pre and post-questionnaire results and the six items in which the visualization takes an important role are evidence that this technology has potential for the learning of vectors. We realize that the use of VR for visualization helps students in general with the course contents, i.e., the overall gain was the same for the control and experimental groups; however, on those items in which the visualization is necessary, students in the experimental group had a better result. Taking as reference the description of the ranges in values for the learning gain in some other topics in physics (Hake, 1998), the results for learning gain for all students in this course is in the middle range. According to the characterization of Hake (1998), this result indicates that this course uses active learning activities. However, the results are different in those items in which visualization was essential. Students in the control group obtained a learning gain in the range considered low, and for students in the experimental group, their gain was still in the middle range. This evidence that the VR technology used in vectors helps students better understand some content in which visualization is an essential tool and has no effect on other types of content.

TABLE 6 Description of categories for question E2: "I think the most valuable of this experience was."

Category	Description	Example	E2 (%)
Educational experience	Students describe aspects of the educational experience, such as the professor's involvement, the time, the experimentation, and the educational innovation or technology.	"That the professor took the time to teach us this topic with a new technology, so that we could understand the topic better."	29
Virtual Reality	Students describe that the use of VR was the most valuable takeaway.	"Learning to use VR."	25
Visualization	Students describe that the ability to visualize the vectors was the most valuable of their experience.	"The experience of visualizing the vector in real life."	25
Learning	Students highlight learning as the most valuable takeaway.	"Understanding the topic excellently."	17
Other	Unclassifiable answers		4
Total			100

TABLE 7 Description of categories for question E3: "If the sessions were not helpful, it could be because of."

Category	Description	Example	E3 (%)
Attention	Students describe that their lack of attention affected their experience.	"I was not paying attention to the explanations."	31
VR use	Students describe that not knowing how to use the VR beforehand affected their experience.	"That I did not understand well how to use it."	18
They were helpful	Students do not provide an answer because they specify that the VR experience was helpful.	"They did help."	11
Time	Students describe that the time was not enough.	"I did not understand many things because they were too fast."	8
Interest	Students describe that their lack of interest affected their experience.	"Lack of interest."	6
Knowledge	Students identify that their knowledge was limited.	"I did not understand the theory."	5
Other	Unclassifiable answers.		7
Unanswered	Students left the question blank.		14
Total			100

The results of the experience survey (subsection Student's Perception of Learning Outcomes Achievement) present positive student perceptions of the use of this technology. The 15-Likert type items (see Table 3) are part of the evidence of how students perceive the technology as a learning tool and the value of the tool. In the learning tool dimension of the survey, the students' agreement is between 82 and 97%. Students perceive that VR helped them better understand the vector concepts in the class, such as the three-dimensional vectors, visualization of the angles, and components of vectors. If we look at the pre and post-test questionnaire results, we have evidence that this is not only their perception; students did better on those concepts.

There are also positive students' perceptions of the value tool dimension. However, in this dimension, the results are not as good as in the learning tool dimension. We interpret the best results of this dimension to be in items in terms of access. Students agreed with "It would be great to have VR to use at home" since, in that way, they could have used the tool in a more flexible way (access to the tool). Moreover, students agreed with "The next semester, I will definitely look for some VR support" which is another way of access for future use that could have come in handy in other courses.

On the other hand, the lowest proportion of agreement came in items for which students were asked for extra work. The items "I would like to come to the VR lab by myself and work on preassigned material" and "I would equally attend the VR sessions if they did not count toward my final grade" have this characteristic. They are items in which students have to do extra work, either going to the lab or doing the activities without credit. However, students still have positive perceptions, with the agreement of 67 and 77%, respectively.

Table 4 and Figure 4 show a connection between students' perceptions and what they learn. Table 4 shows that the percentages for each category (each level) are similar for components and angles. The difference is in the 3D visualization and identification. However, the results agree with the content. In LO2 (angles), students think more about identifying them, which is one of the most challenging tasks in this topic. On the other hand, in LO1 (components), students think more of the 3D visualization, which is essential for vectors in three dimensions. In particular identification, the highest-level category besides understanding has 37% for angles, which is essential to answer some pre- and post-questionnaire questions.

We also found that some students value the technology by itself. Table 5 shows that 25% of students answered that what they learned was the use of VR, opposite to the rest, in which they mentioned content (3D vector, angles, components, projections) or tools for learning like visualization. The same happens in Table 6, in which 25% of students described that using VR was their most valuable takeaway. In any use of new technology, some students will pay more attention to the technology instead of what the technology is used for.

A small proportion of students blame VR whether they have problems learning. In Table 7, we present evidence of that tiny proportion. It is helpful to identify blank answers because of how the question was framed. We asked students to provide a reason if the sessions were not helpful, so the students who left the question blank probably did not think of why the session would not be helpful. This, supported by the category "They were helpful," adds to 25% of students. We think this is a promising finding because, regardless of students' limitations, we can see that at least a quarter of students' experiences was not affected negatively by internal or external factors.

Conclusion

In this study, we examined the impact of virtual reality on students' learning and perception of the experience in a university introductory physics course in which vectors are part of the content. We used PC-powered VR equipment, each one with two controllers to interact with the virtual environment. We used Gravity Sketch, a software that allows students to manipulate vectors through a three-dimensional grid. It is possible to visualize, draw coordinate axes, identify components and angles, locate the vectors in the grid, and measure the vectors' length. The students worked in teams with preassigned activities that guided their use of the VR equipment and promoted observation. We had one control group and one experimental group. We measured their performance in a pre-post questionnaire and a survey about their perception of VR's use regarding their learning objectives and their experience in the VR sessions.

We found that on those items in which the visualization was important, students in the experimental group, i.e., using VR, did better than those who did not use VR. We have evidence that VR can help students visualize angles and components that help them solve problems better. It does not help students with all content, only on those problems in which the visualization has a central role. The use of VR technology positively impacts students' perceptions of their experience. They value the VR assistance to help them better understand the vector concepts in the class, and some value the tool even if its use does not count toward credit. Students' perceptions agree with their learning. Students perceive that VR helped them visualize angles and components essential for their performance in our content questionnaire. Some students will pay more attention to the technology instead of what the technology is used for. About one out of four students still found the use of VR as their most important learning. Finally, we found a small proportion of students who blame VR whether they have problems learning. Most of them blame personal reasons.

The limitations of this study might be that we developed our experiment in a Mexican university with specific university content. However, for instance, comparing our university educational system to that of the US, there are not many differences. Students study the same mathematics and physics before college and in their first year in a university engineering degree. We believe our results would be comparable to those in other universities worldwide whether VR is used in vector teaching.

This study's findings contribute to the knowledge of using technology for education at the university level. This study helps instructors consider how they can incorporate VR in their classes, and we encourage university instructors to use VR in their classes. For future studies, we recommend using VR in other physics topics in which visualization is essential, such as electricity and magnetism, a discipline in which the object, the physical quantity (e.g., electric field) is abstract. The only way to access the object is through representations, something virtual reality can help.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their oral informed consent to participate in this study.

Author contributions

EC contributed to the study design, analysis of results, discussion, and wrote a first version of the manuscript. IH contributed to the study design, data collection, and analysis of results. GZ contributed to the study design, analysis of results, and discussion. All authors revised the manuscript before submission.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix

APPENDIX TABLE 1 Eight multiple-choice questions that required explicit computation of magnitude and projection of specific vectors.

Item	Question	Options
Q7	Calculate the magnitude of the vector A = 2.5i + 3.8j + 4.6k	a. 4.55 b. 6.47 c. 41.85 d. 10.9
Q8	Calculate the magnitude of the vector B = 5.3i − 2.2j − 3.7k	a. 46.62 b. 5.74 c. 6.82 d. 11.2
Q9	Calculate the magnitude of the vector C = 6.8i − 5.1k	a. 1.7 b. 11.9 c. 72.25 d. 8.5
Q10	Calculate the theta angle of the vector A = 2.5i + 3.8j + 4.6k	a. 44.7° b. 67.3° c. 157.3° d. 134.7°
Q11	Calculate the alpha angle of the vector B = 5.3i − 2.2j − 3.7k	a. 129° b. 108.82° c. 39° d. 18.82°
Q12	Calculate the beta angle of the vector C = 6.8i − 5.1k	a. 0° b. 36.87° c. 90° d. 180°
Q13	What is the projection of the vector A = 2.5i + 3.8j + 4.6k on the x-y plane?	a. 2.5 i b. 2.5 i + 4.6 k c. 3.8 j + 4.6 k d. 2.5 i + 3.8 j
Q14	What is the projection of the vector B = 5.3i − 2.2j − 3.7k on the x-y plane?	a. 32.93 b. 5.74 c. 6.82 d. 3.1

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Should spirituality be included in entrepreneurship education program curriculum to boost students' entrepreneurial intention?

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Spirituality is now becoming popular because of the physical and mental advantages it brings to entrepreneurship. Regardless of its more philosophical measurement, changes owing to spirituality have been distinguished in people's mental and standards of conduct. This investigation aims to examine the qualities related to university students, looking to explicitly comprehend the separate individual qualities or the psychological and cognitive inclinations. Tested on a sample of 300 students, Structural Equation Modeling results exhibit that those who participate in spiritual rituals tend to reinforce the mental and psychological credits connected with an entrepreneurial intention. Since entrepreneurial behavior is a priority to boost economic growth, spirituality should be coordinated as a mandatory subject in general instruction from primary school onward. The results of this exploration could be a model for the Indonesian government as they attempt to search for the best model for Entrepreneurship Education Program (EEP).

KEYWORDS

spirituality, entrepreneurship, psychological, cognitive, university

Introduction

Numerous administration activities in business have concluded that Indonesian youth are hesitant to become entrepreneurs (Wibowo et al., 2019; Kurniawati et al., 2020). Nonetheless, a new exploration (Handayati et al., 2020; Basuki, Widyanti and Rajiani, 2021) confirmed that Indonesian adolescents are extremely mindful and have an inspirational mentality toward the business venture. What is required presently is accurately identifying them. Subsequently, colleges and the public authority should investigate what kind of businesspeople they need in this country. Moreover, there is proof that we need to move attention from conventional instructing and assessment techniques toward less common ways to deal with entrepreneurial training, including

appropriation practices such as spirituality (Margaça et al., 2020). Spirituality brings physical and mental advantages to its specialists (Iqbal and Ahmad, 2020). Examination of the impacts of spirituality has shown that there are clear psychological and cognitive preferences, including expanded memory limit, better focus, improved learning capacities and self-awareness, as well as lower nervousness levels (Robinson, 2020).

The impact of spirituality inside the field of entrepreneurship has been attracting insightful consideration (Smith et al., 2019; Block et al., 2020). The convergence of these constructs gives a comprehension of how an entrepreneur's uplifted awareness and convictions can affect business exercises and vital qualities of the entrepreneurial process. These include the acknowledgment of chances and the formation of new pursuits. In a religious community or country like Indonesia, religion plays a more predominant role than social class (Anggadwita et al., 2017). Subsequently, strictness reflected in spirituality can trigger enterprising expectations (Sulung et al., 2020). The act of spirituality among Banjar people in South Kalimantan can be seen in a spirituality practice called *the haul*, which has consistently been held each year to commemorate KH. Zaini Abdul Ghani (Rajiani et al., 2019). This commemoration is the greatest spiritual practice in South Kalimantan, attracting countless travelers and even a large number of individuals from different districts. Strangely, all of Banjar society feel the benefit of this ritual by giving willful help to the achievement of the entire process of *haul* pilgrims. Something intriguing to note is the arrangement of a rest territory for visitors from different districts, significantly over one hundred kilometers from the area of the *haul*, beginning a few days prior and proceeding even after the *haul* has finished. Each rest region gives free food and beverages to the thousands of pilgrims. Additionally, numerous accessible conveniences are offered along the way, like housing, tire fixing services, medical assistance, and fuel.

This study aims to examine the individual and intellectual qualities of entrepreneurs as recognized by different scholars (for example, Turner and Gianiodis, 2018; Wang et al., 2019; Rajagopal, 2021) and the positive psychological and cognitive impacts presented by spirituality as affirmed by previous studies (Schnitker et al., 2021). Two research questions are placed: (1) does the act of spirituality contribute toward entrepreneurs' psychological attributes? and (2) does the act of spirituality contribute to the learning of entrepreneurial cognitive processes?

These issues are significant because of the impact they could have on bringing spirituality into education, helping to advance students' psychological and cognitive attributes that could in turn promote entrepreneurship (Rodrigues et al., 2019; Aryeh, 2020; Maritz et al., 2021). Consequently, this examination aims to investigate whether the psychological and cognitive attributes incited by the act of spirituality contribute to advancing psychological and cognitive characteristics related to potential entrepreneurs among university students.

Literature review

Entrepreneurs' psychological and cognitive attributes

Researchers have long been focused on how and why entrepreneurs choose to seek out business ventures. Changing inspiration and conduct systems were examined, many of which have demonstrated conflicting results (Covin et al., 2020). The extra examination has distinguished specific psychological attributes that would incline individuals toward adventure creation, like responsibility, constancy, need for accomplishment, locus of control, capacity to bear uncertainty, hazard inclination, drive, and awareness of chance (Embi et al., 2019; Meyer and Meyer, 2020; Mujahid et al., 2020). Nonetheless, psychological attributes have been demonstrated to be unfit to distinguish between entrepreneurs and non-entrepreneurs adequately because of the expected absence of agreement around such attributes. The shared complementarity between psychological attributes and cognitive factors produces a singular conduct that is the consequence of a person's choice dependent on the people's objective and way of thinking (Bergner, 2020). Consequently, cognitive factors offer help to investigate the qualities innate to entrepreneurship.

One of the ideas to consider while breaking down business from the viewpoint of cognitive hypothesis is alertness, as characterized by Neneh (2019), summed up as the capacity to discover without observing. The same author maintained that the understanding and mental portrayal of entrepreneurs varies from that of the rest of the populace because the previous is guided by entrepreneur alertness (EA), seen as a particular pattern of information-processing and insight and as a cognitive tool used in analyzing opportunities.

Chavoushi et al. (2021) confirmed that a few people exhibit this mental pattern and a propensity to search out and distinguish market vulnerability. They can comprehend data that does not find a place with their predominant mental outline and adjust it to incorporate the new data. In this way, EA can be considered a particular mental composition that empowers the person to be aware of new freedoms and react accordingly. The idea of EA is related to psychological and cognitive properties because these are related to veridical insight and translation. In contrast, the previous is related to how entrepreneurs see and comprehend the market. On the other hand, the last arrangements deal with the way to distinguish the main impetuses and essential variables behind market factors and moves and synergizes dynamic connections between them (Li et al., 2020).

Dheer and Lenartowicz (2020) opine that entrepreneurial cognitions are the information structures that individuals use to make appraisals, decisions, or choices, including the assessment of chances, the making of new pursuits, and the age of development. The cognitive perspective highlights the role of mental processes that bring about explicit practices, precisely the routes identified with individual decision-making in the quest for direct targets. Thus, the utilization of a cognitive approach in this setting looks to see how the entrepreneurs' mental models assemble snippets of data that initially do not appear to have any kind of interconnection to encourage the foundation of new businesses.

Exploration directed by Middermann (2020) found that the cognitions of people with "proficient entrepreneurial cognitions" differ from those of business non-entrepreneurs. Likewise, Huber et al. (2020) contend that, besides the competencies and capacities demanded to operate businesses successfully, people must also possess a mental map that assists them in assessing the possible achievement of an undertaking before it is dispatched.

Teaching entrepreneurship: A new model

The debate on whether entrepreneurship can be taught or not is flourishing (Bhatia and Levina, 2020). However, scholars do accept that creative inspiration can be developed with tacit entrepreneurship schooling (Arsawan et al., 2020; García-Morales et al., 2020; Handayati et al., 2020). Consequently, some scientists, chipping away at the supposition that innovative mentalities are inert across the populace, concur that the related practices can be taught in formal education. There is developing acknowledgment that psychological and cognitive processes may bring about a more thorough comprehension of variables impacting entrepreneurial behavior. Margaça et al. (2021) contend that the psychological characteristics of entrepreneurs can be learned or potentially reinforced. Hägg and Kurczewska (2020) underline that the accomplishments of instructive courses in entrepreneurship rely fundamentally upon being able to teach these psychological characteristics. Although Jena (2020), among others, has avowed stimulating entrepreneurial characteristics since an early age and may support entrepreneurship as a lifelong alternative, no observational testing of their assessment has been embraced.

Much effort has been placed into supporting entrepreneurship, and this pattern has been trending worldwide, including in Indonesia. Notwithstanding, contrasted with different nations, new entrepreneurs in Indonesia are lacking. Indonesia's accomplishment is behind its neighboring countries of Singapore, Brunei Darussalam, and Malaysia (Handayati et al., 2020). To expand the number of businesspeople, the Indonesian government has trialed a few advancements, including establishing entrepreneurship education programs in colleges (Saptono et al., 2020) with unconvincing outcomes. This is demonstrated by the high joblessness level of college graduates (Siregar, 2020). In particular, business training has not formed an entrepreneurship mentality in students. In other words, the current substance of courses has not yet reached the core component of entrepreneurship (Ingalagi et al., 2021) and, at this point, does not advance individual self-improvement (Haque et al., 2019). Undoubtedly, the cognitive perspective on entrepreneurship calls for new instructions to be conveyed to help students become entrepreneurs.

The point departure proposed by the authors of the present paper is that this new learning process should include spirituality. Febriani (2020) characterizes spirituality as one's progress toward and experience of association with oneself, connectedness with others and nature, and connectedness with the transcendent. Some developed or developing countries have applied this concept as a learning strategy (Bettignies, 2019; Meyer and Kot, 2019; Nawaz et al., 2020; Khalid, 2021; Rahiman et al., 2021).

These empirical results allowed us to assume the following research hypotheses:

> Hypothesis 1 (H1): the practice of spirituality positively strengthens students' capacity to acquire the psychological attributes of potential entrepreneurs.

> Hypothesis 2 (H2): spirituality positively strengthens students' capacity to acquire the cognitive attributes of potential entrepreneurs.

> Hypothesis 3 (H3): the practice of spirituality influences students' propensity to start their own business.

Data and methodology

This study is a quantitative method aimed at testing and identifying variable dependency by analyzing the interaction of spiritual, psychological, and cognitive attributes toward the propensity to set up businesses among university students in South Kalimantan, Indonesia. The 300 respondents were made up of last year's students. Hair et al. (2012) assure that the minimum number of samples is five times the number of indicators. Since there are 17 indicators, the minimum number of samples is 85. Thus, 300 samples is adequate for hypothesis testing. The sample selection method uses purposive sampling, which is based on the willingness of the Whatsapp social media group members to participate. This group contains final year students. Psychological factors were estimated, utilizing a 6-item test adapted from the work of Mujahid et al. (2020). The items are labeled self-confidence (x1.1), self-realization

(x1.2), autonomy (x1.3), innovation (x1.4), self-control (x1.5), and tolerance of risk (x1.6). Cognitive factors were estimated with identification of new opportunities (x2.1), valuation of opportunity (x2.2), entrepreneur alertness (x2.3), effective problem solving (x2.4), lessened perception of risk (x2.5), and greater perception of success than failure (x2.6) adapted from Dheer and Lenartowicz (2020) and Chavoushi et al. (2021). To identify the practice of spirituality, students were asked, "*Do you regularly attend the haul of KH. Zaini bin Abdul Ghani?*" This question is to provide the foundation for comparing the propensity for entrepreneurial behavior among those who engage in spirituality and those who do not. The propensity for entrepreneurial behavior is quantified with the Measure of Entrepreneurial Tendencies and Abilities (META), developed by Ahmetoglu et al. (2015). META has four dimensions: Entrepreneurial Proactivity (y2.1), Entrepreneurial Creativity (y2.2), Entrepreneurial Opportunism (y2.3), and Entrepreneurial Vision (y2.4). Items were operated on a five-point Likert scale ranging from 'completely disagree' to 'completely agree', and Structural Equation Modeling with the assistance of SPSS Amos was used to examine the relationship.

SEM includes a series of statistical procedures for assessing underlying relations between variables. Schreiber et al. (2006) confirm that the measures enabling justification were mainly: Chi-square ($\chi 2$), The Minimum Sample Discrepancy Function ($\chi 2$/df), Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), CFI (Comparative Fit Index), and RMSEA (Root Mean Square Error of Approximation). The coefficient alpha was examined to determine reliability, and those values must be 0.60 or higher (Bonett and Wright, 2015). Factors loading are estimated to ascertain discriminant validity by retaining factors loading above 0.50 in the model (Hair et al., 2012).

The theoretical model of the research is summed up in **Figure 1**.

Yet, self-reported questionnaires are prone to social desirability bias, which is the propensity of respondents to reply in a socially acceptable manner. Following Podsakoff et al. (2012), sources of method bias are observed in the Most Extreme Responses (MRS). They are items with the highest loading factor in Confirmatory Factor Analysis (Mishra, 2016). Those items are omitted, and then the model is recalculated. If the result shows no significant change in $\chi 2$, $\chi 2$/df, GFI, AGFI, CFI, and RMSEA, it is determined that there is no bias.

Results and discussions

The measurement model in **Table 1** shows that all factors loading exceeded 0.50, confirming that the instrument had fulfilled satisfactory convergent validity criteria.

The full specified model of the research is depicted in **Figure 2**.

TABLE 1 Loading factors of construct.

Construct	Loading factors
x1.1 < — Psychological	0.820
x1.2 < — Psychological	0.849
x1.3 < — Psychological	0.793
x1.4 < — Psychological	0.802
x1.5 < — Psychological	0.627
x1.6 < — Psychological	0.621
x2.1 < — Cognitive	0.819
x2.2 < — Cognitive	0.814
x2.3 < — Cognitive	0.625
x2.4 < — Cognitive	0.715
x2.5 < — Cognitive	0.643
x2.6 < — Cognitive	0.611
y1.1 < —Spirituality	0.725
y2.1 < — Propensity	0.893
y2.2 < — Propensity	0.820
y2.3 < — Propensity	0.801
y2.4 < — Propensity	0.792

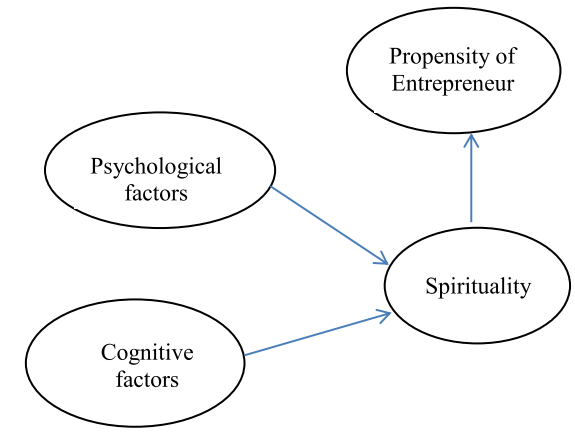

FIGURE 1
Theoretical framework.

SEM needs a small value for Chi-square statistic ($\chi 2$) and probability (P) smaller than 0.05 and other alternative measurements to evaluate the model fit (Shipley and Douma, 2020). This model meets the model's goodness-of-fit by referring to the $\chi 2$ test ($\chi 2$ = 9.902) and probability (P = 0.04). Also, when examined from other measurements, the model indicates an appropriate fitness: CMIN/DF = 1.857 (expected smaller than 2), GFI = 0.992 (higher than 0.90), AGFI = 0.912 (higher than 0.90), CFI = 0.977 (higher than 0.95), TLI = 0.963 (higher than 0.95), and RMSEA = 0.071 (higher than 0.06) (Hair et al., 2012).

Most Extreme Responses (MRS) were identified in four items: (a) In the future, I intend to participate in founding a new business venture; (b) In the end, you

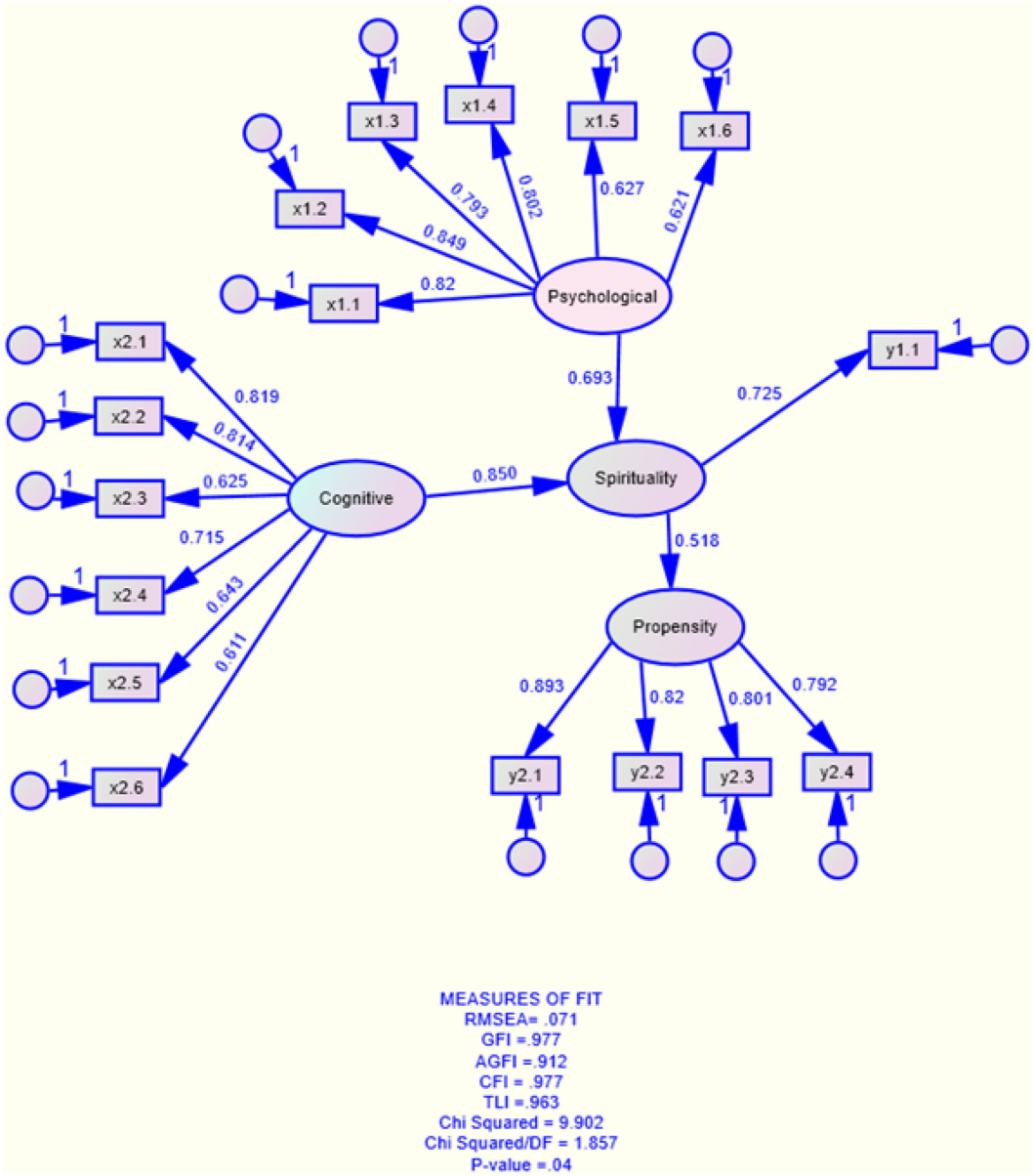

FIGURE 2
Full model.

are convinced of the probability that the business will thrive; (c) I have recently searched for information on ways and means to find a new business model; and (d) If my research during my study has marketing potential, I would like to participate in the new business model to commercialize the research. However, after omitting those four items, the result remains the same, indicating that there is no bias of respondents answering questions in a socially acceptable manner.

The summary result of structural equation modeling is presented in Table 2.

The table indicated that three paths are significant. The critical ratio (CR) value of psychological factors = 4.410 and significance of < 0.000 confirm the first hypothesis: the practice of spirituality positively strengthens students' capacity to acquire the psychological attributes of potential entrepreneurs.

Similarly, the critical ratio (CR) of cognitive attributes = 5.778 and significance of < 0.000 confirm the second hypothesis: the practice of spirituality positively strengthens students' capacity to acquire the cognitive attributes of potential entrepreneurs. Finally, the critical ratio (CR) of spirituality = 0.2110 and significance of < 0.000 confirm the

TABLE 2 Summary of the structural equation modeling.

Constructs	Estimate	SE.	CR.	*P*	Conclusion
Psychological < – Spirituality	0.693	0.018	4.410	***	Significant
Cognitive < – Spirituality	0.850	0.105	5.778	***	Significant
Spirituality < – Propensity	0.518	0.028	2.110	***	Significant

***$p < 0.00$.

third hypothesis that the practice of spirituality influences students' propensity to start their own businesses.

The result of this research clearly indicates that spirituality affects the entrepreneurial tendency of students in South Kalimantan, Indonesia, supporting previous studies conducted in other regions of Indonesia (Sulung et al., 2020).

A positive and critical impact of spiritual practices inside entrepreneurial ideas gives an expected answer for the difficulties of understanding the entrepreneurial mindset. Up to this point, conventional entrepreneurship literature has commonly disregarded qualities like religion and spirituality when leading the investigation into entrepreneurial motivation and behavior.

A significant part of the entrepreneurship literature proposes that organizations thrive where entrepreneurial qualities like individualism, rationality, risk-taking, self-interest, autonomy, achievement, self-reliance, and long-term orientation prevail (Embi et al., 2019; Mujahid et al., 2020). Consequently two suppositions : (1) values widespread inside the entirety of entrepreneurs, and (2) values fundamentally identified with achievement in new pursuit creation, come up.

Similarly, as there is no ideal approach to seeking venture development, there appears to be no best entrepreneurship model pertinent to all circumstances and people. Examination of the improvement of entrepreneurs recommends that the craving for self-satisfaction and essential work are regularly the primary motivators for the individuals who choose to go into their own business (Smith et al., 2019; Block et al., 2020), which are the two elements related with most meanings of spirituality (Febriani, 2020). This condition is suited to Banjarese Indonesian culture, where Islam represents the central constituent in ethnic acknowledgment. All Banjarese Indonesians are Muslim, and Islam affects lifestyle. Subsequently, Islam affects fundamental aspects of everyday life (Basuki, Widyanti and Rajiani, 2021), including the thought of the prominent ulema KH. Zaini bin Abdul Ghani on entrepreneurship. Although most of Indonesians are Muslim, an ulema is hardly portrayed as an influential figure in rehearsing business.

KH. Zaini Abdul Ghani is an exception as he was successful in the concept of teaching religion as well as developing an economic base that benefited the community. He taught that entrepreneurship was a duty to communities, families, and the Almighty. This deeply engrained virtue strongly impacts people's attitudes and motivations toward entrepreneurship in a way that is significantly different from many traditional entrepreneurs.

Millions of people mourned his passing, and his haul became the arena of spirituality, with students regularly attending the ceremony.

Though the current trends emphasize the mastery of information systems (Khalid and Kot, 2021), digital payment (Chaveesuk et al., 2022), university product commercialization (Ismail et al., 2020) and emotional intelligence (Rahiman et al., 2020), policymakers, including entrepreneurship education programs evaluating university performance, should also include spirituality. Consequently, university managers must be aware that the best way to promote entrepreneurial activity in their institutions is to create the conditions necessary to increase the spirituality of their academics. Further, entrepreneurship education programs run by Indonesian universities should focus on strengthening the spirituality of the potential entrepreneurs by conveying all the obstacles when launching a new business venture. However, it is not about committing to psychological attributes and the cognitive domain of entrepreneurial work. Instead, the three paths can be developed in parallel and complement their essential synergies in molding prospective entrepreneurs emerging as fresh university graduates.

Conclusion

A significant part of the conventional entrepreneurship literature revolves around estimating execution factors that are not difficult to assemble, as opposed to those that are significant to the religious or spiritual entrepreneur. Since entrepreneurs with a tendency toward these qualities may characterize achievement uniquely in contrast to traditional entrepreneurs, monetary measures might be of negligible significance to them. The entrepreneurship education program in Indonesian universities should utilize proportions of achievement directly relevant to spiritual and religious entrepreneurs on an individual premise instead of focusing exclusively on targeting monetary measures. In a religious society like Indonesia, numerous businesspeople feel that rewarding their networks, clients, and different firm partners or helping others achieve individual objectives is a good sign that they are prevailing in their business attempts. In that capacity, applying the Western maverick idea

in surveying potential entrepreneurs might not be pertinent to yielding the expected outcome.

Despite the effort we put into the plan of the current investigation, it is not without restrictions. The examination was exploratory and cross-sectional, which makes it hard to build up causal connections between the factors of our model. In this way, we have suggested that psychological attributes, cognitive characteristics, and spirituality predict entrepreneurial propensity among students in any case. But it could be that the relationship is vice versa, i.e., that the ambition to become an entrepreneur is what determines the potential psychological attributes, cognitive factors, and spirituality. Along these lines, future research should conduct a longitudinal report that could affirm the causal connections that presented themselves.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study involving human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants in accordance with the national legislation and the institutional requirements.

Author contributions

SH and IR: conceptualization. SH and EA: methodology. EA: software, resources, data curation, investigation, visualization, and project administration. SH, EA, and IR: validation. IR: formal analysis and writing—review and editing. SH: writing—original draft preparation, supervision, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Educational model transition: Student evaluation of teaching amid the COVID-19 pandemic

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The Education 4.0 Framework calls for Higher Education Institutions (HEIs) to innovate their curriculum for developing the competencies of the future. Tecnologico de Monterrey started a transition from an active-learning educational model to Tec21, a challenge-based learning educational model focused on competency development. After one semester of this transition, the COVID-19 pandemic disrupted education worldwide, causing most universities to adapt to online education. We found the opportunity to analyze the institutional Student Evaluation of Teaching (SET) survey at different stages of the COVID-19 pandemic, prior to the outbreak, in the transition to online learning, and after the transition to fully online course delivery. We performed this analysis separately for the two coexisting educational models and each of the schools at the university. We also compared the SET scores for the spring semester of 2021, when the two educational models had a comparable number of students. We found that SET scores were not negatively impacted by the COVID-19 pandemic hinting toward positive implications about the institutional response to the pandemic. Another finding is that the Tec21 educational model has received higher SET scores, which implies a positive perception by students. There were a few exceptions to these results, which we address explicitly; for instance, the COVID-19 pandemic might have affected SET scores in the School of Medicine and Health Sciences. Further research is necessary to evaluate the implementation of the Tec21 model comprehensively.

KEYWORDS

educational innovation, higher education, student evaluation of teaching, COVID-19, Tec21

Introduction

The Fourth Industrial Revolution emphasizes the need for digital and socio-emotional skills development. However, most education worldwide is still satisfying the needs demanded by the First and Second Industrial Revolutions (World Economic Forum, 2020). Higher Education Institutions (HEIs) must respond to the needs of competency development for preparing future professionals with disciplinary content as well as digital and socio-emotional skills, within the Education 4.0 Framework. Innovative pedagogies, such as experiential learning, are key approaches for driving innovation in educational systems (World Economic Forum, 2020). Universities in different parts of the world have responded to the needs posed by the Education 4.0 Framework by presenting proposals for change and their respective analyses (Buasuwan, 2018; Vu, 2018; Ovinova and Shraiber, 2019; Sudaryono et al., 2019), and by implementing new educational models or pedagogies (Anaraki, 2018; Muawiyah et al., 2018; Ab Rahman et al., 2019; Almeida and Simoes, 2019; Anito and Morales, 2019). The role of HEI is to adapt to the needs of the future, while responding to the present context, highly disrupted by the COVID-19 pandemic.

Higher Education Institutions worldwide responded differently to the COVID-19 pandemic. Developed economies in Europe generally reported campus closure and moving to online teaching, while not all HEIs in the United Stated of America did so. In developing economies, campus closure and switching to online learning depended on the country's policy, the preparedness of faculty and students' anxiety levels (Sasere and Makhasane, 2020). For example, in Brazil, upon the onset of the pandemic authorities suspended face-to-face activities in HEIs (Gisela Biberg-Salum et al., 2020). Several HEIs reported their support and evaluation practices for changing from face-to-face to remote learning. Moreover, faculty needed preparation in pedagogical approach and technological support for adapting their educational content and delivery to online platforms (Quezada et al., 2020). The University of Turin evaluated the support provided during the emergency transition from face-to-face to online teaching, exploring influential or unfavorable elements (Floris et al., 2020). A model based on the response of three European HEIs to COVID-19 shows that IT use and practices pass through different phases of exploration and exploitation, finding that these phases present challenges that can be alleviated with well-timed management (Carugati et al., 2020). A study in Europe about anatomy education emphasizes the strengths, weaknesses, opportunities, and threats of adapting to distance learning (Longhurst et al., 2020). They consider the development of new online resources and upskilling in new technologies and resources as organizational strengths; time constraints, lack of practical sessions and issues with assessment as organizational weaknesses; academic collaboration, working remotely and the incorporation of blended learning in future curriculum development as environmental opportunities, and reduced student engagement and diminished professor-student relationship as environmental threats. A study performed in Spain analyzed how students adapted to the situation posed by the COVID-19 pandemic and found a lack of preparedness and facing difficulties with the online implementation which have translated to additional effort required by students and lower academic performance (Faura-Martínez et al., 2022). A study in Saudi Arabia gathered evidence on the positive impact of using social media on students' academic performance during the COVID-19 pandemic highlighting the perceived usefulness, ease of use and enjoyment (Alismaiel et al., 2022). Additionally, the topic has been of interest for meta-analyses and review studies that analyze and summarize a vast number of articles that have tackled HEIs institutional response to the COVID-19 pandemic (Karakose, 2021; Zhang et al., 2022).

In the university where this study takes place, the educational model is shifting from a traditional active-learning approach to a competency-based model (known as Tec21) as an attempt to contribute to competency development considering the Education 4.0 Framework. The implementation of the Tec21 educational model happened almost simultaneously with the COVID-19 pandemic. Extensive research has studied the implementation of the Tec21 model during the COVID-19 pandemic, specially at its intersection with the Education 4.0 Framework. One of such studies proposes that transforming the concept of sustainability into a transversal competency present in all academic programs enables students to focus their knowledge on actions that lead to sustainable development (Membrillo-Hernández et al., 2021). Another study arguments that only through the design of flexible, interactive and technology-centered courses based on the Fourth Industrial Revolution can academia prepare students for the challenges of the future (Membrillo-Hernández et al., 2019). Another study presented a Capstone project focusing on the intersection between the Tec21 Model and the Education 4.0 Framework, where students proposed solutions to a specific problem of the automotive industry (López et al., 2021). This project showcases the nature of the Tec21 Model because it places students in a challenging experience directly linked with the public and private sectors, in innovative spaces and resulting in the development of disciplinary and transversal competencies. The authors highlighted that some students were connected to high-end companies, such as Tesla, to make internships as a result of their competency development in this project. In a different project, students solved the challenge of improving the energetic efficiency in the artisanal production of an alcoholic beverage in Mexico (Reyna-González et al., 2020) leading to the development of disciplinary and transversal competencies in students, as well as a vision for applying engineering solutions to social problems. A case

study about interactive education reported that the use of interactive education improves the way of teaching, reinforces competencies, and enhances students' creativity and motivation (López Ríos et al., 2020). Along these lines, a case study presented the inclusion of artificial intelligence as an educational strategy implemented in the Tec21 model for the digital transformation required by the Education 4.0 Framework (Cantú-Ortiz et al., 2020).

We aim to add to this research from the perspective of SET. While some of the cited studies take a look at the evolution of Tec21 through the lens of SET (Membrillo-Hernández et al., 2019; Reyna-González et al., 2020) no previous study has comprehensively evaluated the institutional SET including students of all schools and courses, and as a means for comparison with the traditional model. The specific objective of this study is therefore to compare how students evaluate their professors' performance with respect to the educational innovation that intersects with the Education 4.0 Framework, the Tec 21 model, and the traditional educational model. Since this transition has happened mostly amid the COVID-19 pandemic, we also aim to analyze the potential shift in students' opinion of their professors' performance in three different periods of the pandemic: pre-COVID-19, trans-COVID-19 (which stands for the transition to online teaching and learning) and intra-COVID-19 (during the pandemic, since by June 2021 the world was not entirely free of this global challenge). We aim to answer the research questions as follows: (1) Do students in the traditional and the Tec21 educational model evaluate their professors differently in the SET survey at different stages of the pandemic (pre-, trans- and intra-COVID-19)? (2) Do students in the Tec21 educational model evaluate their professors differently than students in the traditional educational model?

Study context

Student evaluation of teaching

Evaluating students' experience with the transformations that take place in face of the Education 4.0 Framework and the COVID-19 pandemic is an important task. There are multiple ways to evaluate students' experience, such as satisfaction surveys and conducting in-depth studies of specific implementations. One way of evaluating their experience is through institutional Student Evaluation of Teaching (SET) surveys. The validity of SET use for making academic decisions has been criticized due to different biases, such as student's and teacher's gender, student's age, teacher's experience (Spooren et al., 2013), and cultural bias (Arnold and Versluis, 2019), among others. Other studies have found that SET surveys can be useful for understanding the students' experience, rather than satisfaction (Warfvinge et al., 2021). Different studies that use SET scores in the context of experiential learning before the pandemic have found positive evaluations. Problem-based learning with a client based and a non-client-based approach was overall highly rated, except for the question related to students' motivation to learn in the client-based projects (Appiah-Kubi, 2018). The authors attribute this to the fact that client-based projects may require a lot of time and can be unstructured resulting in students being unable to control changes. The implementation of a Global Experience, an innovative program designed to broaden students' engagement through international experiential learning, in South Australia resulted in positive evaluations in SET, among other instruments (Feast et al., 2011).

In face of the COVID-19 pandemic, SET scores have been used to study whether the change to online teaching affected the way students evaluated faculty. There are some mixed results; for instance, when shifting from in-person to online teaching, the SET scores lowered for faculty in communication courses (LeBlanc, 2021). Regarding gender bias, several studies have found no significant gender-related differences in students' evaluation of teaching in different contexts (Arrona-Palacios et al., 2020; Tangalakis et al., 2022). However, in the COVID-19 pandemic, male students make more negative comments about their female professors' teaching style (Tangalakis et al., 2022). On the positive side, studies have reported that overall student evaluation was not affected by the changes in instruction or life experiences outside of the professor's control (Boysen, 2020). Moreover, the factors that have affected SET during the pandemic are the professors' educational skills, personal and ethical characteristics and their views on principles and rules (Sepahi et al., 2021). Some professors found the change to online teaching amid the pandemic as a challenge that would allow them to grow, while others perceived it as a threat. These attitudes are related to burnout levels and student evaluation of teaching (Daumiller et al., 2021). During the pandemic, professors found the feedback received from SETs useful for improving their teaching practices and meeting students' needs (Silalahi, 2021).

Institutional educational model

We present some of the characteristics that differentiate the competency-based educational model (Tec21) from the traditional active-learning model regarding pedagogical approach. The pedagogical approach in the traditional educational model was lecture-based with active learning components. Students would take 16-week long courses in the semester, presenting their final exams in the last 2 weeks of the semester. In general, undergraduate courses are comprised

of 3 lecture hours and 5 coursework hours per week. Some courses include laboratories, when applicable, as part of their coursework hours (with no extra credit for students). The objectives for each course is to gain disciplinary knowledge or develop skills necessary for their future careers. Professors are encouraged to include active learning strategies and collaborative work, in addition to using digital technologies for educational innovation. Professors have access to continuous learning tools focused on the use of a wide range of digital technologies (e.g., virtual reality, interactive videos) and active-learning strategies (e.g., problem-based learning, tutorials) (Vicerrectoría de Facultad, 2022).

In the Tec21 educational model, the pedagogical design and approach changes its focus from content-based knowledge to competency development (Tecnologico de Monterrey, 2018). This change involves a reconfiguration of courses into 5- or 10-week blocks. The semester is restructured into three 5-week periods with immersive weeks after each period (a total of 18 weeks). The blocks can take one or two periods, and, in general, take from 4 to 12 h of synchronous learning per week. The objective of each block is defined through disciplinary and transversal competency development, which is achieved through solving challenges associated with real world problems in their fields of study. Challenge-based learning is at the core of the Tec21 model. Each block requires a solution to a challenge directly related to the disciplinary and transversal competencies that would be developed within the respective block. The block is structured into learning modules that also include the learning content to provide students with the theoretical and practical knowledge needed to solve the challenge.

The shift from the traditional to the Tec21 educational model is ongoing. A few semesters before the rollout of the Tec21 educational model, between August 2016 and June 2019, a few select programs implemented the flexibility of degree choice by defining Career Paths. These implementations were at the early stages of the educational model. In August 2019, the Tec21 educational model officially started for the incoming students in all undergraduate programs across 26 campuses of the university. The students who had initially enrolled to the traditional educational model would continue their degree in the same format but were given the option to enroll in the Tec21 educational model. During the first semester of the academic year 2019-2020 all first-year students were enrolled in the Tec21 model, while second, third- and fourth-year students continued studying in the traditional model. The full shift to the new model will take place when all the students who enrolled to the traditional model before August 2019 complete their studies. During this period (presumably, from 2019 to 2023), the two educational models will coexist; however, the number of students in the traditional model decreases, as that of Tec21 model increases.

Institutional response to the COVID-19 pandemic

Pre-COVID-19

In August 2019, the institution offered the first full implementation of the Tec21 educational model. During this semester, students in the traditional educational model were taking courses from their second, third or fourth year of studies, while students in the Tec21 educational model entered their first year. In this study, we refer to the semester August-December 2019 (AD2019) as pre-COVID-19, as this was the only semester when the two educational models coexisted before the pandemic stroke. All activities and courses during this semester occurred in person. There is a solid body of data about the semesters prior to AD2019, and with respect to the traditional educational model hence minimal premise for comparison between models. The data obtained with students from the traditional educational model has been analyzed and presented in previous studies (Arrona-Palacios et al., 2020; Okoye et al., 2020).

Trans-COVID-19

The COVID-19 pandemic was declared on March 11, 2020, disrupting educational activities worldwide. The following day, Tecnologico de Monterrey suspended all activities for the upcoming week, from March 13 to 20, with the aim to resume activities fully online on March 23 with the virtual model HyFlex + Tec. The academic semester which started in February would end in June 2020 (FJ2020). The educational activities at the beginning of the semester until March 13 were held in-person at every campus of the institution. After the declaration of the pandemic, the involved stakeholders (students, professors, directors, administrators and policymakers) had to transition their entire operation to the HyFlex + Tec in a matter of 1 week. To highlight the transition that took place in the semester FJ2020, we named this stage as the "Trans-COVID-19." The educational technologies mainly employed in this transition were Zoom for synchronous course delivery and Canvas or Blackboard as the Learning Management System. Both tools were previously available to the professors through their institutional access and approximately 80% of professors were familiar with these tools. Nevertheless, the institution provided with appropriate training during the 1-week pause of activities to ensure an adequate transition for all professors and students. Furthermore, all courses were assigned an academic helper called "Academic Buddy," who were university staff to provide technical support to professors in their online experience. At this period of the pandemic, the university estimated over 55,000 class sessions to be delivered per week, anticipating the need to adapt and make the necessary adjustments to face the challenges imposed by COVID-19. The university monitored the emotional well-being of the community throughout the

pandemic, identifying the most frequently reported feelings of students being anxious, stressed, overwhelmed, tired or even depressed (Camacho-Zuñiga et al., 2021).

Intra-COVID-19

During the fall semester of 2020 (AD2020), the university continued delivering online classes. As the vaccination against COVID-19 progressed, the institution launched a program to consciously return to in-person activities known as the Hybrid in-Person + Remote Simultaneous (HPRS) model. Across 26 campuses, those with reduced number of infection reports were allowed to return to in-person activities, following strict protocols in a controlled hybrid environment. To this end, the university provided adequate infrastructure and training to the professors for having students both in person and online simultaneously. This program began in the spring semester of 2021 (FJ2021) with only a few campuses delivering in-person classes slowly increasing the number of in-person activities. The transition is still ongoing. Since the challenges of the pandemic were still ongoing, we refer to the semesters AD2020 and FJ2021 as "Intra-COVID-19."

Methodology

At the moment of this study, we are presumably at the midpoint of the transition between the two educational models. The pandemic may have affected the way students evaluate their professors due to several factors including emotions, students' opinion regarding the institutional response to the COVID-19 pandemic, and professors' ability to shift to online education, among others. Considering this scenario, we present a study that analyses students' evaluation of teaching comparing pivotal moments relevant to the transition from in-person to online education and from the traditional to the Tec21 educational model. The transition from in-person to online education is analyzed for the two models independently, while the transition from the traditional to the Tec21 model is analyzed for the semester of FJ2021, when the two populations are comparable in size.

Data collection

The participants of this study were the undergraduate students of large, multi-campus, private Mexican university, Tecnologico de Monterrey. The instrument used in this study is the institutional SET, Student Opinion Survey (ECOA, for its acronym in Spanish). This survey was designed to collect students' opinion regarding their professors' academic performance. Students evaluated their professors in an interval scale from 0 to 10. The evaluation included the quality of the course delivery, the professors' competencies and other academic services offered by directors and departments. The survey was designed and delivered in Spanish, the main language in the institution. This instrument has shown acceptable reliability in previous studies (Arrona-Palacios et al., 2020). The survey included several evaluation criteria to assess different aspects of the professors' academic performance including course delivery methodology, knowledge and experience, guidance and feedback, course grading and evaluation, and an overall evaluation of professors' performance.

A total of 35,840 students answered the ECOA survey during four semesters, which represents an average of 68% of the students across the four semesters (58% in AD2019, 78% in FJ2020, 74% in AD2020, and 63% in FJ2021). The survey was applied to students across School of Engineering and Sciences, Business School, School of Social Science and Government, School of Medicine and Health Sciences, School of Humanities and Education, and School of Architecture, Art and Design. **Table 1** summarizes the number of participants in each semester, schools and the respective educational model. For reminder, pre-COVID-19 was the semester prior to the COVID-19 pandemic with full in-person learning; trans-COVID-19 was the semester when the COVID-19 pandemic started and the transition to online learning was implemented; and intra-COVID-19 were two semesters after the transition to online learning. The survey was administered in the last week of classes and before the end of the semester. The data collection was completely anonymous, complying with the principles of the Declaration of Helsinki of research with human participants. This research has received the ethical approvals from the Office of the Vice-rectory of Investigation, Tecnologico de Monterrey, Mexico.

This study focuses on the final question of the survey since it provides students' overall opinion regarding their professors' performance. The phrasing of the final question is different for students in the traditional educational model than in the Tec21 educational model. The ECOA for students in the traditional educational model asks "Would you recommend a friend to take a course with this professor?" while the ECOA for students in Tec21 asks "In general, my learning experience with this professor was." The answer to both questions is a 0 to 10 scale.

Data analysis

To answer the research questions, we analyzed the data using the Statistical Package for the Social Sciences (SPSS) as a comparison between samples at different stages of the pandemic. We used a 2-tailed *t*-test to compare the results from students at each school in different moments. The comparison pre- v. trans-COVID-19 provides an account of whether students answered the ECOA differently immediately before the

TABLE 1 Summary of participants in each educational model and school in the pre-, trans, and intra-COVID-19 semesters.

Educational model school	Pre-COVID-19	Trans-COVID-19	Intra-COVID-19	
	AD2019	FJ2020	AD2020	FJ2021
Traditional	**6699**	**6266**	**5278**	**4800**
School of architecture, art and design	584	547	525	480
School of social science and government	653	582	474	444
School of humanities and education	837	781	611	524
School of engineering and sciences	2388	2309	1889	1683
School of medicine and health sciences	683	550	435	411
Business school	1554	1497	1344	1258
Tec21	**2336**	**2329**	**3908**	**4224**
School of architecture, art and design	231	216	444	421
School of social science and government	211	195	379	403
School of humanities and education	278	323	465	454
School of engineering and sciences	883	793	1342	1480
School of medicine and health sciences	115	121	165	229
Business school	618	681	1113	1237
Total	9035	8595	9186	9024

pandemic (AD2019), when they had fully in-person education, compared to the semester when the pandemic was declared (FJ2020), when they had to transition to fully online learning in a week. The comparison pre- v. intra-COVID-19 describes the differences in students' evaluation of teaching between two fall semesters (same course offering), one fully in-person before the pandemic (AD2019) and the other fully online, after the pandemic (AD2020). The comparison trans- v. intra-COVID-19 analyses whether there were significant differences during and after the transition to online learning between two spring semesters, FJ2020 and FJ2021. The comparison between educational models was performed only for the FJ2021 semester, when the two populations were comparable ($n_{Traditional}$ = 4,800, n_{Tec21} = 4,224). For all tests, the null hypothesis is that the means are equal, we consider a significance of α = 0.05.

Results and discussion

We present and discuss the results in two subsections. In the first subsection, we analyze the longitudinal SET scores at different stages of the pandemic. This analysis approaches the first research question: Do students in the traditional and the Tec21 educational model evaluate their professors differently in the SET survey at different stages of the pandemic (pre-, trans- and intra-COVID-19)? We first present the descriptive statistics of the SET scores for the two academic models across the six schools at the different stages of the pandemic. Afterward, we provide the comparison between academic periods, to reveal the possible changes brought by the transition to online learning amid the pandemic. In the second subsection, we analyze the cross-sectional SET scores during the FJ2021 semester, when the population of both educational models was comparable. This analysis approaches the second research question: Do students in the Tec21 educational model evaluate their professors differently than students in the traditional educational model?

Longitudinal analysis of student evaluation of teaching scores at different stages of the pandemic

Descriptive statistics

The average evaluation for all schools in AD2019 was 8.67 (from a maximum of 10.00) in both educational models; in FJ2020, 8.78 in the traditional and 8.90 in the Tec21 educational model; in AD2020, 8.80 in the traditional and 8.99 in the Tec21 educational model, and in FJ2021, 8.77 in the traditional and 9.00 in the Tec21 educational model. We present the results of the descriptive analysis for each school and educational model in Table 2.

Comparison between academic periods at different stages of the pandemic

From the results presented in the descriptive statistics, we may infer that there was an improvement between the pre- and trans-COVID-19 periods. However, the trans- and intra-COVID-19 seem constant. We present the results of the comparisons between periods in Table 3, highlighting the periods with a significant difference.

TABLE 2 Average evaluation by educational model and school along the different COVID-19 periods and standard deviation in parenthesis.

Educational model school	Pre-COVID-19	Trans-COVID-19	Intra-COVID-19	
	AD2019	FJ2020	AD2020	FJ2021
Traditional	μ (σ)	μ (σ)	μ (σ)	μ (σ)
School of architecture, art and design	8.52 (1.45)	8.71 (1.28)	8.75 (1.09)	8.61 (1.26)
School of social science and government	8.69 (1.08)	8.76 (1.14)	8.78 (1.14)	8.75 (1.21)
School of humanities and education	8.78 (1.09)	8.93 (1.00)	9.00 (0.93)	9.00 (0.95)
School of engineering and sciences	8.64 (1.17)	8.72 (1.15)	8.77 (1.08)	8.83 (1.05)
School of medicine and health science	8.73 (1.85)	8.93 (1.70)	8.84 (1.72)	8.59 (2.01)
Business school	8.67 (1.11)	8.77 (1.11)	8.77 (1.11)	8.74 (1.15)
Tec21	μ (σ)	μ (σ)	μ (σ)	μ (σ)
School of architecture, art and design	8.66 (0.99)	8.85 (0.80)	9.01 (0.88)	8.86 (1.02)
School of social science and government	8.65 (1.05)	8.79 (0.94)	8.91 (0.89)	8.91 (0.94)
School of humanities and education	9.00 (0.81)	9.07 (0.67)	9.33 (0.52)	9.28 (0.65)
School of engineering and sciences	8.42 (1.09)	8.69 (0.91)	8.81 (0.82)	8.88 (0.90)
School of medicine and health science	8.79 (0.95)	9.06 (0.64)	9.05 (0.78)	9.05 (0.94)
Business school	8.87 (1.02)	9.09 (0.71)	9.07 (0.76)	9.12 (0.79)

TABLE 3 Statistical significance (*p*-value) of two-tailed *t*-test comparison between COVID-19 periods.

Educational model school	Pre- v. trans-COVID-19 AD2019 v. FJ2020	Pre- v. intra-COVID-19 AD2019 v. AD2020	Trans- v. intra-COVID-19 FJ2020 v. FJ2021
Traditional			
School of architecture, art and design	0.017	0.003	0.217
School of social science and government	0.274	0.184	0.892
School of humanities and education	0.005	0.000	0.199
School of engineering and sciences	0.014	0.000	0.003
School of medicine and health science	0.046	0.296	0.005
Business school	0.009	0.015	0.413
Tec21			
School of architecture, art and design	0.024	0.000	0.933
School of social science and government	0.162	0.001	0.143
School of humanities and education	0.270	0.000	0.000
School of engineering and sciences	0.000	0.000	0.000
School of medicine and health science	0.008	0.011	0.892
Business school	0.000	0.000	0.488

*$\alpha = 0.05$.

Transition to online learning

We studied differences between the pre-COVID-19 and the trans-COVID-19 periods, to identify whether the COVID-19 pandemic influenced students' evaluation of teaching. The results show significant differences between these periods. For students in the traditional model, there is an improvement in students' evaluation of teaching in all schools except for the School of Social Science and Government. For students in the Tec21 model, there is significant improvement in most schools, except the School of Social Science and Government and the School of Humanities and Education. In these cases, there seems to be an improvement, but it is not significant. The improvement on students' evaluation of teaching during the transition to online learning is coherent with the positive outcomes found in studies performed internationally. The International Association of Universities (IAU) highlights positive impacts on students generated through transitioning to online education. The report specifies that the flexibility and community engagement initiatives which were considerably increased in Latin American education system throughout the COVID-19 pandemic have had a large share in generating positive educational outcomes

(Marinoni et al., 2020). Moreover, an increased teacher-student interaction, new opportunities for content development, and resilience to adapt to online learning and adopt new technologies were observed in the time of pandemic (Oliveira et al., 2021). Another study demonstrated that the feedback of students and faculty has overall been positive focusing on satisfaction and effectiveness (Abu Talib et al., 2021), while the academic performance of students has increased in emergency remote teaching (Iglesias-Pradas et al., 2021).

To reduce the effects of the differences between the courses offered in the fall and spring semesters, we compared the two semesters in the intra-COVID-19 period. For the students in the traditional educational model, the results present no significant differences. For the students in the Tec21 educational model, we found significant differences only in the case of the School of Architecture, Art and Design (p-value: 0.022), and the School of Engineering and Sciences (p-value: 0.029). Given this finding, we decided to make the following comparisons: pre-COVID-19 v. intra-COVID-19 comparing the fall semesters of AD2019 and AD2020, and trans-COVID-19 v. intra-COVID-19 comparing the spring semesters of FJ2020 and FJ2021.

When comparing pre- and intra-COVID-19 (AD2019 v. AD2020), the evidence shows significant differences in most schools in the traditional model, except for the School of Social Science and Government and the School of Medicine and Health Science. In both cases, an improvement was observed, however, not significant. In the Tec21 educational model, the improvement was significant in all schools. Previous findings of the institutional monitoring process of student's feelings amid the pandemic reported that students felt anxious, stressed, overwhelmed, tired and depressed (Camacho-Zuñiga et al., 2021). One of the main findings of this study is that in the longitudinal comparison for each educational model, the results provide evidence that students evaluated their professors more positively during and after the transition to online teaching versus face-to-face interaction consistently within schools. This is coherent with other studies in that the students' evaluation was not negatively affected by the changes that professors implemented due to a situation beyond their control (Boysen, 2020). Moreover, the institutional response generated a positive impact as the university provided faculty training to face this new challenge during the week of paused activities, and tech guidance for professors who were not familiar with the technological tools through the "Academic Buddies" initiative (Vicerrectoría de Facultad, 2022). The institution was also committed to providing continuous faculty training, hence professors remained motivated to embrace challenges and to receive feedback for continuous improvement of their courses. These are characteristics that affect the way students evaluate their professors (Daumiller et al., 2021; Silalahi, 2021) which also help explain why the students perceived their professors' performance as higher when facing the COVID-19 pandemic.

Fully online learning

We found contrasting results when comparing the trans- and intra-COVID-19 periods (FJ2020 v. FJ2021). In this case, for the traditional model, only the School of Engineering and Sciences and the School of Medicine and Health Science presented significant differences as the former showed an improvement in their students' evaluation of teaching, while the latter experienced a decline. This, in general, could be an indicator of the greater toll the COVID-19 pandemic has taken on medical and health science students compared to the rest. While medical students are somewhat aware of the threat posed by the virus, their lack of clinical experience prevents them from being involved in patient care, which may lead to feelings of frustration (Nieto and López, 2020). Moreover, the possibility of high exposure to the virus during clinical practice may cause fear among health science students in addition to feelings of frustration and worry which may add to their learning experience and negatively affecting their perception of teaching. The research-based evidence suggests that the feeling of frustration as a social factor may be even stronger than the fear of exposure to virus-related risks (Shanahan et al., 2020). It is also important to note that most health science faculty are also practicing medical experts who are likely to be in the front line of response to the COVID-19 crisis. This could potentially affect the timely and effective course delivery which in turn may affect both the student's evaluation of teaching and their own perception of skill development (López-Ruiz, 2020).

Overall, we propose a comprehensive analysis of the impact of the pandemic on students should be performed in conjugation with their respective disciplines in order to understand the challenges each group may face in a more profound manner. We also propose that deeper insights on the impact of the pandemic on medical students should be generated to understand the differences among those undertaking pre-clinical courses as opposed to those in clinical practice courses and whether the latter may mead to enhanced anxiety among students.

Cross-sectional analysis: Comparison between educational models

As described before, we present the comparison between models only for the FJ2021 semester in which the sample size for both educational models were comparable (**Table 4**). The results yield a significant increase in students' evaluation of their professors in the Tec21 educational model compared to the traditional model in all schools, except for the School of Engineering and Science where the improvement is not statistically significant.

This positive response of the students to the new educational model across schools reflects the effectiveness of implementing challenge-based and experiential learning to improve student's

TABLE 4 Statistical significance (*p*-value) of two-tailed *t*-test comparison between educational models for the FJ2021 semester.

Semester: FJ2021 school	Educational model		
	Traditional	Tec21	*P*-value
	μ (σ)	μ (σ)	
School of architecture, art and design	8.61 (1.26)	8.86 (1.02)	0.002
School of social science and government	8.75 (1.21)	8.91 (0.94)	0.030
School of humanities and education	9.00 (0.95)	9.28 (0.65)	0.000
School of engineering and sciences	8.83 (1.05)	8.88 (0.90)	0.106
School of medicine and health science	8.59 (2.01)	9.05 (0.94)	0.001
Business school	8.74 (1.15)	9.12 (0.79)	0.000

*α = 0.05.

experience of higher education. The Engineering and Sciences domain can be heavily affected by the lack of access to experimentation and laboratories during the pandemic, which is not necessarily the case in other schools. Contrasting with previous reports, students' satisfaction with the design and implementation of the challenge-based learning in this school was generally high (Campos et al., 2021; Zavala et al., 2021). Several studies have reported positive results regarding competency development related to the Education 4.0 Framework in the Tec21 Educational Model in the School of Engineering and Science (Reyna-González et al., 2020; López et al., 2021). Nevertheless, students can be rather harsh in their evaluation of what they perceive as difficult (Rosen, 2018). It is also important to note that the students within the traditional model were in their final years of studies as opposed to those studying Tec21 Educational model who were at the initial phases of their academic journey. These reasons can explain a smaller level of significance in the students' evaluation of the Tec21 model within specific school.

As mentioned before, we find it crucial to conduct an in-depth study on the disciplinary influence of the pandemic on students to raise awareness among the higher education stakeholders and to tune and refine the educational policies.

Conclusion

This study analyses whether student's evaluation of teaching was affected by the pandemic and by the ongoing educational model transition in our institution. The analysis longitudinal data of the institutional SET survey during three stages of the pandemic, and cross-sectional data of the same instrument between the two educational models was performed for all the schools that conform the institution. To answer the first research question, the analysis compared the SET scores at different stages of the pandemic, pre-, trans-, and intra-COVID-19 with a *t*-test for each of the different and independently for each educational model. Both the longitudinal comparisons at different stages of the COVID-19 pandemic, as well as the cross-sectional comparison between educational models, yielded positive results. In most schools, the results indicated statistically significant improvements from the pre-pandemic period to the trans- or intra-COVID-19 periods. This is a positive indicator as it implies that the institutional response to the COVID-19 pandemic was well-perceived by students. From the analysis, it is evident that external negative factors outside institutions' and professors' control have not necessarily affected the SET scores in a negative manner. The only instance where the results yielded a significant decrease in SET scores was in the School of Medicine and Health Science, which can be due to the pressure the medical staff, faculty and students have undergone in the critical conditions exposed by the pandemic.

In response to the second research question, the analysis compared the SET scores between the two educational models in the semester of FJ2021. During this semester, the implementation of the Tec21 educational model was in the middle of its transition (fourth semester), and the two populations had a comparable number of students. It is important to note that, at this stage of the transition, all students in Tec21 were in their first 2 years of higher education, while the students in the traditional educational model were in their last 2 years of their programs. We observed that the Tec21 educational model was rated highly in all schools compared to the traditional model. In the School of Engineering and Science the improvement was not statistically significant, which hints to the lack of access to the laboratory, science and engineering facilities which are the necessary components of studying in this specific field.

The current study is limited by multiple factors. Primarily, the analyzed question for comparing the two educational models slightly varied from the traditional model to Tec21. This has limited our analysis to a certain extend. Another limitation is that the students' populations for the two educational models were not experiencing the same phase of education (freshmen as opposed to nearly graduating samples) hence a certain degree of bias seems to be inevitable. As the time progresses, the study can be advanced to have a closer comparison of the students' opinion with respect to the educational model whereby they are trained. Moreover, the discipline plays a crucial role in understanding the students' needs and demands and those of professors. We can further improve our finding by performing a more in-depth discipline-based analysis of the evaluations. The results of this study provide insights on the importance of higher education institutional response to crises such as the COVID-19 pandemic, and of studying the shifts of students' evaluation of teaching under such circumstances. Moreover,

the evidence suggests that institutional changes in educational models with an emphasis on experiential learning and the Education 4.0 Framework is beneficial for students' perception of higher education experience.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Office of the Vice-rectory of Investigation, Tecnológico de Monterrey, Mexico. The patients/participants provided their written informed consent to participate in this study.

Author contributions

EC: conception, research design, data curation, formal data analysis, writing – final draft, and project administration. SD, JO, and RC: data curation, validation, and writing – review and comments. JE: supervision and review and comments. SH: supervision and writing – review, comments, and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Nuclear history, politics, and futures from (A)toms-to(Z)oom: Design and deployment of a remote-learning special-topics course for nuclear engineering education

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To address the lack of familiarity with nuclear history common among nuclear engineers and physicists, we outline the design and deployment of a special-topics course entitled "NE290: Nuclear History, Politics, and Futures" throughout which we contextualize the importance of the field at its inception, in current affairs, and in future endeavors. We argue that understanding this history is paramount in internalizing a sense of respect for the scientific, technical, and sociological ramifications of an unlocked atom—as well as its perils. We begin by outlining the gaps in secondary educational offerings for nuclear history and their importance in consideration with nontechnical engineering guidelines. We then outline a number of ABET specifications as pedagogical goals for NE290 from which we derive a list of target student learning objectives. Next, we outline the NE290 syllabus in terms of assignments and an overview of course content in the form of a class timeline. We provide an extensive description of the materials and teaching methodologies for the four units of NE290: Twentieth-Century Physics, Physics in WWII, the Early Cold War, and the Late Cold War and Modern Era. We detail the sequence of lectures across the course and historical timelines leading up to a showcasing of NE290 final projects which mirror in creativity the novelty of course offering. Because NE290 was first offered during Spring 2021 during the COVID-19 pandemic, additional measures in the form of new tools were used to augment the mandate of remote learning. In particular, we leveraged the newfound ubiquity of videoconferencing technology to recruit geographically diverse guest lecturers and used the MIRO tool for virtual whiteboarding. Lastly, we provide an accounting of course outcomes drawn from student feedback which—in tandem with the complete distribution of course material—facilitates the integration of nuclear history into the curriculum for the wider nuclear engineering and physics communities.

KEYWORDS

nuclear physics and engineering history, remote education, STEM pedagogy, nontechnical engineering education, history of science

1. Introduction

As of 2021, the Accreditation Board for Engineering and Technology (ABET) program criteria ($\mathfrak{C}$) for Nuclear, Radiological, and Similarly Named Engineering programs require curriculum (ABET, 2021) in:

$\mathfrak{C}_1$. Mathematics, to support analyses of complex nuclear or radiological problems;
$\mathfrak{C}_2$. Atomic and nuclear physics;
$\mathfrak{C}_3$. Transport and interaction of radiation with matter;
$\mathfrak{C}_4$. Nuclear or radiological systems and processes;
$\mathfrak{C}_5$. Nuclear fuel cycles;
$\mathfrak{C}_6$. Nuclear radiation detection and measurement; and
$\mathfrak{C}_7$. Nuclear or radiological system design.

For aspiring students still in secondary education, the framing of Nuclear Engineering in terms of an evolving story in shades of 6-degrees-of-separation offers an alternative pedagogical pathway to learning (Foster et al., 2010). In undergraduate and graduate STEM programs, such anecdotes are most often found in a slide-or-two as preface for a technical discussion of engineering principles. However, by incorporating stories and anecdotes drawn from nuclear history, we aim to better convey the interactions and excitement that connected the scientists and policy makers who changed history. For students at the undergraduate and graduate level, ABET has provided a Code of Ethics of Engineers replete with a number of fundamental principles and canons (Rice, 1922) to guide future engineers as they uphold and advance the integrity, honor, and dignity of the engineering profession. However, there can be no advance of engineering integrity, honor, and dignity without an appreciation of the history that shaped the transformation from ideas and imagination to realized engineering marvels.

To address the lack of familiarity with nuclear history common among nuclear engineers and physicists, we designed a special-topics course entitled "NE290: Nuclear History, Politics, and Futures" throughout which we contextualize the importance of the field at its inception, in current affairs, and in future endeavors. We argue that understanding this history is paramount in internalizing a sense of respect for the fruits of an unlocked atom as well as its perils. Here we will begin with a description of the course then lead into an outline of active reading assignments and a detailed summary of the course content. We will then describe our efforts to foster understanding and collaboration through the remote learning environment and final assignments. We will then discuss preliminary course outcomes.

1.1. History of science

The study of the history of science is an important and valuable pursuit for engineers and engineering students. This field offers a wealth of knowledge and insights that can inform and enrich the practice of engineering, and it should be an integral part of engineering education. First and foremost, the history of science provides a rich and diverse context for understanding the development of engineering and the role of engineering in society. By studying the history of science, engineers can gain a deeper appreciation for the contributions of their predecessors, as well as an understanding of the ways in which engineering has evolved over time. This can provide a broader perspective on the field, helping engineers to see their work in the larger context of human history. Second, the history of science can provide valuable insights into the processes of scientific discovery and technological innovation. By studying the successes and failures of the past, engineers can learn valuable lessons about the challenges and opportunities that they may encounter in their own work. This can help them to avoid common pitfalls and to identify new opportunities for innovation. Third, the study of the history of science can also help to foster critical thinking and problem-solving skills. By examining the ways in which scientists and engineers have approached and solved problems in the past, engineering students can learn how to think creatively and systematically about their own work. This can help them to develop the skills that they need to succeed in the rapidly changing and complex world of engineering. Overall, the study of the history of science is an essential part of engineering education. By providing a rich and diverse context for understanding the field, as well as valuable insights into the processes of scientific discovery and technological innovation, the history of science can enrich the practice of engineering and help to prepare students for success in their careers (Dennett and Ridley, 1995; Porter, 2003; Stadermann and Goedhart, 2021; Woitkowski et al., 2021; Volfson et al., 2022).

2. NE290 description

The NE290 course was designed to address and exceed the nontechnical ABET specifications for Student Outcomes ($\mathfrak{O}$), primarily:

$\mathfrak{O}_1$. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
$\mathfrak{O}_2$. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
$\mathfrak{O}_3$. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

These nontechnical outcomes correspond to many of the precepts that would be gained through the proposed formal historical education.

NE290 spans over a century of nuclear history. We began with a unit on twentieth-century developments in fundamental physics and mathematics that evolved alongside the first experimental evidence of atomic and nuclear structure. Our next unit described the lead-up to and developments of the Manhattan project as well as its international counterparts. We then explored the early atomic age with a look at how the growing tension with the Soviets led to an arms race that dominated foreign policy for decades. This unit offered additional focus on the era of nuclear-adjacent technologies, such as strategic bombers, as well as the development of the nuclear submarine, the space race, and the hydrogen bomb. In along this timeline of key events, we explored the social and political aspects of the field through literature that speaks to the tolls of the nuclear complex, nuclear testing, and the growing disillusionment and terror inspired by nuclear technology (Wellerstein, 2016, 2021; Kristiansen, 2017; Turner et al., 2020). We also explored the still-present shadows

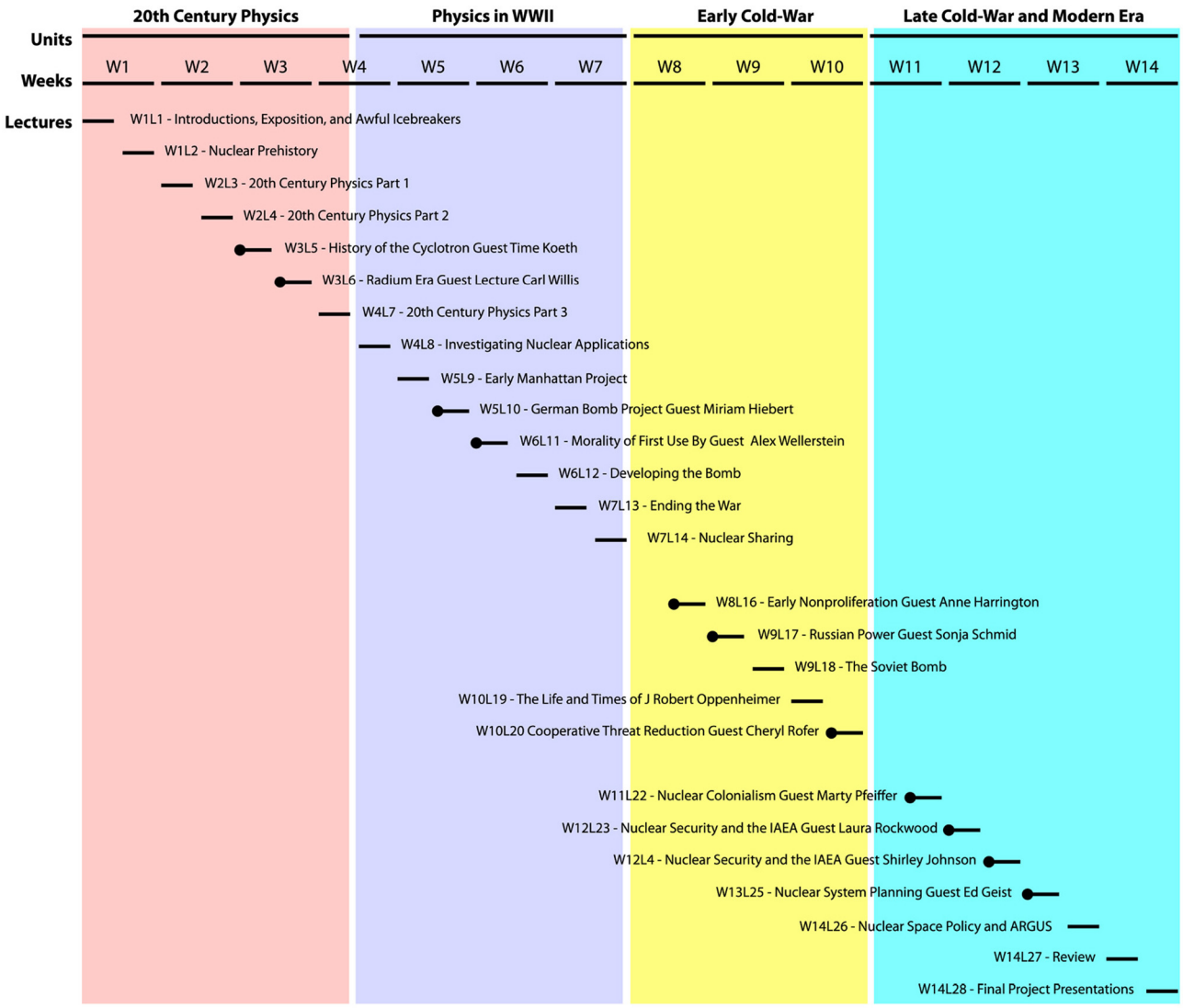

FIGURE 1
Graphical syllabus for NE290 course as broken down hierarchically in terms of units, weeks, and lectures. Units are colored. Guest lectures are indicated by a ◯ marker. All lectures slides are provided as supporting information.

of nuclear winter and the evolution of post-Cold War nuclear arsenals. Throughout each of these units, we organized the lectures and assignments in accordance with following set of learning outcomes ($\mathfrak{B}$) based on Bloom's Taxonomy (Bloom et al., 1984):

$\mathfrak{B}_1$ **Analyze** how the Manhattan project was influenced by these discoveries.
$\mathfrak{B}_2$ **Sequence** the complex historical basis for nuclear armament.
$\mathfrak{B}_3$ **Summarize** the landmark players that shaped the nuclear engineering communities.
$\mathfrak{B}_4$ **Summarize** the persistent problems in nuclear policy and engineering from a historical perspective.
$\mathfrak{B}_5$ **Analyze** how current persistent problems in nuclear policy and engineering can be related to problems solved through a historical perspective.
$\mathfrak{B}_6$ **Synthesize** solutions to current persistent problems in nuclear policy and engineering from solutions to past problems.
$\mathfrak{B}_7$ **Analyze** impact of nuclear physics on international relations and world affairs.

These learning outcomes roughly correspond to the breakdown of the NE290 timeline of nuclear history into units as shown in Figure 1. Throughout the semester, the class was graded based on the following:

- Weekly reading responses 30%.
- Class participation 20%.
- Term paper 50%.

3. Active reading assignments

Much of the process for becoming conversant in history is active reading. We prepared a schedule with a wide array of readings spanning historical biographies to social science literature. Whenever

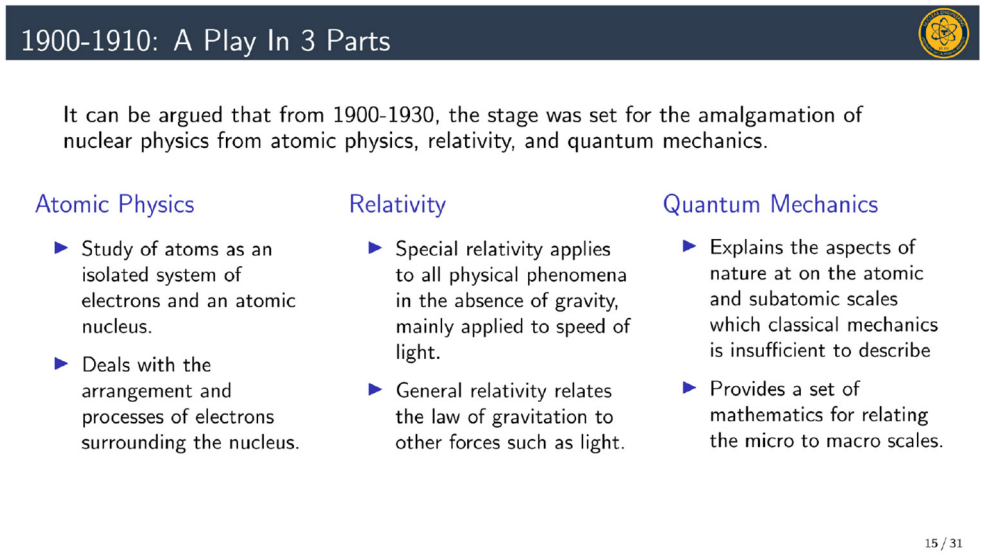

FIGURE 2
A play in two parts. Lecture W2L3.

possible, we also provided media in the form of audiobooks, films, and artwork to augment the learning process. Students were expected to provide a thoughtful weekly response (~1 page) to the reading materials and class lectures. Each week, a random selection of students would be asked to share their responses with the class to foster a discussion, so students needed to be prepared to engage and discuss both the literature and their interpretations of it. We believed that students would become conversant in history in part by developing a faculty for creatively processing the past in the present for a better future—and to aid in this, we prepared an interactive MIRO board across which for posting materials and adding comments and suggestions. When not asked for a response page, students were assigned the task of adding content to MIRO that they felt brought the history to life.

4. Course content

4.1. Twentieth-century physics

NE290 began with a unit on the history of physics from 18th through twentieth-century physics. Our lecture on nuclear prehistory (W1L2) focused on natural nuclear reactors (Jensen et al., 1996; Mathieu et al., 2001; Ebisuzaki and Maruyama, 2017), first encounters with radiation-induced illness (Robison and Mould, 2006), and the initial industrial uses of Uranium (Caley, 1948). This lecture was intended to give broad background on natural radioactivity and non-nuclear uses of nuclear material.

We began our initial history lecture with a discussion of some of the first observations of plasma effects such as the 1675 "ghostly lights in barometers" (Banks, 2009) and the 1719 developments in the "influence machine" that could produce significant Mercury discharge and its relationship to "exceed the performance of cat fur and a glass rod" (Picard, 1676). This later bit of humor set the tone for the course in terms of our use of humor and anecdotes while also playing a part of the basis for the 1880s development of cathode rays (Braun, 1897), 1985 discovery of x-rays by Röntgen (1895), 1896 discovery of radioactivity by Becquerel (1896), 1897 discovery of the electron by Thomson (1897), and the 1890s efforts by Curie leading to the co-discovery of radium (Curie and Lippmann, 1898). Our history was also framed within the larger political and social movements to add further context for how, when, and why such advances were made. Lectures by the primary teaching team were then augmented by guest lectures on the history of the cyclotron (W3L5) by Dr. Tim Koeth (University of Maryland) and the "Radium Era" (W3L6) by Dr. Carl Willis (University of New Mexico) which combined early nuclear history with technical elements of engineering.

We then transitioned into the crux of the initial unit on twentieth-century physics with the learning outcomes organized such that students would be able to:

- $\mathfrak{L}_1$ **Recall** the major historical milestones in early twentieth-century physics and describe the experiments that led to them.
- $\mathfrak{L}_2$ **Organize** the events on a timeline.
- $\mathfrak{L}_3$ **Draw** connections between the developments in atomic physics, relativity, and quantum mechanics and explain their roots in nuclear physics.

The beginning of this unit focused on setting the stage of physics (1890—1899) and understanding the "play in 3 parts" (1900–1910) between quantum mechanics, atomic physics, and relativity (1910–1930) as shown in Figure 2. Lectures dealing with the early history from 1900 to 1910 began with a discussion of the development of the mathematical landscape and key players that provided the historical context for later revelations in nuclear, atomic, quantum, and relativistic theories. Among these were Georg Cantors (1845–1918) standardization of mathematics through set theory (Cantor, 1879), David Hilbert's (1862–1943) distillation of what would later be christened "Hilbert Spaces" by John von Neumann (1903–1957) (von Neumann, 1930) and would prove critical in downstream

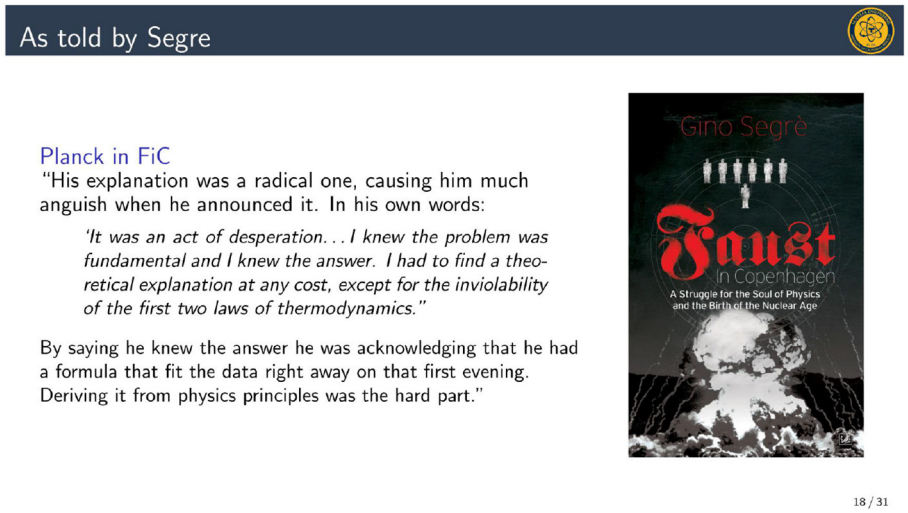

FIGURE 3
Planck in *Faust in Copenhagen*. Lecture W2L3.

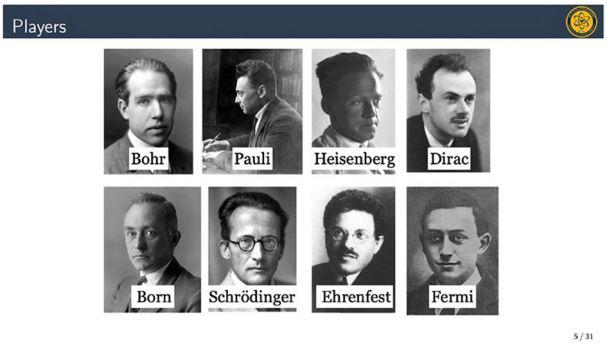

FIGURE 4
Important players in twentieth-century physics. Lecture W2L4.

developments in quantum mechanics (Hilbert et al., 1928), especially as it relates to Werner Heisenberg's (1901–1976) matrix methods (Peres and Mayer, 1994).

With this requisite appreciation of the mathematical underpinnings taken care of, we introduced quantum mechanics through the works of Max Karl Planck (1858–1947) and his interest in addressing a 1859 question from Kirchoff on how intensity of electromagnetic radiation emitted by a black-body depends on the frequency of the radiation and the temperature of the body. Using Planck as the primary figure allowed us to begin discussions of the first primary reading in the form of Segre's *Faust in Copenhagen* (Segrè, 2007) (Figure 3) and the framing of the importance of historical figures at scientific gatherings such as the Solvey conferences (Figure 4).

Our goal in these early NE290 lectures was to tell the nuclear history through tales of the physicists who played a central role in its development. In order to augment this history, we used the tale of Goethe's *Faust* (Goethe, 2021) to portray the dual nature of nuclear technologies. The works by Goethe and Segre set the stage as literary basis and historical yarn, respectively, for our introduction of Max Delbruck's (1906–1981) 1932 *The Blegdamsvej Faust*—as translated by George Gamow (1904–1968) (Gamow, 1966). Reserving class-time for students to act out (over Zoom) selected passages from the parody, we aimed to provide an immersive environment where twenty-first-centry nuclear engineering students in California could don the mantle of twentieth-century physicists on a make-shift Swedish stage who themselves were playing roles of sixteenth-century personas. We then built on this physics-as-theater concept to relate previously introduced names from earlier lectures to the outstanding full cast of prominent twentieth-century scientists. Here, the fable allowed us to trace the obsession of the neutron by Pauli and Bohr. Fittingly, *The Blegdamsvej Faust* ends with the neutron's discovery by James Chadwick (1891–1974) cast as Wagner—heralding the transition from scientific discovery to wartime use. We also emphasized that Lise Meitner's (1878–1968) attendance of the performance—but lack of participation amongst the cast—draws attention to the male-centric landscape of academia at the birth of nuclear science. The use of *The Blegdamsvej Faust* was developed throughout NE290 both as an emphasis of the complex bargains inherent to nuclear physicists and as a lens for exploring nuclear history in literature.

4.2. Note on women in science

The twentieth-century saw significant advancements in the field of physics, and many of these developments were led by women. Curie, Juliot-Curie, Noddack, and Meitner (Figures 5–8) were three pioneering female physicists who made significant contributions to the field during this time. Marie Curie is perhaps the most well-known of these three physicists, and with good reason. She was the first woman to win a Nobel Prize, and she did so twice: first in 1903 for her work on radioactivity, and again in 1911 for her discovery of the elements radium and polonium. Her work on radioactivity led to the development of X-ray technology, which revolutionized the field of medicine. Her daughter then made extremely important contributions in the field of artificially induced radiation. Ida Noddack was another important female physicist of the

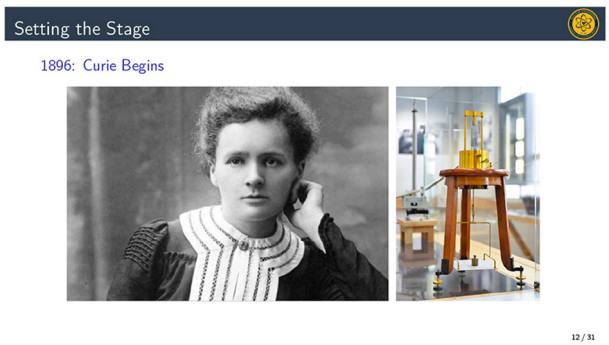

FIGURE 5
Important female players in twentieth-century physics—Curie. Lecture W2L3.

FIGURE 7
Important players in twentieth-century physics—Noddack. Lecture W4L7.

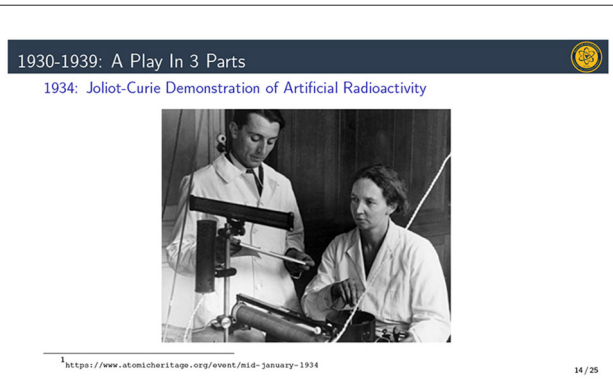

FIGURE 6
Important female players in twentieth-century-century physics—Juliot-Curie. Lecture W4L7.

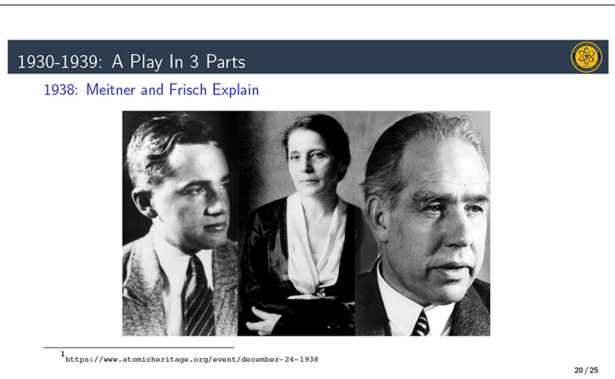

FIGURE 8
Important female players in twentieth-century physics—Meitner. Lecture W4L7.

twentieth-century. She is best known for her work on atomic nuclei, which led to the concept of the atomic nucleus. She also suggested the idea of nuclear fission, which was later developed by other physicists and played a crucial role in the development of nuclear energy. Lise Meitner was another pioneering female physicist of the twentieth-century. She is best known for her work on nuclear fission, which she developed with her colleague, Otto Hahn. She was forced to flee Nazi Germany in 1938 due to her Jewish heritage, but she continued her work in nuclear physics in Sweden. She was eventually awarded the Enrico Fermi Award for her contributions to the field. These three women made significant contributions to the field of physics in the twentieth-century. Their work in radioactivity, atomic nuclei, and nuclear fission helped to advance our understanding of the fundamental nature of matter and laid the foundation for many of the technological developments of the twentieth-century. Despite the challenges they faced as women in a male-dominated field, they persevered and made lasting contributions to the field of physics. While we endeavored to ensure that our class provided an inclusive recounting of history, more effort will need to be placed on ensuring we foster a class with a more diverse representation of woman and peoples of color.

4.3. Physics of WWII

Following the establishment of critical aspects of twentieth-century physics, we continued NE290 with a unit that traced the foundations, establishment, and exploitation of nuclear energy across World War II (WWII). With similar learning outcomes ($\mathfrak{L}_{1,2}$) to the previous unit, we aimed for students:

$\mathfrak{L}_3$ **Draw** connections between the developments in twentieth-century physics and latter Manhattan project.

Like we did with our 1927 introduction of cyclotron technologies (Telegdi, 1998), we began with Szilard's 1933 conceiving of the nuclear chain reduction as an insight garnered from reading H.G. Well's *The World Set Free* (Wells, 1914) in a bathtub (Ottaviani et al., 2001) (Figure 9). From here, our initial lecture outlined the proceeding events that vindicated Szilard and his idea starting with the Ida Noddack's (1896–1978) 1934 proposal for fission and observation of Noddack (1934), Otto Hahn's (1879–1968) 1938 observation (Hahn and Strassmann, 1939), and Meitner's 1938 synthesis (Meitner and Frisch, 1939)—culminating in Fermi's 1938 Nobel Prize and his collaboration with Szilard in realizing *2n* neutron production (Anderson et al., 1939). Framing these achievements in the context of a 1930s world on the brink of war, our initial lecture ended by recounting the 1939 story of Teller and Szilard

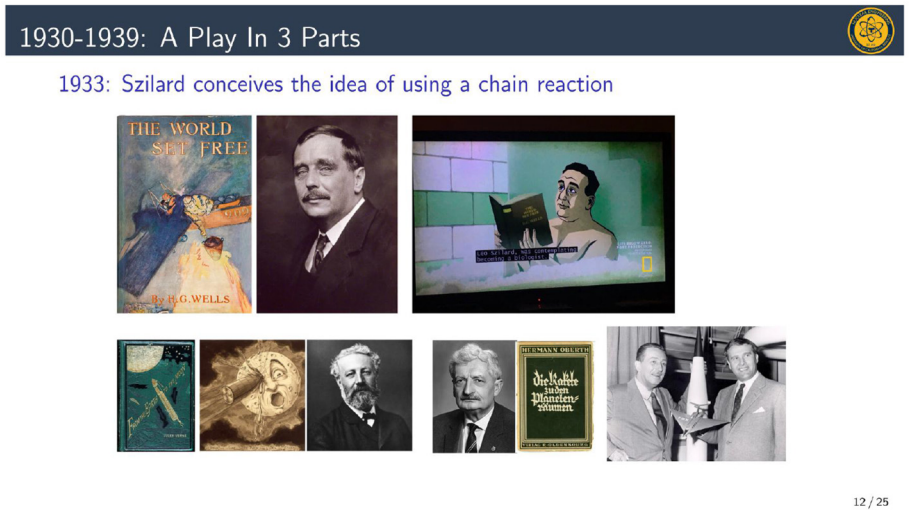

FIGURE 9
Slide detailing Leo Szilard's conceiving of a nuclear chain reaction following insight from H. G. Well's *The World Set Free* Similar scientific insights from adjacent disciplines also shown. Lecture W4L7.

lost in upstate New York—searching for Einstein and his signature on the letter to the U.S. President that would mark the start of the Manhattan Project.

Throughout the remaining lectures in this unit (W4L8-W7L13, meaning Week 4 Lecture 8 to Week 7 Lecture 13), we primarily focused on guiding NE290 students through the timeline of events from 1939 to 1945—outlined in large part by—and with our considerable appreciation to—the *Atomic Heritage Foundation*.[1] In W4L8, we first outlined the 1939–1941 investigations of nuclear weapons through the cross-talk between the U.S. Advisory Committee on Uranium, U.K. consideration of ^{235}U fast fission by Otto Frisch and Rudolf Peirls, and the interplay between the MAUD and Briggs Committees. We then outlined the 1941–1942 Allies' efforts to organize with emphasis on the establishment of Office of Scientific Research (OSRD) and later formation of the S-1 and its scientific pillars (Figure 10). Splitting this lecture, we then provided a technical guide on fissile ^{235}U purification—as outlined originally by the S-1 committee—via liquid thermal diffusion, gaseous thermal diffusion, and electromagnetic separation using the Calutron.

In W5L9, we continued our lessons on the early Manhattan Project of 1942–1943 beginning with a portrait of the military overseer of the Manhattan Engineer District (MED), General Leslie Richard Groves Jr., drawn from a number of historical accounts (Nichols, 1987) (Figure 11). The character of Groves was juxtaposed in discussion when reintroducing MED scientific director J. Robert Oppenheimer to the class—building on the characterization of Oppenheimer as a young idiosyncratic graduate student from the pages of *Faust in Copenhagen*. Given the gravity of his achievements, we dedicated the entirety of W10L19 to Oppenheimer and we made use of a variety of educational mediums beyond biographies (Bird and Sherwin, 2005; Conant, 2006) such as graphic novels (Ottaviani et al., 2001), plays (Goodchild, 1983), and even an opera (Adams et al., 2008) to ensure a unique and complete accounting befitting America's first scientific superstar (Oppenheimer, 1948). In contrast to the historical and literary aspects, we also aimed to frame the story in conjunction with the technical physics for which we provided reading and discussion of the *Los Alamos Primer* (Serber, 1943).

In lectures W6L12 (Developing the Bomb) and W7L13 (Ending the War) we concluded the historical timelines for the unit. Our slides demonstrate our efforts to portray the complexity of outcomes from America's first use of the Atomic Bomb across a variety of factions that included the Japanese victims, the men and women of MED, and the sociopolitical operatives across the military and government hierarchy. In W6L11, guest lecturer Dr. Alex Wellerstein led the class in exploring the morality of first-use, making use of a number of articles that resolved misconceptions and "set the historical record straight" (Wellerstein, 2015, 2020).

Although the focus of this unit was the U.S. led MED efforts, we also endeavored to provide an accountancy for the nuclear wartime weapons programs mounted by Germany, Japan (*Ni-Go*), and the Soviet Union (*Sovetskiy proyekt atomnoy bomby*). The historical record of nuclear weapon development was written by scientists from all corners of the globe, and we endeavored to showcase this global effort whenever possible (Figure 12). While significant events in non-U.S. programs can be found integrated into the timeline presented in lectures, W5L10 guest lecturer Dr. Miriam Hiebert provided an in-depth analysis of the Nazi Uranprojekt ("Uranium Project") and the U.S.-led Alsos Mission tasked with scientific intelligence gathering (Figure 13). Here the NE290 class was reintroduced to an older Heisenberg—who, like Oppenheimer, was scripted into *The Blegdamsvej Faust*. Following this lecture, the class was provided the audiobook of Michael Frayn's play *Copenhagen* (Frayn, 2017) (with voice acting by Benedict Cumberbatch) based on the 1941 meeting in Copenhagen between the physicists Niels Bohr and Heisenberg—and provides a literary window into the circumstances for and ramifications of Heisenberg's place in history. Additionally Hiebert's lecture introduced the class to technical engineering literature which applied modern nuclear physics simulations to reconstructed Nazi-era reactors (Grasso et al., 2009). Heibert's discussion of the Alsos mission led into our final lecture W7L14 detailed the sharing of

1 https://www.atomicheritage.org/

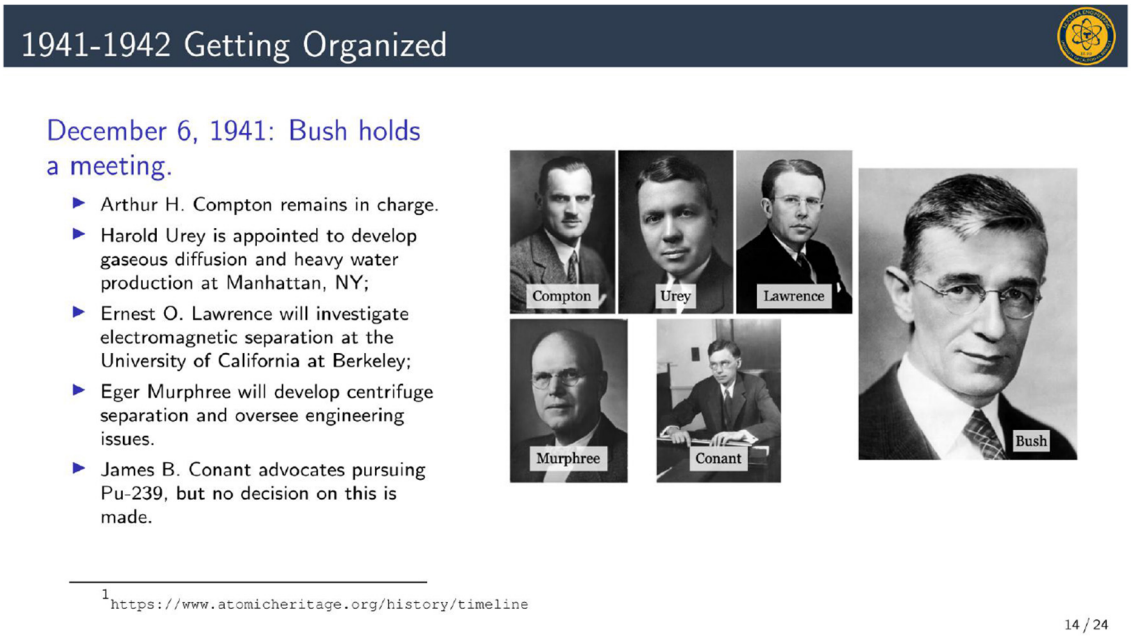

FIGURE 10
Slide detailing organizational leadership and structure of early MED. Lecture W4L8.

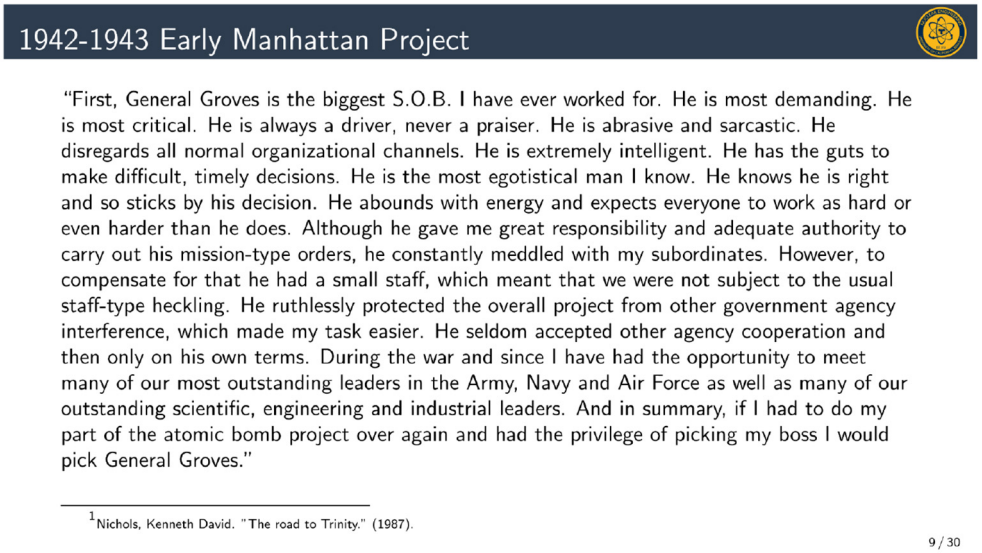

FIGURE 11
Nichols on Groves. Lecture W5L9.

nuclear data (voluntary and otherwise). Here we outlined a number of cases of Soviet spy-craft occurring throughout the wartime MED, and ushering the class into the subsequent unit on the early Cold War.

4.4. Early cold war

The early cold war section of the course focused on the US efforts to build a nuclear arsenal and consider the conditions under which it would be used. This included the formation of the AEC, the provisions of the Atomic Energy Act, the formulation of the first nuclear strategies, and the evolution of command and control.

Topics included the Berlin crisis, massive retaliation, the Castle Bravo test, and the beginning of global anti-nuclear activism. On the Soviet side, topics included the Soviet nuclear program starting from Flyorov's letter to Stalin to the test of RDS-1 in 1949 and RDS-37 in 1955. This series of lectures were augmented with readings from declassified documents that aided students in understanding the gulf between perceptions and the military reality in this era.

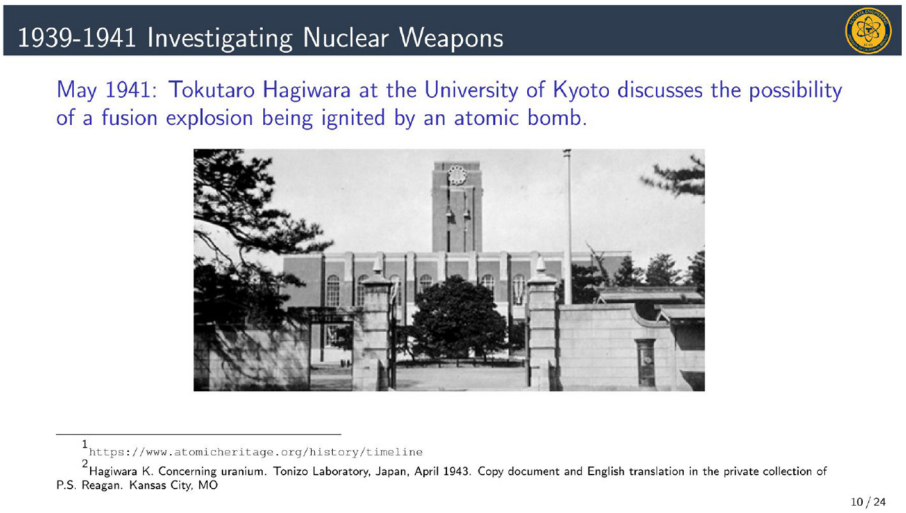

FIGURE 12
Slide recounting earliest conceptualization of a thermonuclear weapon in Japan. Lecture W4L8.

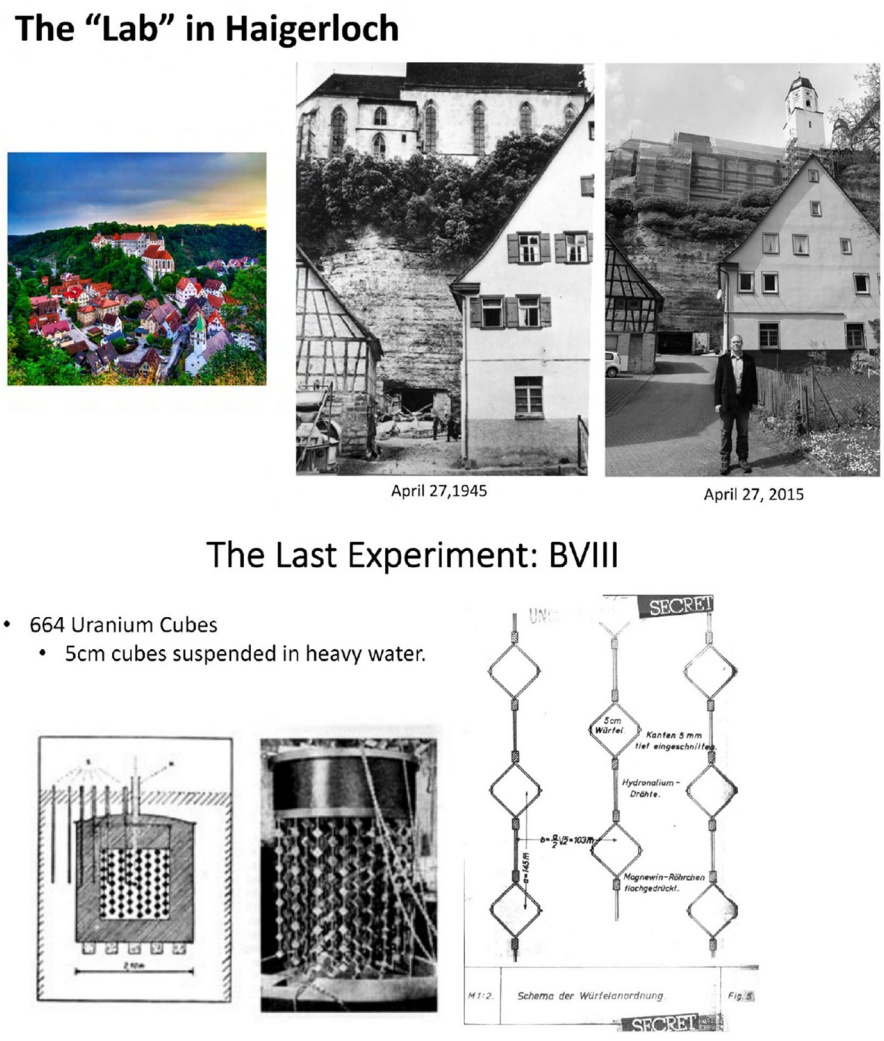

FIGURE 13
Slides depicting Nazi Uranprojekt laboratory led by Heisenberg in Haigerloch and experimental setup of the BVII reactor. Lecture W5L10.

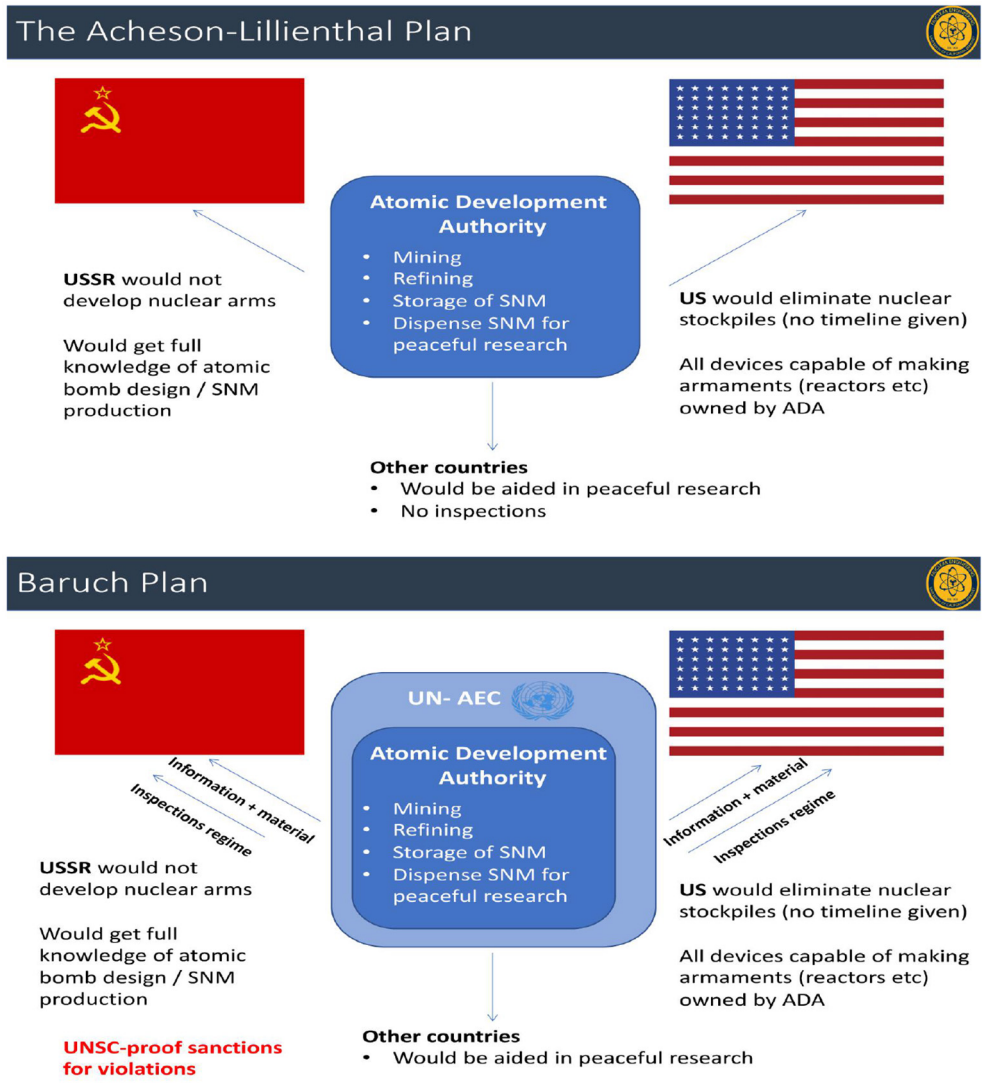

FIGURE 14
Slides outlining the Acheson-Lillienthal **(top)** and Baruch **(bottom)** plans. W7L14.

This unit provided an opportunity to coordinate classroom discussions on topics of public nuclear policy such as the Acheson-Lillienthal Plan as compared to the Baruch Plan (Figure 14). Such discussions allowed the students follow the historical record through the lens of public response to the nuclear energy. Additionally, we contrasted the history of public nuclear policy with lectures on the private aspects of early Cold War nuclear spycraft (Figure 15).

In addition to the technical and international foreign affairs aspects of the early Cold War, we dedicated an entire lecture to examining the 1954 trial of Robert Oppenheimer. We began this lecture with his departure from Los Alamos in 1945 and his subsequent 1947 move to Princeton—setting the stage for Oppenheimer's rise and fall as a public figure. We provided a historical accounting of the political tensions arising from Oppenheimer's chairmanship of the Atomic Energy Commission (AEC) and his difficult relationship to Lewis Strauss—the man who would lead the campaign to remove his security clearance. This lecture allowed us to build on Oppenheimer's role in the previous two units from young scientist to scientific statesman and expand on the narrative of Oppenheimer as a *Faustian* figure through classroom discussion (Figure 16).

4.5. Late cold war and modern era

This section of the course was wide-ranging, and covered everything from the "missile gap" of the early 1960s through contemporary struggles with nuclear proliferation. Guest lecturers were brought in to cover cooperative threat reduction, civil defense, nuclear smuggling, the Iran Deal, and modern efforts to grapple with the toll of the nuclear weapons complex. Of particular importance was the guest lecture by Marty Pfeiffer on Nuclear Colonialism which prompted students to address a number of challenging sociological and ethical considerations inherent to nuclear engineering at large (Figure 17). This course material was unique in that people involved directly in these events were lecturing, connecting the current generation of nuclear scientists to those who made the history they must live with. In comparison to earlier lectures, these dealt with

FIGURE 15
Slides describing Soviet spymasters. W7L14.

topics that do not have settled interpretations. In particular, we had the opportunity to explore varying interpretations of the Iran deal, the value of deterrence in a post-Cold War world, and the modernization of the nuclear arsenal.

5. Remote learning environment

The initial Spring 2021 offering of NE290 occurred during the Pandemic and thus the course was exclusively taught remotely. In order to facilitate an effective learning environment, we tailored NE290 with a number of modern tools including SLACK for communication, bCourses as the primary course file system and location for students to submit assignments and collect grades, and MIRO for interactive class collaboration on a timeline of historical events. The use of MIRO shown in Figure 18. In conjunction with the timeline of historical events, students were provided a "response" or "meta" timeline across which they added their reflection assignments. Our goal was to explore the connection between these two timelines.

6. Term paper

In accordance with the ABET student outcomes ($\mathfrak{O}$) and the target NE290 learning goals ($\mathfrak{B}$), students were assigned a final project based on selection from two options as shown in Figure 19. In Option 1 ("Historical Answers to Modern Problems"), students were asked to consider a problem facing the nuclear community that transcends the bounds of scientific, technical, economic, or security communities, and with their newfound understanding of nuclear history and its impact across the twentieth-century, propose a solution to the present, for the future, based on the past. In Option 2 ("Nuclear Bedtime Story"), students were asked to consider either adapting a work of literature to fit the scope of an important historical event in nuclear physics, nuclear engineering, or national defense such that a reader would be compelled to consider the weight of their chosen theme.

In a fortunate happenstance given the differences in student preference, the class divided itself in approximately equal measure between the two options. A midterm assignment was given for each group to provide answers to the initial questions shown in Figure 19 which were later used for an in-class discussion, and we endeavored to foster cross-talk between the two groups in the form of peer review.

The final deliverable from the Option 1 prompt was a technosociological paper entitled "A Nonproliferation Retrospective: How Past Successes and Failures of the Nonproliferation Regime can Inform Future Actions" with the following synopsis:

> A modern-day problem the nuclear community continuously faces is how to successfully prevent proliferation. This term describes both instances of preventing nuclear states with interests in developing nuclear weapons from actively pursuing them, as well as the more difficult task of halting active development and the elimination of stockpiles. Whether through peaceful negotiations, credible threats, or use of force, a variety of strategies have been attempted throughout the course of the nuclear age with varying degrees of success. We will be undertaking the task of analyzing these precedents to piece together an understanding relating the contextual factors, historical timing, international relationships, and chosen nonproliferation approaches to the resultant response ranging from successful peaceful disarmament in some cases, to hostility and increased risk of nuclear war in others.

The final deliverable from the Option 2 prompt was an illustrated story entitled *The Little Scientist* based on Antoine de Saint-Exupéry's *The Little Prince*. In the original book, the narrator crashes his plane in the Sahara desert and meets the titular young boy. In the re-crafted story—the beginning of which is shown in Figure 20—stranded in the desert, the narrator tries to repair his aircraft from the crash while the little prince recounts his life story. The prince is from his own planet, and he leaves to explore the universe and visits six other planets before arriving on planet Earth. On each planet, the prince interacts with a different character that teaches the readers of this book different things about life and adulthood. The six planets will represent a different theme of life that coincides with a different nuclear technological application. The primary resident on each planet will represent a prominent figure for that particular nuclear technology as shown in Figure 21.

7. Course outcomes

NE290 was offered at UC Berkeley during the COVID-19 pandemic spring of 2021, and so the entirety of the course was conducted remotely via the Zoom tool. The class was composed

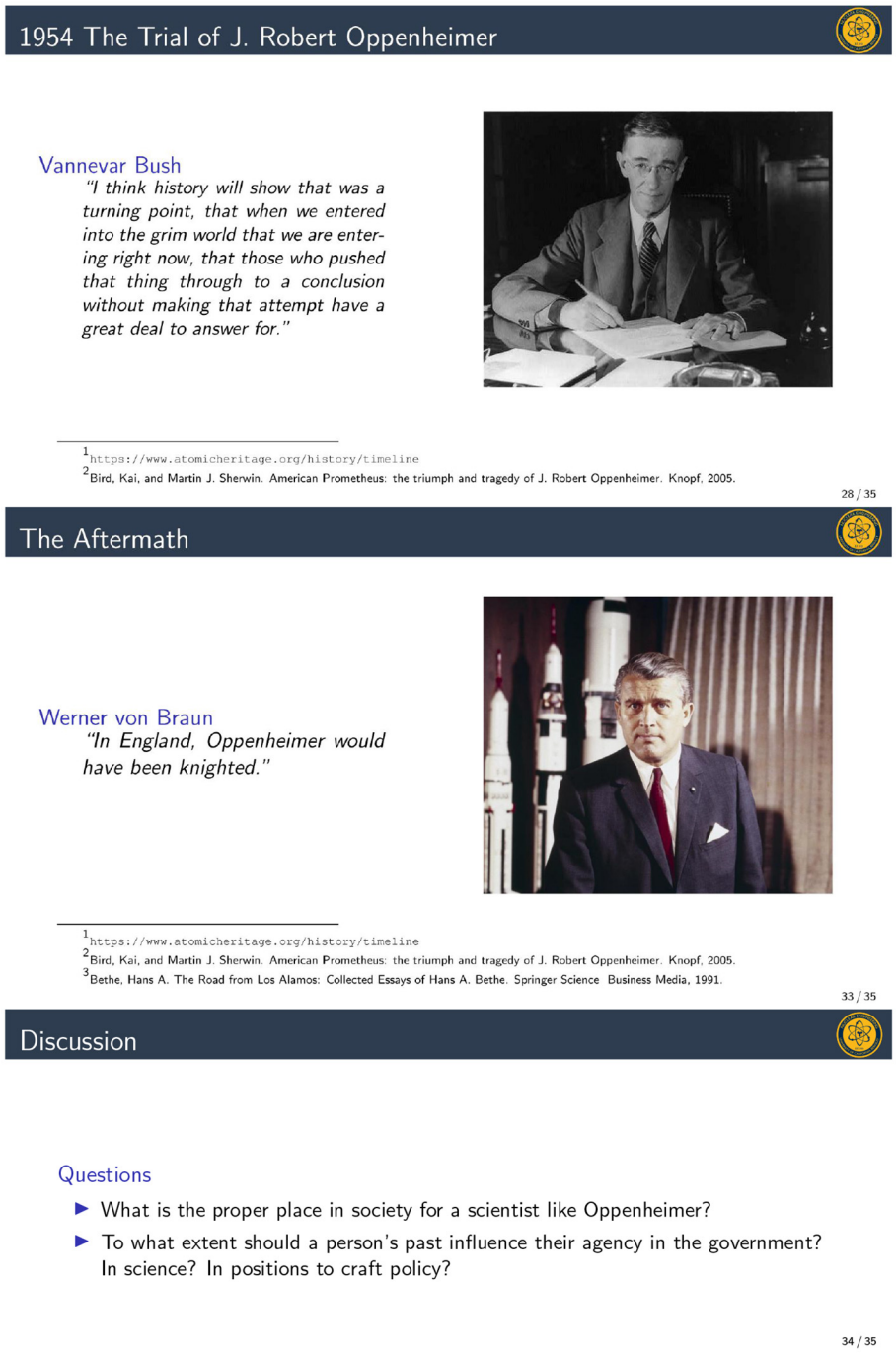

FIGURE 16
Slides outlining the public and scientific response to the trial of Robert Oppenheimer. W10L19.

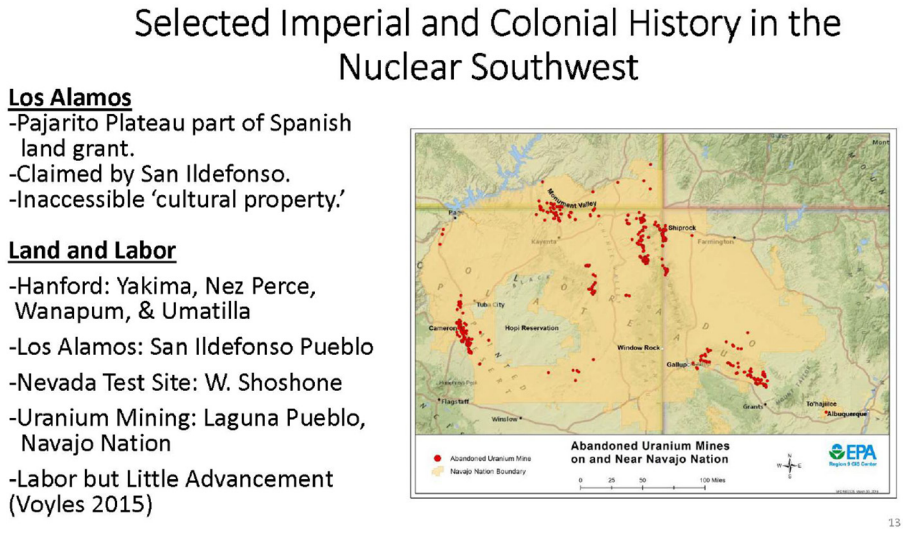

FIGURE 17
Slide outlining imperial and colonial history in the nuclear southwest. W11L22.

of 11 students (2 female and 9 male). In terms of background, 10 were enrolled in nuclear engineering programs; 4 were 1st-year graduate students, 3 were 2nd-year graduate students, 1 was a 3rd-year graduate student, and 1 was an undergraduate junior who was enrolled studying environmental engineering. Following the completion of the course, students were provided a survey to determine the impact of lesson in terms of its pedagogical targets. First students were asked to evaluate how their understanding of nuclear history changed from the beginning to the end of the NE290 course (Red Box).

General Course Questions

1. How would you evaluate your understanding of nuclear history **PRIOR** to starting NE290.
2. How would you evaluate your understanding of nuclear history AFTER to completing NE290.

Students where then asked questions (Green Box) pertaining to how NE290 aided their agency toward the nontechnical ABET goals ($\mathfrak{O}$) as shown in Figure 22A. Specifically students were asked to evaluate their growth in ABET outcomes on a scale of 1-10.

ABET Outcome Questions

1. How would you evaluate how NE290 helped your ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
2. How would you evaluate how NE290 helped your ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
3. How would you evaluate how NE290 helped your ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

The results show post NE290, students feel they gained agency in ($\mathfrak{O}_1$) an ability to recognize ethical and professional responsibilities in engineering situations and ($\mathfrak{O}_3$) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies. However, the feedback for ($\mathfrak{O}_2$) suggest that the strategies taken to provide additional practice on engineering teams were insufficient—providing an important path forward for educators in preparing to offer an NE290-like course.

Students where then asked questions (Blue Box) designed to evaluate their abilities relating to the learning outcomes based on Bloom's taxonomy ($\mathfrak{B}$) prior to and post completion of the NE290 course as shown in Figure 22B. Similar to before, students were asked to evaluate their growth in Bloom Taxonomy outcomes on a scale of 1-10.

Bloom's Taxonomy Questions

1. **PRIOR** to NE290, how would you evaluate your ability to Sequence, Summarize, and Diagram the historical events for twentieth-century physics leading to the Manhattan project.
2. **POST** NE290, how would you evaluate your ability to Sequence, Summarize, and Diagram the historical events for twentieth-century physics leading to the Manhattan project.
3. **PRIOR** to NE290, how would you evaluate your ability to Sequence the complex historical basis for nuclear armament.
4. **POST** NE290, how would you evaluate your ability to Sequence the complex historical basis for nuclear armament.
5. **PRIOR** to NE290, how would you evaluate your ability to Summarize the landmark players that shaped the nuclear engineering communities.
6. **POST** NE290, how would you evaluate your ability to Summarize the landmark players that shaped the nuclear engineering communities.
7. **PRIOR** to NE290, how would you evaluate your ability to Summarize the persistent problems in nuclear policy and engineering from a historical perspective.
8. **POST** NE290, how would you evaluate your ability to Summarize the persistent problems in nuclear policy and engineering from a historical perspective.

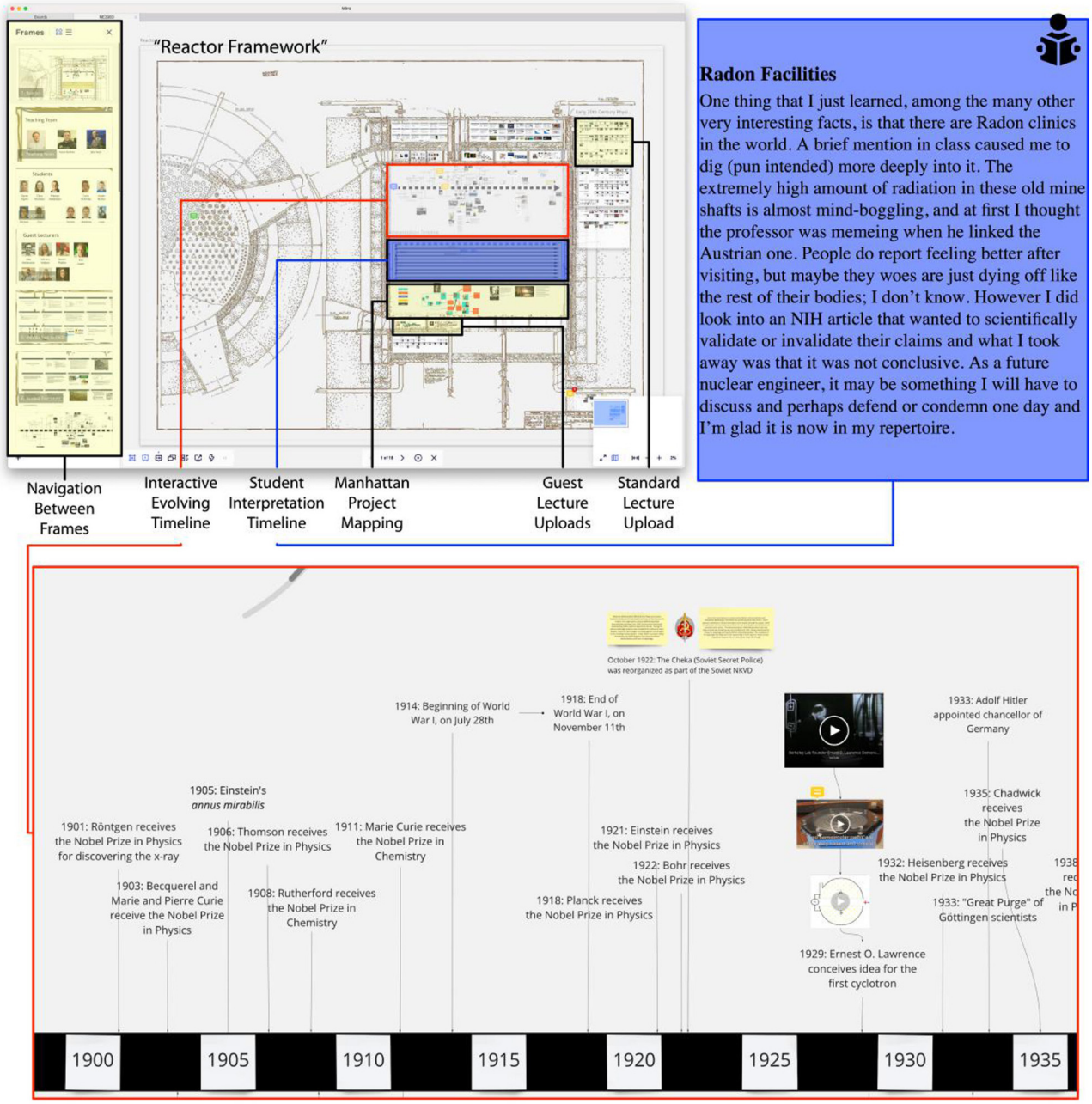

FIGURE 18
Top left shows the complete MIRO board for NE290 and is annotated with specific features including the integrative evolving timeline, student interpretation timeline, and lecture slide integration. **Top right** in blue shows an example of a student response in regards to a lecture that discussed sociological issues concerning Radon contamination. **Bottom** shows an expanded timeline composed of milestones added by students throughout the course of NE290.

9. **PRIOR** to NE290, how would you evaluate your ability to Analyze how current persistent problems in nuclear policy and engineering can be related to problems solved through a historical perspective.
10. **POST** NE290, how would you evaluate your ability to Analyze how current persistent problems in nuclear policy and engineering can be related to problems solved through a historical perspective.
11. **PRIOR** NE290, how would you evaluate your ability to Synthesize solutions to current persistent problems in nuclear policy and engineering from solutions to past problems.
12. **POST** NE290, how would you evaluate your ability to Synthesize solutions to current persistent problems in nuclear policy and engineering from solutions to past problems.
13. **PRIOR** to NE290, how would you evaluate your ability to Analyze impact of nuclear physics on international relations and world affairs.
14. **POST** to NE290, how would you evaluate your ability to Analyze impact of nuclear physics on international relations and world affairs.

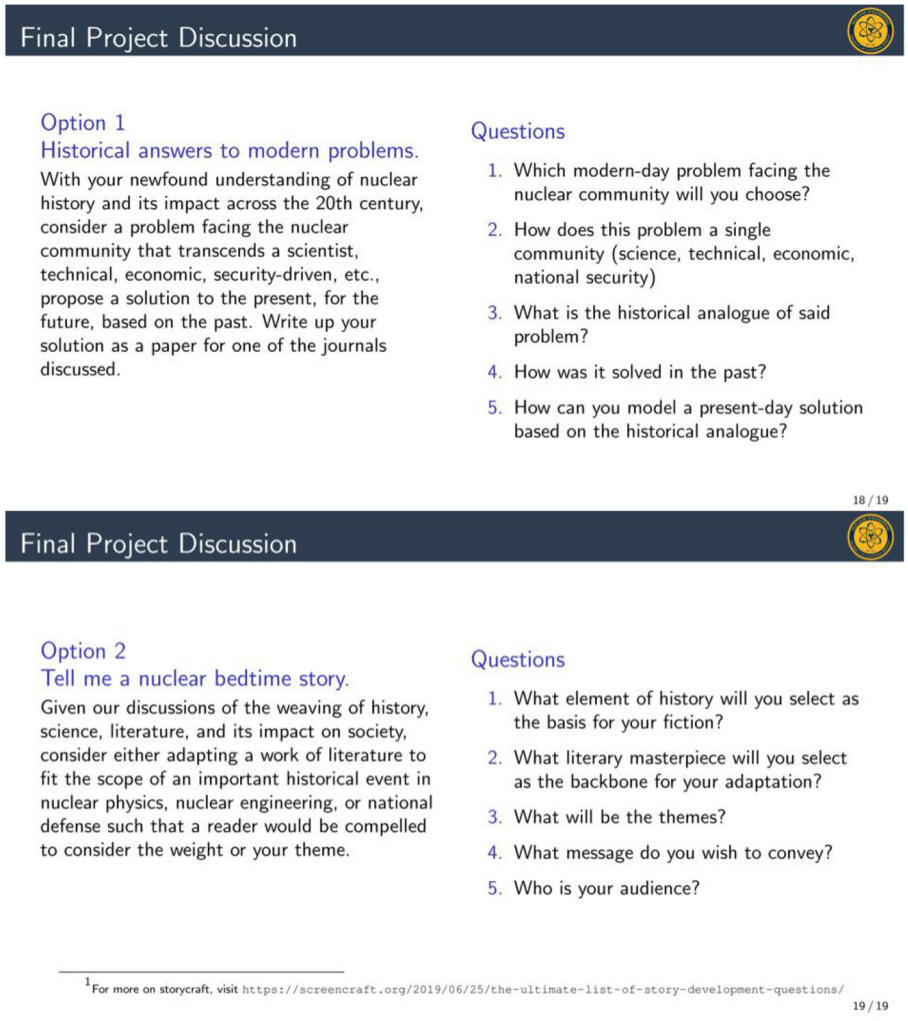

FIGURE 19
Final project assignment options and corresponding initial questions from Lecture W7L13.

Figure 22B shows the increase from reported student agency in addressing specific Bloom Taxonomy outcomes from the beginning (*i*) to the end (*f*) of NE290. Here we report growth in the report student agency in each Bloom Taxonomy element ranging from 2.56 to 4.22 points.

We then asked students to rate the effectiveness of the MIRO and SLACK tools used for remote learning on a scale from 1 to 10 (Gray Box).

Course Tool Questions

1. How would you rate the effectiveness of MIRO during remote learning semester?
2. How would you rate the effectiveness of the custom SLACK during remote learning semester?
3. What tools would you keep if NE290 was taught in-person?

When asked to select only a single tool to keep if NE290 was taught in-person, 44% opted for recorded lectures (enabled by Zoom), 33% selected SLACK, and only 22% opted for keeping MIRO. These results suggest that our use of MIRO will require additional effort in integrating the software during proceeding semesters. In reviewing the free-form feedback from students, we recieved a comment noting, "I thought that MIRO was not helpful at all. It was just too clunky, unpleasant to look at. There's too much information to pack into a nice looking timeline. However, I did like the idea of having all the class content laid out like MIRO did. The execution was off." However, in reviewing the outcome survey, we are pleased the report that when asked to evaluate their understanding of nuclear history prior to and post completion of the course, the students indicated an average jump of ~3.67 from 4 to 7.67. Such feedback, while unofficial, suggests that the efforts to offer the opportunity of exploring nuclear science and engineering from a historical and literary perspective was valuable from an educational perspective.

Here we note that the statistics presented in Figure 22 were calculated from a small sample size—as the course had only 11 people. Here we note that there are limitations in drawing conclusions from such quantitative methods. Ultimately, we see that students report growth in their claimed agency in applying the lessons learned from the course. This itself is a promising reward to developing and offering the course.

Once when I was eight years old, I stumbled into the school library after lunch to be alone, as I often felt myself wanting to be. As I roamed the aisles of books and magazines, I found myself in the science section. Curious, I skimmed through to find something to interest me until it was time to go back to class. 'Transcendentals'? No. Too many problems. 'Antenna Theory'? Not likely. I didn't even own a set of walkie talkies. None of them truly captivated me until I found *it*. With an EXPLOSION of light and colors in a sea of darkness on the cover labelled 'Hubble Legacy', I knew that I just had to flip through this one. Places and shapes that I had never even dreamed of existed within the confines of these pages! I thought deeply about how the news is always complaining about our energy crisis, and here I found a solution to it in a picture book. I got to work immediately drawing inspiration from the book. My first spout of genius looked a lot like this.

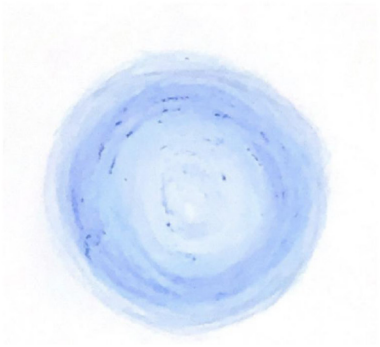

FIGURE 20
Section of final project option 2.

"Well actually my hazmat suit is also safe for space travel. It's a 2-in-1." L.S. assured the inhabitant, while they untied the twine to deflate the balloon, and carefully put it into a pocket.

"One second….here." The strange inhabitant pulled out a set of keys attached to a key ring with a suspiciously familiar, black and yellow symbol attached to it. The two began to walk together.

"By the way, you never told me your name. I'm L.S."

"Just refer to me as Dr. Oppi." The inhabitant replied.

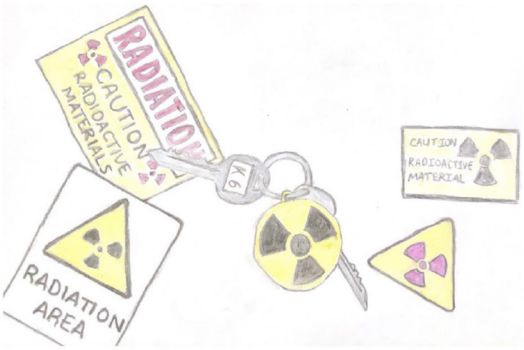

FIGURE 21
Section of final project option 2. Note the introduction of Oppenheimer as a character in the narrative.

8. Concluding remarks

We began this pedagogical effort as graduate students at UC Berkeley after noticing that many of our peers had a number of gaps in their historical knowledge or harbored mistruths and misconceptions about the events that led to the birth of nuclear engineering as a field. To address the lack of familiarity with nuclear history common among nuclear engineers and physicists, we designed and deployed a special-topics course entitled "NE290: Nuclear History, Politics, and Futures" across which we contextualize the importance of the field at its inception, in current affairs, and in future endeavors. Here we have argued that understanding this history is paramount in internalizing a sense of respect for the scientific, technical, and sociological ramifications of an unlocked atom—as well as its perils. We detailed the sequence of lectures across the course and historical timelines—leading up to a showcasing of NE290 final projects which mirror in creativity the novelty of the course offering. Because NE290 was first offered during Spring 2021 during the COVID-19 pandemic, additional measures in the form of new tools were used to augment the mandate of remote learning. In particular, we leveraged the newfound ubiquity of videoconferencing technology to recruit geographically diverse guest lecturers and used the MIRO tool for virtual whiteboarding. Lastly, we provided an accounting of course outcomes drawn from

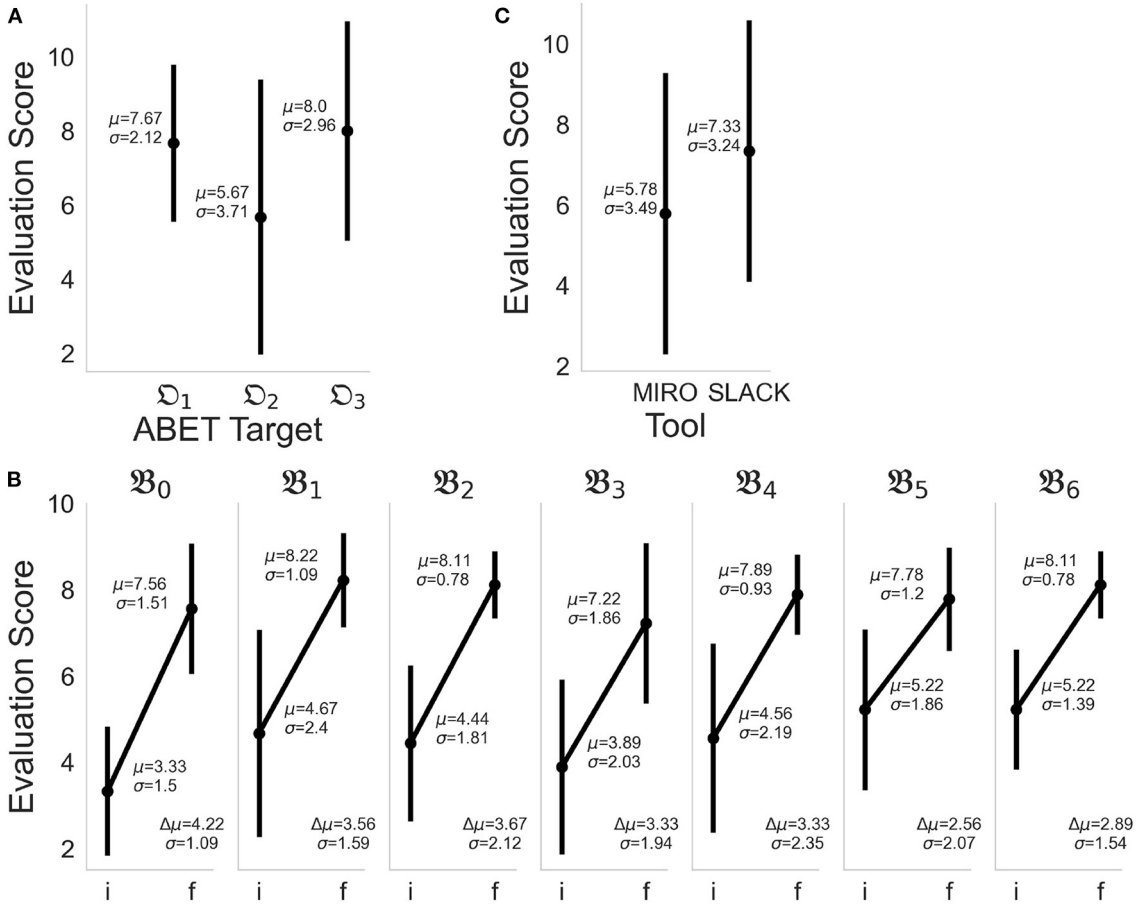

FIGURE 22
Course outcome evaluation calculations based on student survey. Students were asked to evaluate a number of questions based on a 1–10 scale with 1 being to lowest and 10 being the highest. **(A)** Calculated student survey responses addressing ABET Outcomes $\mathfrak{O}$. $\mathfrak{O}_1$ corresponds to an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. $\mathfrak{O}_2$ corresponds to an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. $\mathfrak{O}_3$ corresponds to an ability to acquire and apply new knowledge as needed, using appropriate learning strategies. **(B)** Calculated student survey responses addressing targeted learning outcomes $\mathfrak{B}$ based on Bloom's taxonomy. $\mathfrak{B}_1$ is to **Analyze** how the Manhattan project was influenced by these discoveries. $\mathfrak{B}_2$ is to **Sequence** the complex historical basis for nuclear armament. $\mathfrak{B}_3$ is to **Summarize** the landmark players that shaped the nuclear engineering communities. $\mathfrak{B}_4$ is to **Summarize** the persistent problems in nuclear policy and engineering from a historical perspective. $\mathfrak{B}_5$ is to **Analyze** how current persistent problems in nuclear policy and engineering can be related to problems solved through a historical perspective. $\mathfrak{B}_6$ is to **Synthesize** solutions to current persistent problems in nuclear policy and engineering from solutions to past problems. $\mathfrak{B}_7$ is to **Analyze** impact of nuclear physics on international relations and world affairs. **(C)** Remote Learning Tool Survey.

student feedback which—in tandem with the complete distribution of course material—facilitates the integration of nuclear history into the curriculum for the wider nuclear engineering and physics communities. Ultimately, we feel that the creation of this course has been rewarding, and we hope to see it adapted by the community.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://github.com/aaronreichmenberliner/NE290-Spring2021-Nuclear-History-Politics-Futures-.

Author contributions

AB and JH designed the NE290 course, produced materials, gave lectures, evaluated students, and wrote the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Idea generation and integration method for inclusion and integration teamwork

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Idea generation is fundamental in higher education, principally in engineering and creative areas. The challenge presented in our research was to correctly implement a progressive, intuitive categorization method to generate solutions, unifying individual proposals and ideas through a virtual platform or face-to-face sessions and real-time communication. This paper aims to present the implementation impact from students' first-use perceptions and experiences, segmented by study area, gender, and semesters. Our research began with creating an idea generation method. Experienced design professionals integrated various tools to run on digital platforms. This method was called ICRI, an acronym for Ideation, Categorization, Regrouping, and Ideation. The method had two primary stages. The initial stage employed four-step where the students defined, investigated, established findings, and formed teams to move on to the second stage. This second stage comprised two parts, the first four-step where students generated ideas, reviewed, defined, and grouped them; the second five-step process involved focusing the ideas for regrouping, discussion, fusion, and writing new ideas. This method was applied to start a product design process or design strategy to create a project design. The results revealed high student acceptance of the method due to its practicality, rapidity, and functionality in generating ideas and active, equitable student participation. We found that certain students' profiles are not optimistic about the use of such tools. Also, we found that there were no significant differences by gender of the student profile, but it was noted that female students liked the method more. The findings derived from the creation and application of the ICRI method were consequences of the need to create innovative practices to integrate higher education students. The ICRI method reinforces the trend of educational methods that address the relevance of collaborative idea generation and processes that facilitate effective interactions, even in a virtual and remote mode.

KEYWORDS

educational innovation, higher education, design, teamwork, ideas generation, professional education

1. Introduction

Currently, many professions must generate creative solutions, especially professions in the design process and other professions requiring creativity and innovation for new products, where ideas generation becomes of utmost importance (Ulrich and Eppinger, 2013; Gajda et al., 2017), both individually and in groups (Shubina and Kulakli, 2019). Therefore, ideas generation

is a widely studied topic related to several factors determining its value in different contexts (Choi and Lee, 2015; Hutchinson and Tracey, 2015; Sarkar and Chakrabarti, 2017; Gonçalves and Cash, 2021). Ideas generation is connected to the creativity of individuals, which Ritter et al. (2012) define as creating something new, valuable, and highly appreciated in companies. However, several studies have shown that creativity and idea generation decrease through the years in higher education (Cheung et al., 2003), requiring a focus on observing the process and methods of idea generation in students or those who require it.

Generating ideas in an educational context is complex, this process involves unconscious and conscious thought (Ritter et al., 2012) and requires access to divergent memories and associations (Lacruz Rengel, 2013) and is associated with learning processes. Therefore, the person must have extensive knowledge of the subject and relate or associate the elements of that knowledge (Kilgour et al., 2020). According to Shah et al. (2000), there are two categories of formal methods for generating ideas: intuitive methods, which stimulate unconscious thought; and logical methods, which consider the analysis of the problem and its systematic decomposition through engineering and science cataloging, procedures, and solutions. The emphasis should be on intuitive methods subdivided into germinal, organizational, progressive, transformational, and hybrid classifications. In the 1980s, these categories had already been proposed but were considered with varying ideas and other independent problem elements (Wöhler and Reinhardt, 2021). Despite all this and the different solution development models available, professionals still have a limited understanding of how ideas are generated (Hutchinson and Tracey, 2015).

The relationship between the creative aspects of ideas and professional life is evident. There is a direct correlation between "idea generation for solutions" and "professional careers that resort to idea generation methods." For example, product design, industrial design, or similar careers depend on their culture and limit the generation of more ideas than desired or required (Lacruz-Rengel, 2008). An essential aspect of idea generation is the possibility of collaborative production and solutions that arise from a co-design process (Steen, 2013). This is important for companies because, in most cases, they form multidisciplinary teams to solve their problems or satisfy the needs of their clients holistically (Heslin, 2009; Ulrich and Eppinger, 2013). Several aspects are present in these multidisciplinary teams, people from various organizations or departments share knowledge and combine ideas (Steen, 2013). Also, cultural diversity in a team is positively related to individual and team creativity (Li et al., 2017). In this regard, the need to create working groups has evolved. Even in other professional fields like computational models have been developed that link the interactions of the participants as elements of a system; analyzing interventions that manipulate or control the different variables of the process (Vrgović et al., 2013; De Garrido et al., 2019). However, how far have the idea generating methods evolved? Innovations support methodologies to promote creativity and automate the control, direction, and documentation of the entire process in academics and companies (Herring et al., 2009; Drejeris, 2012; Tavanapour et al., 2019; Kilgour et al., 2020).

For example, in design-related professions in academia or companies, most of the time, solving complex problems must occur quickly; thus, idea generation has become a fundamental professional skill. Effectively, this happens mainly through multidisciplinary teams that include designers or creative professionals (Asante, 2018); however, it does not necessarily happen immediately when a complete idea generation process is started. Several actions are needed to begin a creative process, including gathering all information being developed (Kilgour et al., 2020). In a convoluted process, the union of creativity and the various perspectives of team members to generate solutions can be very complex (Steen, 2013). As mentioned above, this also exists in higher education environments (Law et al., 2013), where interactions, collaborative work, and participation become essential to creating a problem-solving tool. Likewise, students must respond to the creation of ideas and the follow-up of assessments and judgments by their teachers regarding the ideas' originality (Lacruz Rengel, 2013; Kilgour et al., 2020; Cotán et al., 2021). The relevance of creative methods focused on idea generation becomes relevant, particularly in many creative disciplines.

Hanington and Martin (2012), propose a classification of methods that focus on creative aspects, principally in the design process. These methods can be divided into five phases, namely: (1) Planning, scope, and definition; (2) Exploration, synthesis, and design implications; (3) Generation of concepts; (4) Evaluation, refinement, and production; (5) Launch and follow-up. These phases are linked to a generic structure within which the process of product design, service design, or simply problem-solving can be addressed (Ulrich and Eppinger, 2013). Exemplifying what the classification mentions, in the Concept Generation phase (3), methods such as Affinity Diagram, Cognitive Map, Conceptual Map, Generative Research, and Mental Model Diagrams stand out, whose general purpose is the generating new ideas or concepts, by considering the appreciations that have been made to define a situation or problem. Likewise, there are methods such as Brainwriting or Brainstorm Graphic Organizers, which contemplate, in addition to ideas generation, an organization, classification, or hierarchy of these, facilitating the analysis and selection of a final proposal (Hanington and Martin, 2012). On the other hand, there are alternatives with a wide scope of application such as Design Thinking, which involve different methods and assign a very significant value to the ideation or solutions generation (Brown, 2008).

Any of the methods mentioned above takes into consideration the use and performance in person, something that has been modified in recent years due to different factors. Presently, these changes are present in professionals' work where generate ideas in academic or industrial environments through face-to-face work groups or are moving to remote modalities supported by technology. In the transition to remote activities, the question has been raised as to which methods can coexist in their face-to-face or remote format. This research seeks to provide information in this regard since there are several examples of methods based on high-value technological resources that go beyond face-to-face meetings (employment training and teaching, for example) to enable activities to be performed virtually and remotely (Vrgović et al., 2013; Buisine et al., 2016). Evidence suggests that virtuality does not generate a problem if learning or dynamics are online and follow the same conditions (Cotán et al., 2021). Idea generation and their representations have happened remotely with success; since the last decade, collaborative work and idea generation have been supported by accessible technology (Klemmer et al., 2008; Jimenez-Narvaez and Segrera, 2011; Weibel et al., 2011). Undoubtedly, the evolution and changes found around idea generation, collaboration, and practice have led to a series of successes in recent years; however, in generating ideas, we can find other components that can determine a method's effectiveness (Hanington and Martin, 2012), many of these implications are due to interpersonal interactions.

The idea generation and the processes involved are tightly related to the interactions within the workgroups. In this context, studies and analyzes of the relationship between teams are presented (Lacruz-Rengel, 2008), in this relationship, there are components to highlight: the gender of the teams, inclusion, and contextual academic or industrial interactions. In this research, we will emphasize a particular component that is near to education and creative aspects. Studies show a correlation between gender and creative potential, evidencing positive relations in an individual approach (Shubina and Kulakli, 2019). Finding differences in the disposition to critical thinking among student groups with different degrees and genders has been the subject of exploratory studies (Walsh and Hardy, 1999). Mainly in higher education, students show representative behavior distinguished in gender, gender roles, and creativity; including common challenges for gender-diverse teams, where there are discrimination, communication problems, conflicts among team members, and low team cohesion (Santos et al., 2022). The results in other studies indicate that gender diversity is positively related to radical innovation, but it does not promote incremental innovation in the same way (Díaz-García et al., 2013). However, no problems have been found or indications within work teams related to gender and other aspects. This information gathering has given us indications that this research may present new information, as with other examples such as critical thinking during idea generation and creativity, no differences were found between semesters and gender (Zetriuslita et al., 2016) or relationships between gender and gender roles in creative dynamics (Stoltzfus et al., 2011; Alsos et al., 2013). Further indications indicate that in work groups, failures are not a gender element effect (Pearsall et al., 2008). According to Baer and Kaufman (2008), "there continue to be large gender inclusion differences in creative productivity, and these differences represent the most significant unanswered questions about gender and idea generation."

In conclusion, idea generation is a complex and vast process, and the workgroup dynamics and interaction determine nuances that may or may not affect the effectiveness of idea generation. Observing and studying the methods that generate ideas is relevant to providing students with the skills to consistently generate good ideas that help them overcome the creative and innovative challenges they face (Lacruz Rengel, 2013; Law et al., 2013; Hutchinson and Tracey, 2015). Therefore, this research exposes the implementation of an idea generation and integration method for undergraduate students in work groups in a multi-modality, simultaneously using two technological platforms. Due to the recent pandemic and the need to continue higher education studies in an online and hybrid format, this is a novel alternative for creative ideas generation at the higher education level in a presential and hybrid approach (virtual/face-to-face). In this research, our method brings several findings to focus on perception and experience, students' profiles, and gender perspectives regarding the experience of this method for managing and developing creative ideas.

2. Materials and methods

2.1. Participants

The participants were 138 students. The sample characteristics are described in Table 1. All student data were collected during the 2020–2021 semesters.

2.2. Methodology

2.2.1. ICRI method

This article presents the ICRI method (from the acronym "Ideation, Categorization, Regrouping, Ideation") to generate ideas and solutions. This method can be applied virtually through the MIRO® platform and Zoom® as a communication tool and as a hybrid where the team members are present, but the activity is conducted on the MIRO® platform (see Figure 1). The ICRI method is executed in the following steps:

2.2.1.1. Team formation

Students are organized into teams of 4 or 5 members (Cotán et al., 2021) to research a problem or problematic situation to identify the most critical aspects that must be considered when generating a solution (Lilien et al., 2002). The results of the investigation are presented in the form of findings, requirements, conditions, or more (Hanington and Martin, 2012; Ulrich and Eppinger, 2013).

2.2.1.2. Generation of individual ideas

Once the investigation results are defined, the students enter the MIRO® platform, where each team has a defined space to work. In that space, one of the team members writes the five or six most significant results (of the investigation) with the consensus of the whole team. Subsequently, each member of the team generates in writing 10 solutions to the problem, following the results of the investigation. The 10 ideas are recorded without receiving criticism from the team members and without considering the magnitude of the solution proposed to them (Vrgović et al., 2013; De Garrido et al., 2019; Kilgour et al., 2020), similarly to what happens in the Brainwriting method

TABLE 1 Sample characteristics.

Characteristics	Sample	*N*	Percent
Gender	Female	82	59.4%
	Male	56	40.6%
Career	Design	56	40.6%
	Architecture	15	10.9%
	Digital art	10	7.2%
	Music production	4	2.9%
	Social sciences	24	17.4%
	Engineering	29	21%
Semester	Semester 1–2	59	42.8%
	Semester 3–4	38	27.5%
	Semester 5–6	14	10.1%
	Semester 7–8	21	15.2%
	Semester 9	6	4.3%
How did you use the method?	Online (Miro + Zoom)	62	44.9%
	Hybrid (Classroom + Miro)	67	48.6%
	Presential (Post-its)	9	6.5%

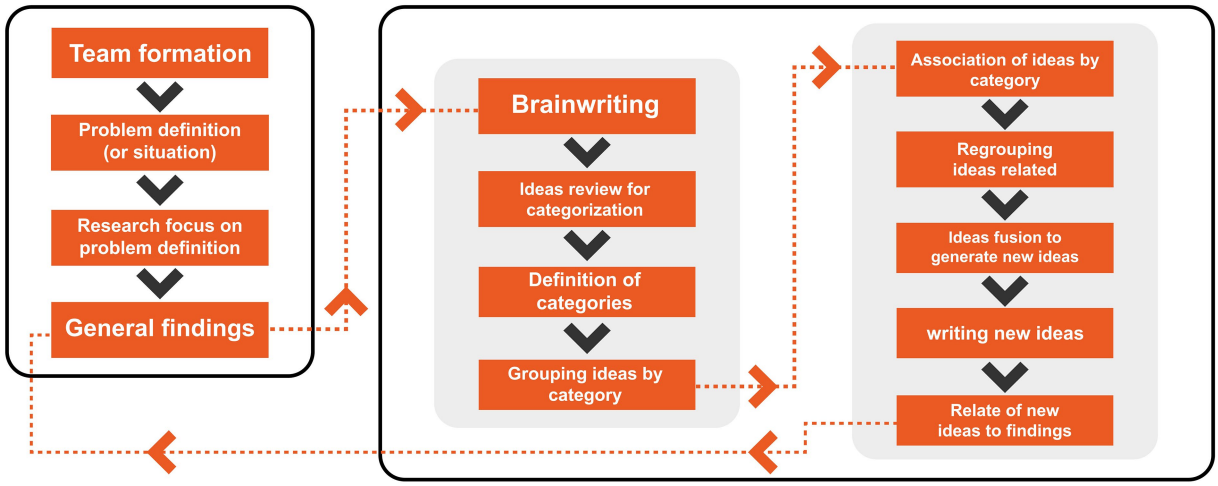

FIGURE 1
ICRI method diagram process.

(Shah et al., 2000). In this way, it is intended to minimize the domination of a team member, the effect of interpersonal conflicts that may exist, and the diversion of the main topic (Heslin, 2009).

2.2.1.3. Discussion of ideas

Once the idea generation is completed, all team members carefully read their colleagues' ideas to identify relevant aspects and similarities between all of them, and the connection with the problem.

2.2.1.4. Proposal of categories

After all team members review the ideas, they propose five or six categories that group the ideas similar to the Affinity Diagramming method (Hanington and Martin, 2012). The categories generated are considered concepts that house the ideas or are more related than others. This allows moving on to the next stage, which consists of regrouping the ideas per the category to which they belong or the one the team considers appropriate. When the ideas have been grouped into categories, new ideas or proposals begin to be generated, intuitively associating (Wöhler and Reinhardt, 2021) the individual ideas but taking at least one from each category. This association of ideas can take place by considering a base idea and adding others with attributes or new characteristics to represent a product, service, or system involving all the associated individual ideas. The method's new ideas or proposals generated from the association are rewritten in a single statement with a coherent description. They are related to the findings that resulted from the investigation and that were initially outlined to verify that the new ideas meet expectations.

2.2.2. Method implementation

The method was implemented for several semesters in different student groups (*classes*). As mentioned before in the participants' section, students belonged to different careers and semesters. The groups were students attending Tecnológico de Monterrey on two different campuses. The implementation began during the critical pandemic when education migrated to an online remote modality. The MIRO platform was used. As mentioned in the ICRI steps, when the students finished the entire research stage of their projects and had precise results obtained by working as a team (four or five members), they used the ICRI method. At this point, students were asked to enter the MIRO® platform, where they found a template previously established by the teacher with the essential sections to start the application. This template included a structure similar to that established for the Brainwriting method. It is noteworthy that up to this point and during the rest of the method's application, the students were not informed about its steps, but rather the teacher guided them step by step as they completed each activity.

2.2.2.1. Individual ideation stage

On the MIRO® platform, the students were asked to write about the most important findings of their research in a specific area. After this, each team member wrote 10 ideas to solve the problem (meeting the project requirements) in a column with *Post-it*-type colored squares, each identified at the top with their name and color choice for all the squares (see Figure 2). Although all team members could read what their classmates were writing, the teacher asked them not to criticize or comment on the ideas until this creative stage was over because most ideas were expected in the shortest possible time.

2.2.2.2. Categorization stage

Once the students finished the ideation part, each team member had to read their classmates' ideas to begin identifying possible categories. This activity requires students to discuss the ideas and generate agreements about the categories they will use or establish after analyzing them. After defining the categories, a team member duplicates all the ideas, which are grouped in the appropriate category (as shown in Figure 2). When the ideas have been regrouped in the categories, the same color is given to them, so their origin is intentionally lost to mitigate the effect of domination or interpersonal conflicts among the group members (Heslin, 2009).

2.2.2.3. Regrouping and new ideas stage

Once the previous categorization is finished, the students begin generating new ideas by intuitively associating one or more from each category without omitting any of them. This process is repeated several times, and discussion within the team is necessary to generate more

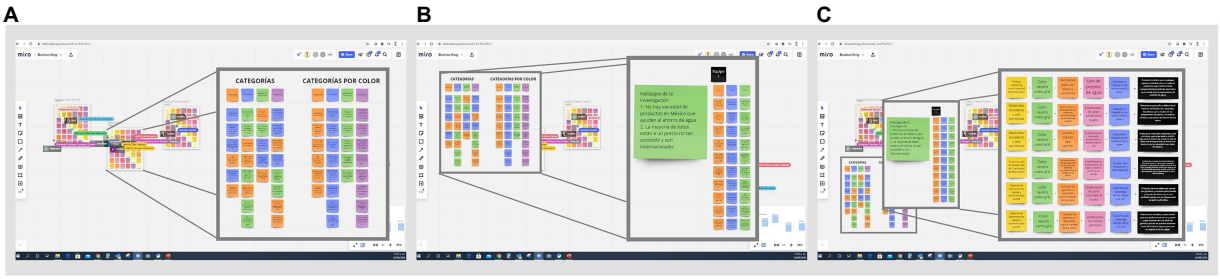

FIGURE 2
ICRI Method steps: **(A)** idea generation by one of the teams, **(B)** ideas grouped by categories and then differentiated with a different color per category, and **(C)** new proposals generated, building on the basic ideas developed previously.

coherent associations that could become complete proposals. The process is repeated until five or six new ideas are reached, which must be rewritten, linking all the individual ideas logically and credibly (see Figure 2). After this, each new proposal is verified for compliance with the research findings or project requirements. It is essential to clarify that individual ideas could be used in more than one of the new ideas, and there could also be more than one idea per category, as mentioned before, but omitting any of the categories was not allowed.

2.2.3. Method evaluation

At the end of the method, the students were surveyed to know their experiences and perception in their idea generation activity. These questions were designed based on previous work that assessed fundamental elements of this type of method and its approach. Also, a preliminary survey was already conducted to test its effectiveness (Canizares and Rojas, 2022). Fundamental aspects based on outcome considered the quantity, quality, novelty, and variety of ideas generated (Shah et al., 2000) and the method's relevance to the students (Smith, 1998).

We applied an online survey instrument with 6 relevant research questions; the other questions in the survey asked for demographic information. The six questions used a five-point Likert scale; the questions were:

- How much do you think this method allows the integration of ideas?
- How much do you think this method provides the same opportunity for participation by all team members?
- How much do you think this method allows you to generate appropriate solution proposals?
- How much do you think this method allows all teams to co-author proposals?
- How much do you consider this method easy and quick to generate good proposals?
- How much did you enjoy using the idea generation method?

3. Results

3.1. Statistical analysis

The results obtained from the online survey about experience and perception are described in Table 2. We divided the data into four analyzes to analyze the ICRI method in depth. A Kolmogorov–Smirnov normality test was applied to the data information, which showed it followed a normal distribution. The statistical method used for analyzes were univariate ANOVA and multivariate ANOVA (MANOVA) with Bonferroni correction. Statistical analysis was performed using SPSS for Windows™ (v.17.0, www.ibm.com/products/spss-statistics).

3.2. Perception-experience according to career

The results of the ANOVA for career factor with the six questions are described in Table 3. The test revealed that the six variables were statistically significant (value <0.05). Figure 3 shows plot representations of the means of the student's answers.

3.3. Perception-experience according to semester

The results of the ANOVA for the semester factor with the six questions are described in Table 4. The test revealed that one of the six variables presented a significant value (< 0.05). The "*How much did you enjoy using the idea generation method*?" question indicated a significant difference ($p = 0.05$). Figure 4 shows plot representations of the means of students' answers.

3.4. Perception-experience according to method application

The results obtained by the ANOVA for the method application factor with the six questions are described in Table 5. The test revealed that no variables presented a statistically significant value (< 0.05).

3.5. Perception-experience according to gender

The results of the ANOVA for gender factor with the six questions are described in Table 6. The test revealed that the six variables presented a statistically significant value (< 0.05). Figure 5 shows plot representations of the means of students' answers.

TABLE 2 Descriptive statistics for questions.

Questions	*N*	Mean	Std. deviation
How much do you think this method allows the integration of ideas?	138	4.44	0.684
How much do you think this method provides the same opportunity for participation by all team members?		4.61	0.739
How much do you think this method allows you to generate appropriate solution proposals?		4.33	0.728
How much do you think this method allows all teams to co-author proposals?		4.50	0.785
How much do you consider this method to be easy and quick to generate good proposals?		4.33	0.738
How much did you enjoy using the idea generation method?		4.31	0.809

3.6. Perception-experience according to gender and career

The results of the MANOVA for gender and career factor interaction with the six questions are described in Table 7. The test revealed four of the six variables had a statistically significant value with Bonferroni correction. The "*How much do you think this method provides the same opportunity for participation by all team members*?" question indicated a significant difference [F (1.986), $p = 0.085$] between factors. The "*How much do you think that this method allows you to generate appropriate solution proposals*?" question indicated a significant difference [F (3.019), $p = 0.013$] between factors. The "*How much do you think this method allows all teams to co-author proposals*?" question indicated a significant difference [F (1.708), $p = 0.138$]. The "How much do you consider this method to be easy and quick to generate good proposals?" question indicated a significant difference [F (2.715), $p = 0.010$]. Figure 6 shows plot representations for gender and career means.

4. Discussion

The ICRI method was designed as a consequence of virtual work in higher education necessitated by the pandemic. However, this dynamic led to educational innovation in the time and moment applied. Students received and perceived the method as good or excellent for idea generation and integration. Moreover, the method helped them generate and integrate multiples ideas and feel included. The sample results revealed significant information through this type of higher education dynamics. The results revealed much information that must be considered for applying this method type in education or as part of a creative disciplinary process to generate ideas to solve design challenges. Joia and Lorenzo (2021) declared that there is a need to develop creative methods, and understand the conditions and dynamics of classes in different contexts, in particular, our research contributes in virtuality mode (Zoom). The global evaluation of the method was positive. The results in Table 2 show that the students assessed the method positively, demonstrating that this method should be used whenever a generating and participation dynamic begins. According to Herring et al. (2009), an idea generation method should be simple and easy to use, in our case, in disciplines where problem-solving is required.

However, this research opened several questions about this educational innovation. If the method worked better for a particular student profile? As mentioned by Steele et al. (2018), generating creative ideas is a process that needs to be evaluated and observed, because it has a latent complexity in its reasoning (Lacruz Rengel, 2013). In our research, the general findings showed that the method's primary dimensions fulfilled its function in the multimodal context. A collaborative idea generation occurred, as a consequence of a co-design process (Steen, 2013). Thus, our students who completed the task of creating, collaborating, and grouping ideas collaboratively arrived at creative solutions. This process can be explained using the measurement elements of their perception of the experience of using the method. The following findings will be discussed here:

The ICRI method applied in different courses required a tool to generate ideas. The first characteristic observed was the students' careers. This opened the possibility of observing how the students' profiles could adopt the method and how they perceived it for the work assigned to them. Figure 3 shows the statistically significant means for these results. For the first question, "*How much do you think this method allows the integration of ideas*?" a closeness in answers can be seen between design ($m = 4.59$), social sciences ($m = 4.50$), and engineering ($m = 4.48$), followed by architecture ($m = 4.33$). However, digital arts ($m = 3.80$) and music production ($m = 3.75$) evaluated below the observed average mean. Thus, students in the latter two career profiles do not entirely agree that the method integrates ideas. However, design, social sciences, and engineering students agree. This is the first evidence of how a method works for specific profiles, as mentioned by Cheung et al. (2003). It is undeniable that discipline impacts the creative processes of undergraduate students. A similar effect is observed in the following two questions: "*How much do you think this method provides the same opportunity for participation by all team members*?" and "*How much do you think this method allows all team members to co-author proposals*?" In the first question, students in design ($m = 4.75$), social sciences ($m = 4.71$), and engineering ($m = 4.66$), followed by architecture ($m = 4.47$), shared the same thought, while music production ($m = 4.00$) and digital arts ($m = 3.90$) students did not. For the second question, design ($m = 4.70$), social sciences ($m = 4.48$), engineering ($m = 4.48$), and architecture ($m = 4.47$) students shared the same consideration, while music production ($m = 4.00$) and digital arts ($m = 3.90$) students once again did not. These questions reveal how a participatory method can be relevant and well perceived in student career profiles, but it does not directly refer to creative and non-creative disciplines. It can be due to a particular way of understanding challenge resolutions and participatory activities in career profiles that can create individual or participatory solutions. This agrees with what was reported by Pennington et al. (2021), that members of an interdisciplinary team might have difficulty sharing and combining knowledge with their peers. The next questions to be reviewed focusing on career profile

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TABLE 3 Descriptive statistical and ANOVA for Career.

Questions	Career	N	Mean	Std. Dev	*F*	*P*
How much do you think this method allows the integration of ideas?	Design	56	4.59	0.532	3.533	0.005*
	Architecture	15	4.33	1.047		
	Digital art	10	3.80	0.789		
	Music production	4	3.75	0.957		
	Social science	24	4.50	0.511		
	Engineering	29	4.48	0.634		
How much do you think this method provides the same opportunity for participation by all team members?	Design	56	4.75	0.640	3.259	0.008*
	Architecture	15	4.47	1.125		
	Digital art	10	3.90	0.876		
	Music production	4	4.00	1.155		
	Social science	24	4.71	0.550		
	Engineering	29	4.66	0.553		
How much do you think this method allows you to generate appropriate solution proposals?	Design	56	4.45	0.570	4.695	0.001*
	Architecture	15	4.33	1.047		
	Digital art	10	3.70	0.483		
	Music production	4	3.25	0.500		
	Social science	24	4.25	0.794		
	Engineering	29	4.55	0.632		
How much do you think this method allows all teams to co-author proposals?	Design	56	4.70	0.685	2.810	0.019*
	Architecture	15	4.47	1.060		
	Digital art	10	3.80	0.789		
	Music production	4	4.00	1.155		
	Social science	24	4.46	0.721		
	Engineering	29	4.48	0.688		
How much do you consider this method to be easy and quick to generate good proposals?	Design	56	4.57	0.628	3.347	0.007*
	Architecture	15	4.27	1.100		
	Digital art	10	3.90	0.316		
	Music production	4	3.50	1.000		
	Social science	24	4.29	0.624		
	Engineering	29	4.21	0.726		
How much did you enjoy using the idea generation method?	Design	56	4.57	0.628	4.026	0.002**
	Architecture	15	4.00	1.000		
	Digital art	10	3.90	0.876		
	Music production	4	3.50	1.291		
	Social science	24	4.04	0.908		
	Engineering	29	4.45	0.632		

*The mean difference is significant at the 0.05 level.

were "*How much do you think this method allows you to generate appropriate solution proposals*?" and "*How much do you consider this method to be easy and quick to generate good proposals*?" For the question about appropriate solutions, engineering ($m = 4.55$) had the highest mean, followed by design ($m = 4.45$), architecture ($m = 4.33$), and social sciences ($m = 4.25$). Digital arts ($m = 3.70$) and music production ($m = 3.25$) had the lowest. However, for the question about easy and quick idea generation, similar means were presented in the career profiles of design ($m = 4.57$), social sciences ($m = 4.29$), architecture ($m = 4.27$), and engineering ($m = 4.21$), but digital arts (3.90) and music product ($m = 3.50$) had lower means. The results of these questions connect to how appropriate and fast the method can facilitate generating ideas. These results reveal that the student's career profile continues to influence the student's perception of this method of idea generation. Agreeing with described elements of ways of understanding idea generation methods (Shah et al., 2000; Hutchinson and Tracey, 2015). In the application of our method and the sample used: design, engineering, and architecture students assessed it the

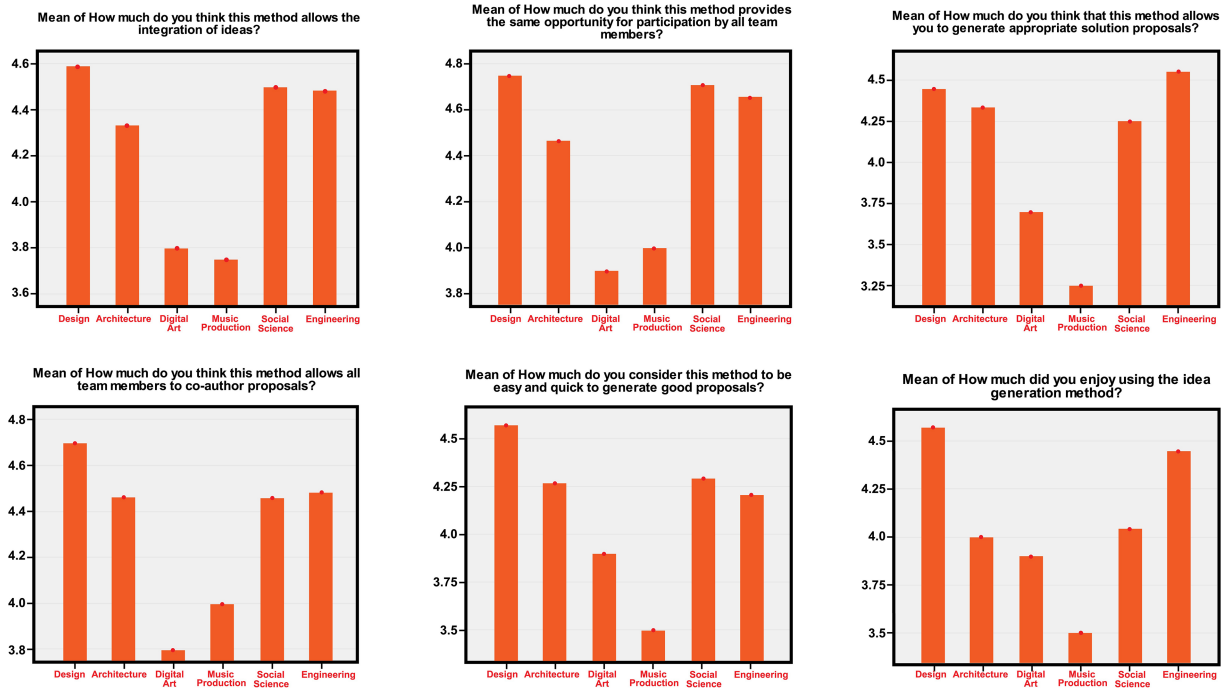

FIGURE 3
Plots of means for careers and perception-experience questions.

highest and digital arts and music production students the lowest. The preceding agrees again with what was mentioned by Cheung et al. (2003), in the sense that the field influences the creative processes, even if there were multiculturally aspects (Li et al., 2017), which can be good, but not all career profiles indicate the same experience. Finally, for the last question considered in the context of the students' career profiles ("How much did you enjoy using the idea generation method?"), the results were similar to the previously analyzed questions, where design ($m = 4.57$) and engineering ($m = 4.45$) students provided the best evaluation, followed by social sciences ($m = 4.04$), architecture ($m = 4.0$), digital arts ($m = 3.90$), and music product ($m = 3.50$). Although everyone generally enjoyed using the method, the design and engineering students principally were the ones assessing it as a better experience. It is also true that environmental factors and individual characteristics collectively affect the creative achievement of university students, as mentioned by Deng et al. (2016), but other aspects have to be better delimited in an investigation of this type.

Delving into students' perceptions, the second characteristic observed was the students' semester. As mentioned before, the ICRI method was applied in different courses that required a tool to generate ideas. Figure 4 shows the statistically significant means for these results. In this case, students' semesters can reveal information about their experience and perception of the method. For the question "*How much did you enjoy using the idea generation method*?" the results showed that the students in semesters 3–4 ($m = 4.55$), semesters 7–8 ($m = 4.48$), and semesters 5–6 ($m = 4.43$) enjoyed the method more than the students of semester 1–2 ($m = 4.08$) and semester 9 ($m = 4.17$). This subtle difference is relevant to how students experienced the method during a specific semester of their career education. The other questions did not reveal a difference between semesters, but we can observe that intermediate and last semester students seemed to be more aware of idea generation and related methods. Snyder et al. (2019) reported differences in student creativity throughout their undergraduate studies; our research showed the same. However, this does not limit the use of this method for the idea generation regardless of your semester. After the career and semester, a third characteristic was observed in the method applied in three modalities, with a significant effect to discuss. The results revealed no differences among students using the method online, hybrid, or presential. This finding is significant for this research, a similar experience and perception result positively. Our method can be applied according to the higher education need, online to presential. The ICRI method was born of necessity in a virtual modality; now, its effects can be extrapolated to presential to describe its impact and experience on students. This is consistent with the fact that hybrid learning is not systematically more or less effective than traditional classroom learning, as mentioned by Müller and Mildenberger (2021), and depends on the necessity. Face-to-face or remote technological support can be both valid alternatives (Vrgović et al., 2013; Buisine et al., 2016). This is one of the main findings that we can highlight in this research, this type of method can be differentiated from other methods (Hanington and Martin, 2012; Ulrich and Eppinger, 2013) because it can be used in different modalities.

After observing the student experience and perception by course, semester, and modality application, we were interested in knowing how the method was perceived per student gender. This last sample characteristic gave us relevant information about students' perceptions and experience of the ICRI method, adding our findings to many previously reviewed works about gender inclusion in idea generation. In these results, the student's opinions were different in each of the questions asked. The female valuation was higher than the male valuation. For the first question, "*How much do you think this method*

TABLE 4 Descriptive Statistical and ANOVA for Semester.

Questions	Semester	*N*	Mean	Std. Dev	*F*	*P*
How much do you think this method allows the integration of ideas?	Semester 1–2	59	4.32	0.797	1.693	0.155
	Semester 3–4	38	4.66	0.534		
	Semester 5–6	14	4.36	0.497		
	Semester 7–8	21	4.38	0.669		
	Semester 9	6	4.67	0.516		
How much do you think this method provides the same opportunity for participation by all team members?	Semester 1–2	59	4.44	0.97	2.084	0.086
	Semester 3–4	38	4.79	0.413		
	Semester 5–6	14	4.79	0.426		
	Semester 7–8	21	4.52	0.602		
	Semester 9	6	5	0		
How much do you think this method allows you to generate appropriate solution proposals?	Semester 1–2	59	4.27	0.784	0.999	0.411
	Semester 3–4	38	4.34	0.708		
	Semester 5–6	14	4.21	0.699		
	Semester 7–8	21	4.43	0.676		
	Semester 9	6	4.83	0.408		
How much do you think this method allows all teams to co-author proposals?	Semester 1–2	59	4.37	0.927	2.43	0.074
	Semester 3–4	38	4.76	0.431		
	Semester 5–6	14	4.5	0.855		
	Semester 7–8	21	4.29	0.784		
	Semester 9	6	4.83	0.408		
How much do you consider this method to be easy and quick to generate good proposals?	Semester 1–2	59	4.25	0.801	2.23	0.051
	Semester 3–4	38	4.55	0.602		
	Semester 5–6	14	4.5	0.65		
	Semester 7–8	21	4	0.707		
	Semester 9	6	4.5	0.837		
How much did you enjoy using the idea generation method?	Semester 1–2	59	4.08	0.877	4.442	0.050*
	Semester 3–4	38	4.55	0.795		
	Semester 5–6	14	4.43	0.514		
	Semester 7–8	21	4.48	0.68		
	Semester 9	6	4.17	0.753		

*The mean difference is significant at the 0.05 level.

allows the integration of ideas?" female students ($m = 4.59$) opined higher than male students ($m = 4.23$). For the question "*How much do you think this method provides the same opportunity for participation by all team members*?" the same effect was observed where female students ($m = 4.59$) exceeded the opinion of male students ($m = 4.45$). In the following questions, the distance in the means is more evident. The "*How much do you think that this method allows you to generate appropriate solution proposals*?" question had means of female ($m = 4.50$) and male ($m = 4.09$). The "*How much do you think this method allows all team members to co-author proposals*?" question resulted in female ($m = 4.68$) and male ($m = 4.23$) means. The "*How much do you consider this method to be easy and quick to generate good proposals*?" question provided female ($m = 4.49$) and male ($m = 4.11$) means, and the "*How much do you consider this method suitable for integrating individual ideas with those of a team*?" question had a female ($m = 4.73$) and male ($m = 4.21$) means. Finally, the "*How much did you enjoy using the idea generation method*?" question revealed a statistically significant difference. The females ($m = 4.48$) enjoyed it much more than the males ($m = 4.07$).

Exploring gender perception is part of the contribution to the acceptance of a method, either because it can be used for any student or because it can be a motivational tool. In either case, understanding gender perception is a research topic that can be further explored. These findings, as mentioned before, put in evidence the experience and perception of women students with a higher impact from the methodology than male students. Idea generation and participatory methods have been discussed several times as crucial dynamics, and this method reveals a positive experience and perception in the woman sample. A method with a gender inclusion perspective contributes to idea generation, as mentioned by Li et al. (2017); diversity and inclusion positively influence the creativity of multicultural teams. It is important to note that participatory methods

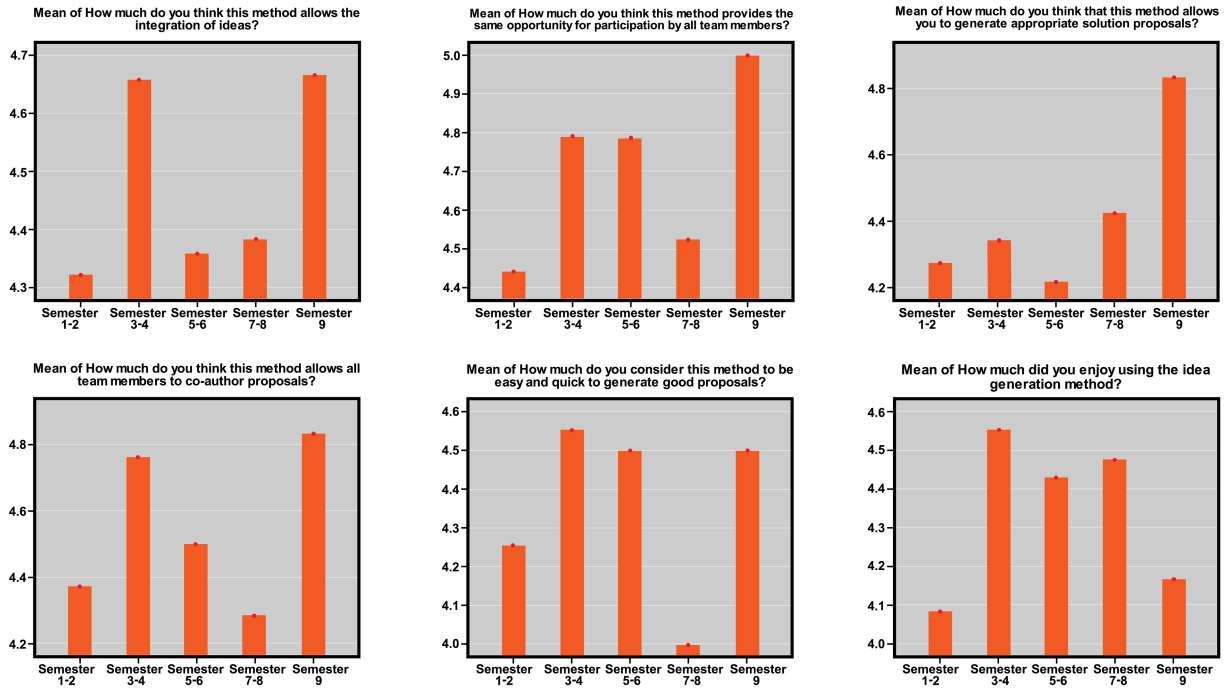

FIGURE 4
Plots of means for semesters and perception-experience questions.

TABLE 5 Descriptive statistical and ANOVA for method application.

Questions	Application	*N*	Mean	Std. Dev	*F*	*P*
How much do you think this method allows the integration of ideas?	Online (Miro + Zoom)	62	4.45	0.67	0.121	0.886
	Hybrid (ClassRoom + Miro)	67	4.45	0.702		
	Presencial (Post-its)	9	4.33	0.707		
How much do you think this method provides the same opportunity for participation by all team members?	Online (Miro + Zoom)	62	4.44	0.783	0.469	0.627
	Hybrid (ClassRoom + Miro)	67	4.52	0.705		
	Presencial (Post-its)	9	5	0.726		
How much do you think this method allows you to generate appropriate solution proposals?	Online (Miro + Zoom)	62	4.39	0.662	0.534	0.587
	Hybrid (ClassRoom + Miro)	67	4.27	0.79		
	Presencial (Post-its)	9	4.44	0.726		
How much do you think this method allows all teams to co-author proposals?	Online (Miro + Zoom)	62	4.42	0.841	0.712	0.492
	Hybrid (ClassRoom + Miro)	67	4.58	0.742		
	Presencial (Post-its)	9	4.44	0.726		
How much do you consider this method to be easy and quick to generate good proposals?	Online (Miro + Zoom)	62	4.27	0.682	0.395	0.675
	Hybrid (ClassRoom + Miro)	67	4.37	0.795		
	Presencial (Post-its)	9	4.44	0.726		
How much did you enjoy using the idea generation method?	Online (Miro + Zoom)	62	4.31	0.692	0.13	0.878
	Hybrid (ClassRoom + Miro)	67	4.3	0.905		
	Presencial (Post-its)	9	4.44	0.882		

*The mean difference is significant at the 0.05 level.

should be designed to be a similar experience for everybody. If we can ensure that a method works the same for everyone, the participation of all people can equally impact the creativity of ideas (Bart et al., 2015; Shubina and Kulakli, 2019). Finally, a last observation was made with the data obtained from the research. After observing all the sample characteristics, we decided to observe two characteristics for more information about the students' perceptions and experiences using the ICRI method. The final observation was made by looking at

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TABLE 6 Descriptive statistical and ANOVA for GENDER.

Questions	Gender	*N*	Mean	Std. Dev	*F*	*P*
How much do you think this method allows the integration of ideas?	Female	82	4.59	0.543	9.429	0.003*
	Male	56	4.23	0.809		
How much do you think this method provides the same opportunity for participation by all team members?	Female	82	4.72	0.653	4.662	0.033*
	Male	56	4.45	0.829		
How much do you think this method allows you to generate appropriate solution proposals?	Female	82	4.50	0.550	11.385	0.001*
	Male	56	4.09	0.880		
How much do you think this method allows all teams to co-author proposals?	Female	82	4.68	0.683	11.829	0.001*
	Male	56	4.23	0.853		
How much do you consider this method to be easy and quick to generate good proposals?	Female	82	4.49	0.614	9.389	0.003*
	Male	56	4.11	0.846		
How much did you enjoy using the idea generation method?	Female	82	4.48	0.652	8.784	0.004*
	Male	56	4.07	0.951		

*The mean difference is significant at the 0.05 level.

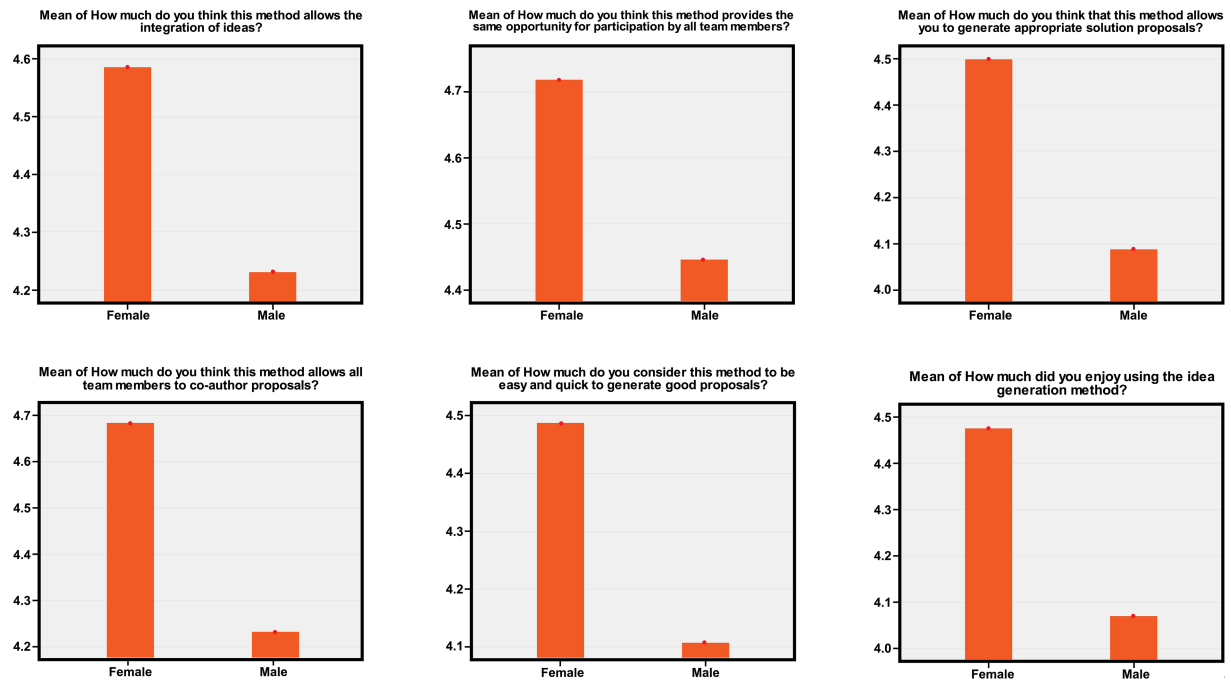

FIGURE 5
Plots of means for gender and perception-experience questions.

gender and career. This interaction showed significant differences in method perception and experience. We focused on the higher assessments to observe the effects in this sample segmentation. The first question analyzed was "*How much do you think this method provides the same opportunity for participation by all team members*?" where design ($m_{female} = 4.76$) and engineering ($m_{female} = 4.82$) females were the two highest, in contrast to their counterparts, design ($m_{male} = 4.73$) and engineering ($m_{male} = 4.56$). The second question reviewed was, "*How much do you think that this method allows you to generate appropriate solution proposals*?" Engineering ($m_{female} = 4.73$) and social sciences ($m_{female} = 4.64$) females were the two highest, in contrast to their male counterparts in Engineering ($m_{male} = 4.44$) and design ($m_{male} = 4.40$). The third question examined was, "*How much do you think this method allows all team members to co-author proposals*?" Social sciences ($m_{female} = 4.82$) and design ($m_{female} = 4.76$) females were the two highest, in contrast with males in design ($m_{male} = 4.40$) and engineering ($m_{male} = 4.44$). The last question observed was, "*How much do you consider this method to be easy and quick to generate good proposals*?" Design ($m_{female} = 4.59$) and architecture ($m_{female} = 4.58$) females were highest, in contrast with

TABLE 7 Statistical result of multivariable ANOVA (MANOVA) for independent variables for questions.

Questions	SS	dF	MS	*F*	*p*
Gender*Career					
How much do you think this method allows the integration of ideas?	2.490	5	0.498	1.249	0.290
How much do you think this method provides the same opportunity for participation by all team members?	4.699	5	0.940	1.986	0.085[a]
How much do you think this method allows you to generate appropriate solution proposals?	6.037	5	1.207	3.019	0.013[b]
How much do you think this method allows all teams to co-author proposals?	4.498	5	0.900	1.708	0.138[c]
How much do you consider this method to be easy and quick to generate good proposals?	7.057	5	1.411	2.715	0.010[d]
How much did you enjoy using the idea generation method?	2.305	5	0.7461	0.817	0.540

[a]*R* Squared = 0.215 (Adjusted *R* Squared = 0.147), [b]*R* Squared = 0.204 (Adjusted *R* Squared = 0.134). [c]*R* Squared = 0.214 (Adjusted R Squared = 0.146), [d]*R* Squared = 0.214 (Adjusted *R* Squared = 0.146).

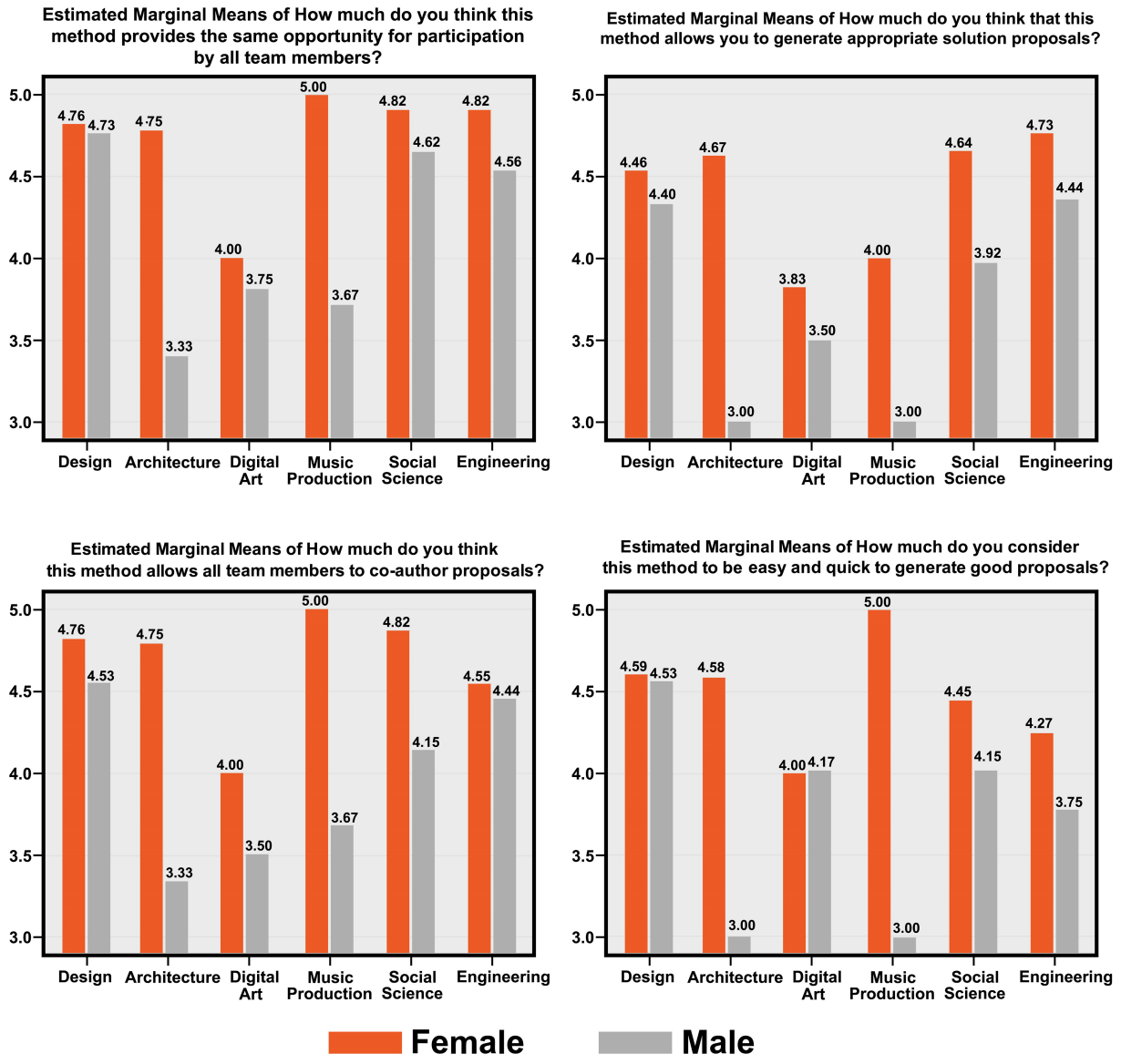

FIGURE 6
Plots of means for gender-career and perception-experience questions.

males in design ($m_{male} = 4.53$) and engineering ($m_{male} = 4.17$). The findings of this last analysis only supported what had already been explored in previous observations. The female students had better impressions and perceptions according to their answers, in contrast to the male students, even in the same career. This further ensures the relevance of applying these methods in any career and gender context. Additionally, in conjunction with career profiles, women in careers who need problem-solving tools assessed the method better than men. This knowledge adds to several things that Alsos et al. (2013), Zetriuslita et al. (2016), and Stoltzfus et al. (2011) mentioned about gender not affecting work and idea generation in creative productivity.

Finally, all the findings of this research give us more information on the perception of this educational innovation proposal, however, we must warn of certain limitations that were also detected. Two important limitations must be considered to incorporate the ICRI method in further studies. First, the method application must contemplate the situation or problem to be solved, the method is mainly conditioned to solutions focused on products, services, experiences, etc. However, it should not be limited to this, but more sample groups and punctuated problem-solving situations are needed. Second, the method's efficacy needs to be validated by similar activities with a control group in order to further investigate the use of the method. The sample to be used can be further refined by student profile and demographics of interest. The capture instrument (survey) can be further refined by adding more demographic and interest information. However, the dynamics within the classroom are complex for the selection of a sample to be specific.

5. Conclusion

The development of the ICRI method resulted from the changes necessitated by the need for virtuality in higher education due to the pandemic. The students' perception and experience of the method indicate that its implementation can be seen as an educational innovation because it was very well accepted, principally in women's experiences. In addition to the above, the ICRI method helped students generate many ideas in a virtual context, giving a systemic response to the problematic situations that the students faced when gathering, developing, and selecting ideas and creative proposals as a team. Above all, the main findings highlighted women's positive perception and experience in design, engineering, and architecture, where they appreciated the integration of ideas and the method's relevance. These outcomes revealed fairness and parity in idea generation and student collaboration. Similarly, the students considered the ease and speed of the method adequate, which invites them to use it again. Unfortunately, we found that careers such as digital arts and music production had a lesser agreement with the method or the aspects surrounding idea generation and its usefulness in their professional activities.

The ICRI method reinforces the trend of educational methods that address the importance of generating ideas collaboratively, and having processes that facilitate effective interactions, even virtually and remotely, as the circumstance of recent years promotes. On the other hand, based on the findings of this research, the positive evaluation of the students suggests that the ICRI method is considered an innovative tool for idea generation at the higher education level, aligning with similar method dynamics, students appreciate the opportunity to reuse the method to solve a challenge under any future conditions. In conclusion, we emphasize that this research is the starting point of a series of observations that will add more findings as more students use the ICRI method. As mentioned above, there are opportunities to delve deeper into motivational, cultural and personality aspects of the students. This first interaction uncovered areas for improvement concerning moments in the method's steps. We must document and create evidence regarding how some of the work moments occur. For example, what is the process of combining ideas in each category? Furthermore, this research can establish more limited sample observation parameters for observing and measuring the method's impact on equitable and similar characteristics (for example, samples outside of creative industries or engineering). Finally, with the limitations or advantages of technology, the ICRI method must develop and implement other resources that allow maximizing its attributes, considering the possibility of implementation in other contexts and the opportunity for future work with this research.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

All authors contributed to the article and approved the submitted version. JCMC designed the study and supervised the whole study. J-CR conducted the statistical analyzes. AA supported with implemented sample. All authors assisted in write, revision process, read, and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Knowledge based urban development: An approach to innovation districts based on education

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Education is a concept that encompasses not only the teaching-learning process but also the conditions, environment, and facilities in which it takes place. Education is a precondition to development because it serves as a society's primary engine of innovation. Therefore, the concept of a space designated as an Innovation District is essential for the creation of Sustainable Cities since it is in such spaces that jobs are created and new markets specializing in products and high-added value services emerge. However, in the past, successful innovation districts have generally been found in developed countries, which have sufficient resources to invest in projects of this magnitude. Our methodology consists of a case study, the city of Querétaro, in central Mexico, to analyze the role of higher education within developing countries that seek to create innovation districts. We employ quantitative methods such as Geographic Information Systems (GIS) and locations quotients, along with qualitative documentary analysis, to conduct a spatial-urban analysis, characterize the industrial configuration, and to analyze the design of educational models adapted to the needs of specific industries. The results of our case study suggest that cities from developing countries that are fast industrializing can best maximize their chances of success by encouraging an explicit collaboration between industry and education through a Triple Helix Model. Such a collaboration would be based on matching educational competencies with opportunities for industrial reconfiguration to carefully select the location for the new district and decide over its area of specialization.

KEYWORDS

innovation districts, STEM education, educational innovation, socially oriented education, higher education

Introduction

In a competitive world, where the knowledge economy and information serve as the main sources of innovation and economic growth, governments seek strategies to transform and increase the sophistication of their current production capabilities. Regional studies and economic geography have recently been paying more attention to the concept of the *innovation district*. An innovation district is a nexus of knowledge-based development in cities, where public and private actors work to foster, attract, and retain investment and talent in order to revitalize urban areas and increase knowledge-economy activities and general innovation (Esmaeilpoorarabi et al., 2020). An innovation

district is a geographic area where leading-edge anchor institutions and companies both cluster and connect with start-ups, business incubators, and accelerators. Notable examples are Silicon Valley, 22@Barcelona and One-North in Singapore (Bottero et al., 2020). At the country level, we find Finland, United States and Australia as leading countries with an established policy of promoting this kind of innovation precincts (Esmaeilpoorarabi et al., 2018).

Regions and countries seek to nurture and develop their own innovation districts to create jobs and insert themselves into new markets by specializing into high value-added products and services. A new global network and division of labor encourage cities and regions to find a niche market in the new economies associated with information technology (Znagui and Rahmouni, 2019). Knowledge and innovation are the two most important resources needed to build a successful innovation district. To the extent that cities and regions can insert themselves into such a dynamic of knowledge creation and innovation, their economies will generate high value-added products and services through research, technology, and intellectual capacity.

Although knowledge is a necessary component of success, it, alone, is not sufficient to create an innovation district's success. Innovation is a creative way of thinking and acting, based on new perspectives and applications that help industry and science gain a strong competitive position (Yigitcanlar and Inkinen, 2019). Unlike with an industrial policy of the past, generating both knowledge and innovation is a complex issue that requires the collaboration of multiple actors from academia, government, and the private sector operating through what is known as the Triple Helix Model (Cai and Amaral, 2021). Economic growth based on innovation and knowledge requires the transformation of education, research and development tasks into knowledge and viable economic results. While education as such is the foundation of innovative growth, it is important to distinguish between formal education and the operational skills of implementation and practice that are typically obtained through work rather than study. The challenge is to create an educational model that includes the development of these important skills as well. In this way, the collaboration between education and skills are connected within a pool of resources: universities, local companies, and other intermediaries then work together to produce a platform or innovation system. Then, the collaborative network requires an organizational and institutional effort to drive it.

In summary, innovation districts offer a "leapfrog opportunity" for regions to join the global economy and create high-paying jobs related to innovation, creativity, and digital transformation. Countries aspire to build their own Silicon Valleys. However, the successful cases found in the literature are concentrated in rich countries that have enough resources to invest in a project of this magnitude. Such countries can build first-class facilities for the district, have highly developed technological industries, have a strong public/private system of education, and have strong institutions to coordinate a Triple Helix Model with multiple stakeholders. Given this history, the research question for this paper is: *How can developing countries aspiring to build an innovation district increase their chances of success?* What steps should they follow to design a sufficiently robust strategy that rises the probability of the strategy's success? Working from the international literature on innovation districts, we propose a conceptual and methodological framework where quantitative methods are combined in the areas of industry analysis, spatial-urban analysis, and design of educational models adapted to the needs of industries, with the aim of designing a collaborative strategy based on the Triple Helix. We attempt to answer this question through a case study of the city of the Queretaro, in central Mexico.

The type of strategy referred in the research question is a framework for the development of innovation ecosystems through the identification and prioritization of productive capabilities that ensure a strategic collaboration of the three key actors under the Triple Helix Model, specifically highlighting the strategic participation of universities and other higher education institutions in the development of the productive knowledge necessary to achieve the proposed objectives. Legal, economic and financial incentives and an appropriate institutional framework must be put in place to make this collaboration most likely to happen.

Literature review

The literature on innovation districts can be divided into two groups. We find the first one in the field of economic geography, where the work of scholars such as Michael Storper and Allen J. Scott are amongst the most prominent (Kemeny and Storper, 2020; Scott, 2022). This group argues that institutions are the crucial element for the success of an innovation district (Martin et al., 2018). Institutions can be described as hard or soft. Hard ones have a defined organizational framework that facilitates communication and collaboration among government, industry, and universities. Soft institutions are the organizations that provide cultural and informal ties that foster creativity and provide the ability to recombine inputs and knowledge inputs in order to craft new ones. Soft institutions constitute the social and cultural elements that favor innovation and nurture new knowledge. One classic example that illustrates this theory is that of the emergence, at the beginning of the 20th century, of Detroit as an automotive innovation district (Drucker et al., 2019). In Detroit, there was a preexisting culture of entrepreneurship and access to capital based on the shipyards and boat production. The mixture of pre-existent institutions and cultural capital facilitated the transition from a nautical to an automotive industry; and skills and materials were reconfigured to generate new markets, products, and services. According to this school of thought, the emergence of an innovation district such as Silicon Valley or Bangalore is something organic and heavily influenced by the pre-existing soft institutions. Given this relationship, it is, thus, difficult to replicate through top-down planning design.

The second body of literature on innovation districts comes from the field of urban economics and authors such as Florida and Mellander (2020), Glaeser (2022), and others (Pratt, 2021). These authors argue that the attraction and retention of highly specialized human capital is the critical element for the success of an innovation district (Zhang et al., 2020). Florida calls this sector of the population the creative class, and to the extent that a city can attract and retain this creative class, new entrepreneurial ventures will begin to sprout (Mellander and Florida, 2018). He further adds that this class highly values a certain lifestyle and access to certain types of amenities such as cafes, art galleries, and restaurants. Therefore, cities should focus on fostering the creation of innovation districts that guarantee access to such amenities, including affordable housing. According to Florida, the creative class is nomadic and moves to where it finds the urban environments that best support its expression. His theory has been influential in the planning and design of innovation districts, most notably in Southeast Asia, where live-work-play-learning communities have become popular (Esmaeilpoorarabi et al., 2018). These communities consist of innovation districts that offer

integrated housing, workplace amenities, and leisure offerings to attract and retain the creative class. Austin, TX is also seen as a success story for its cultural and musical offerings (Baily and Montalbano, 2018). As can be noted, the planning of these communities or districts has been careful and favored mixed uses that combine services, as well as interventions of urban space for the creation of cultural and leisure amenities. In summary, the two academic traditions offer two contrasting visions of the feasibility of attaining a successful innovation district by design that uses a top-down approach: centered on institutions and centered around the presence of the creative class. Tan Yigitcanlar (Yigitcanlar and Inkinen, 2019) and his group at the Queensland University of Technology in Australia propose a third approach based on the concept of *knowledge-based urban development* (Carrillo et al., 2018). This concept entails an array of factors that range from governance and education to urban development. The regions with the capability of tapping these varied encompassing elements increase the chances of success of the innovation district.

Despite the great deal of literature on innovation districts, we identify an important gap regarding the role of higher education in the success of innovation districts. The referred literature in innovation districts typically endorses the Triple Helix Model of governance described above (Etzkowitz and Zhou, 2017; Galvao et al., 2019; Cai and Amaral, 2021), which—again—focuses on the governance model and institutional arrangement among these three actors. The literature on Triple Helix Model also recognizes the need for universities to build the human capital that will grasp the opportunities that an innovation district generates. However, they do not delve into the identification of the necessary skills for the development of productive activities, nor the design of educational and pedagogical models that are more suitable in this Triple Helix Model to sustain the growth of an innovation district. Thus, the challenge for the current study is to create an educational framework to support students´ innovation and learning activities in the niche markets where regions seek to specialize. This is an opportunity for the field of education to contribute to this literature by claiming a more essential and active role for pedagogy in the design and planning of innovation districts that also take into consideration the specific industrial and urban context of the region. We explicitly address this role and these relationships in the framework described below.

Conceptual framework

Innovation districts are knowledge precincts that specialize in innovation and creativity. Within such districts, both information technologies (IT) and human capital are needed to recombine or create new products. Thus, the formation, attraction, and retention of human capital are critical for the success of a district. Our proposed framework focuses on the development of human capital, for which it is necessary to teach both so-called "hard" (technical) and "soft" (humanistic) knowledge and associated skills. The technical knowledge must be linked to the existing industrial or economic profile of the city, while the humanistic skills encourage the development of critical thinking and creativity in students.

The literature on innovation districts from economic geography focuses on the role played by institutions of higher education in the emergence of knowledge precincts, but it does not address the educational aspects of these precincts in enough detail. The creation of new or proposed industrial firms in the region creates a demand for new worker competencies that is generally not met by existing academic programs. Higher education institutions need to continually adapt and change to teach both the newly emergent required technical competencies and the additional necessary competencies that foster innovation and creativity in students. We consider that both aspects are critical to an innovation district's consolidation and success within a region. These competencies must be found within the industrial capabilities of the local region and linked to the urban context in the location of the proposed innovation district.

Fostering creativity and innovation in human capital to create a creative class is a daunting task that could benefit enormously from the recent advances in the field of education. The concept of Education 4.0 that offers students both technical competencies and experiential learning can provide the foundation for specific pedagogical models that allow innovation districts to attain their full potential. However, to adapt curricula and teaching practices, a feedback loop must be established between academia and industry both during the district planning stages and as the established district evolves.

Though an important consideration, the specific role each party takes in this interchange has not been discussed in enough detail in the current literature about either stage. This paper discusses ways such a feedback loop could be initiated and spells out the influence and importance of the university's role and teaching practices. We do so by investigating the triple helix model and proposing specific ways for government, business, and academia to partner and collaborate (Figure 1).

To determine the potential of a region based on its industrial configuration and to select specific industries with local potential for innovation and continued growth, an initial diagnosis of industrial capabilities is needed. To generate the capabilities identified in the industrial diagnosis and to propose an educational plan, an evaluation of the current educational system is needed. Finally, to retain and maintain the human capital that will be needed, features of the urban environment must be considered in determining the location where the proposed district should be placed. This is particularly useful for countries in the global south seeking to maximize resources and to increase the odds of success of an innovation district. The next section introduces our case study.

Methodology

Our methodology consisted of a Descriptive Case Study. To ensure the validity of the construct, the following three conditions were considered fulfilled (Rashid et al., 2019):

a. The form of the research question is how or why and requires an explanatory answer,
b. There is no investigative requirement to control behavioral events, and
c. The focus of the research is on contemporary events.

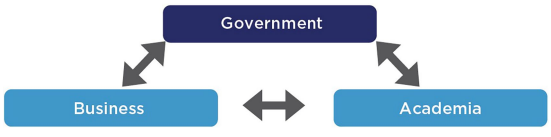

FIGURE 1
Triple Helix Model. Own elaboration.

The case study method implemented in this paper described and discussed a contemporary phenomenon in depth and related it to its real-life context, ensuring that the boundaries between phenomenon and context did not overlap (Yin, 2018). The research met these criteria and conditions: The research questions sought to investigate the impact of a more in-depth industry assessment and specially designed education policy in increasing the chances of success of a planned innovation district within the context of developing countries.

Case study selection: Queretaro, Mexico

The case study focused on the Metropolitan Area of Queretaro (MAQ), a 3-h drive from Mexico City, which has become an important industrial hub for the country. The city's international airport offers direct flights and connections to other regions of Mexico and the United States. MAQ was selected specifically in an attempt an answer to our research question about collaboration frameworks between academia, business and government to increase the chances of success for an innovation district at developing countries. MAQ is an urban region in a developing country, that has experienced accelerated industrial growth in the manufacturing sector. A similarly fast paced urbanization has accompanied this industrial growth, shaped by processes of urbanization that are common to fast-growing cities in Latin America, such as sprawl, informality and lack of infrastructure (Nieto and Niño-Amézquita, 2019).

In terms of innovation, the MAQ has the intention of planning and developing an innovation district. Different stakeholders have announced their ambitions to plan for one, including the two largest universities (a public and a private one), and both the state and local governments. These stakeholders have taken the initial steps in the planning process. Public officials interviewed for our research announced their ambition to have an innovation district specialized in gaming and the metaverse or a creative district specialized in design. However, again, the biggest challenge to leapfrog to such creation of new jobs might be the formation of human capital through very specialized higher education programs.

In this context, the local government, academia, and business work together to foster an innovation district for the region. The goal of such an innovation district is twofold: to leapfrog from manufacturing to more productive jobs, and to regenerate the urban space and create a district that can attract and retain the most productive human capital in the city. In the past, the problem has been that it is hard to combine these differing goals, especially for relatively poor regions. The case of MAQ can help to elucidate a pathway for regions to combine education and industrial policy to make precision shots that increase the likelihood of successfully establishing a thriving innovation district.

Case study description

MAQ's urban area has grown at a faster rate than its overall population. Between 1990 and 2020, the population of the metropolitan area increased from 579,597 inhabitants to 1.4 million, while its urban area increased from 60 square kilometers to 250. The population doubled while the urbanized area grew more than fourfold. This burgeoning growth resulted in a 42% reduction in population density over thirty years. In other words, the metropolitan area was forced to provide public services for an area that was 4.2 times bigger but had only 2.4 times more resources available (Elías and Cruz, 2018).

A comparison of the total population reported in census tracts from 2000, 2010, and 2020 shows that the highest rates of demographic growth occurred in the suburbs and outskirts of the city. The downtown area and the functional urban areas-- built in the 1960s and 1970s-- lose population and turn to commercial uses. The depopulating downtown area is a historic site with many cultural amenities that caused UNESCO to add it to its list of World Heritage Sites in 1996, in part because of its architecture that dates to the XVII and XVIII centuries. Today, city's downtown is a commercial and touristic area that houses boutique hotels, restaurants, and shops. In terms of employment, the city is experiencing a slow transition to a polycentric structure, as employment is slowly migrating to the suburbs, following an earlier the population shift. This change is creating new centralities located near the new suburbs. The city's changing morphology requires an expanded transportation infrastructure to connect new sub-centers of employment without using the already congested central area as a hub.

On the economic side, it is important to highlight the growth and industrial transformation that the Metropolitan Area of Querétaro (MAQ) had in 15 recent years (2004–2019). With regard to employment, in the 2004 Economic Censuses,[1] it can be seen that the number of employed in the MAQ totaled 177,493, while for 2019 the total was 506,960 (INEGI, 2019). This growth in employment was accompanied by a transformation in shared employment within the secondary sector (manufacturing industries, mainly), which increased from 31 to 35% of total employment in the region. Although the tertiary sector registered growth in absolute terms, its relative importance fell from 69 to 65% in the same period.

One of the most interesting results of the industrial transformation during this period was the appearance of new and more technical industries, which may, at first glance, seem to explain the strong economic growth that the MAQ has had in recent years (Geografía (INEGI), 2019). Figure 2 shows the 10 industries that did not exist in 2004 but that by 2019 already accounted for a significant amount of local employment. Over this 15-year period, the city both became a global hub for aerospace manufacturing and financial services, wholesale trade, and other manufacturing industries also experienced impressive growth.

To thrive in the global economy, innovation districts often focus on industries producing high added value within the areas of knowledge and technology. Mexico's 2019 Economic Census (INEGI, 2019), shows that the country's manufacturing industries generated around 52% of the total added value. In a disaggregated manner, the following industries were the leaders in terms of value creation: parts for motor vehicles (16%), plastic products (6%), pharmaceutical products (5%), aerospace equipment (2%), and electrical appliances (2%).

With regard to higher education, in the State of Queretaro and based on information from the National Association of Universities and Institutions of Higher Education, ANUIES, (ANUIES, 2022), we can observe that from the period 2011–2012 to 2020–2021, the number students enrolled increased by 66%, from 49,627 to 82,341. Moreover, the enrollment of students in professional and technological careers related to STEM increased by 60% (from 18,134 to 28,994 students). Of

1 Economic Censuses are the most detailed and disaggregated source of economic and industrial information in Mexico. They are collected every 5years by the National Institute of Statistics and Geography (INEGI).

the total number of higher education students in the state, 86% were concentrated in the MAQ, which included the municipalities of Queretaro, Corregidora, and El Marquez.

Figure 3 below shows the total figures for enrollment in higher education from 2011 to 2022 and the corresponding figures for STEM careers. A drop in total enrollment due to the impact of the COVID-19 pandemic can be observed in the 2019–2020 period, with a slight recovery occurring in the following period. In terms of education, we observe an increase in the enrollment of students in STEM, but the numbers have been stagnant for the past decade. Also, the increase in STEM numbers for the region was lower than the population growth for the last ten years (relative to now).

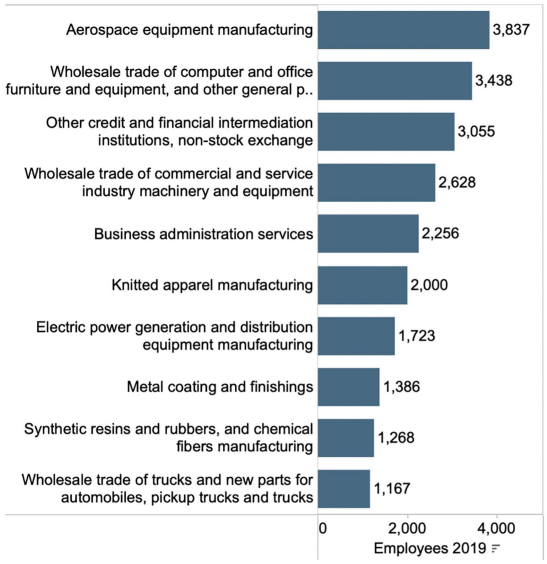

FIGURE 2
Top 10 industries that have emerged from 2004 to 2019. Own calculation based on Economic Censuses (INEGI) of 2004 and 2019.

In summary, the MAQ is a region with an impressive rate of growth with regard to its economy, population, and sprawl of the urbanized area. Economic development has attracted new industries and people seeking jobs from other regions of Mexico, creating an increased demand for housing and land zoned as industrial, all of which have shaped the process of urbanization. The city has favored a model of suburbanization and depopulation of the central area, although the old areas of Queretaro are rich in amenities and are neighborhoods that could be well suited to a project like an innovation district, which would, in turn, attract and retain a creative class. Despite all this potential, enrollment in STEM in higher education has increased but has remained stagnant for the last decade and this is a limitation to economic growth. Education policy must play a more active role in the planning and execution of economic plans for the region.

A diagnosis to create specific recommendations for a triple helix model

Within our conceptual framework and the local context of the MAQ, it is understood that the probability of developing new industries and goods in innovation districts will be strongly linked to the availability of human capital able to innovate and recombine existing capacities in new products and services. Achieving a history of success in innovation districts requires specific education strategies to form the required capabilities in the short, medium, and long term. These strategies must include consideration of the urban component since it seeks not only to train but also to attract and retain specialized human capital by offering the appropriate amenities for their lifestyle. It must be noted that this is not a minor task for subnational governments (state and municipal) since it requires not only great technical, financial, and institutional capabilities, but also a shared

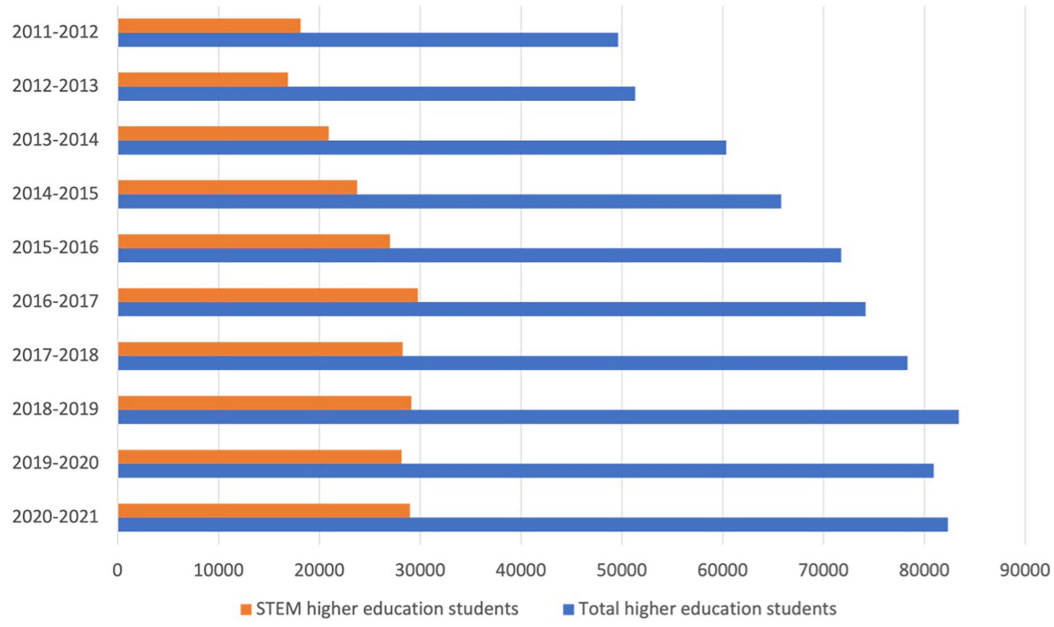

FIGURE 3
Enrollment of students in higher education and STEM degrees in the State of Queretaro by year. Own elaboration based on ANUIES, 2022.

long-term vision established jointly by government, companies, the community, and educational centers. Our proposed framework supports the goal of creating such an innovation ecosystem by providing the following three assessments in the planning stage: industrial, urban, and educational. The following sections discusses the three of these regarding the MAQ.

Assessment methods

Industrial assessment

A disaggregated diagnosis of the economic and industrial structure of the MAQ was developed to identify strategic industries for the specialization of the district, in terms of their:

1. Economic weight, added value, and employment generated in the area;
2. Potential for integration into local, national, and international supply chains;
3. Technological sophistication and potential to generate new productive capabilities within the region; and.
4. Potential to generate new productive capabilities in the region that would drive opportunities for innovation in products and services, and result in greater diversification leading towards more technologically sophisticated industries.

Our assessment identifies the industries or services with high economic weight, competitiveness, and technological level that could serve as a foundation for an innovation district in the MAQ, and its assessment is based on the methods from economic complexity (Hidalgo, 2021). Using the data from the 2019 Economic Census, we first prioritized industries that rank high for (1) economic weight for the MAQ in terms of employed personnel and added value; (2) competitiveness based on their level of specialization or the degree of relatedness to existing productive capabilities (distance); and (3) sophistication or technological level, based on the index of industrial complexity. Next, we used the Industrial Complexity Index (ICI)[2] to identify industries with greater sophistication and a higher technological level. See (Hidalgo, 2021) for the derivation of the mathematical specification of the ICI. Finally, we built a composite index to rank the industries by their economic impact (both value added and employment) and for their current proximity to the existing productive capabilities of the region. Refer to (Balland et al., 2022) for the methodology used to calculate the shortest distance between industries. Data to compute the indexes were processed in Excel and R. Visualization is performed in Tableau.

Urban assessment

Our main method of analysis consisted of using Geographic Information Systems (GIS) in Python programming language and QGIS software to process spatial and census data for the MAQ. We calculated the build area of the city from the Global Impervious Surface Area (GISA) dataset to characterize urban growth and sprawl (Huang et al., 2021). GISA is a raster file that uses remote sensing data to classify 30×30-meter pixels into built and non-built categories for the surface areas. By adding up the area of built pixels inside the MAQ, it was possible for us to estimate the total impervious area for the region for the years since 1990.

Additionally, the decennial census information for 1990, 2000, 2010, and 2020 per unit area was processed, using census blocks and census tract, along with GIS. This profile enabled us to characterize the change in demographic and sociodemographic attributes over the decades by looking at the rate of change in the total population and the sociodemographic composition of neighborhoods.

Educational assessment

The model of Education, Competencies, and Learning that was designed in this study to assess for the educational programs of an Innovation District in the MAQ was based on the dynamic Strategic Intelligence platform of the 2022 WEF (World Economic Forum, 2022). The platform's information draws on the collective intelligence of the WEF network to explore key trends, interconnections, and interdependencies between industry and regional or global issues. The visual representation of this topic, *Transformation Map*, is an interactive version available online at,[3] where an overview of issues and key trends affecting them can be found, along with summaries and links to the latest research and analyses on each of the trends. The summaries for the countries also include data from the WEF benchmarking indices.

To search for key occupations by industrial branch and the skills associated with these occupations, the National Occupation and Employment Survey, ENOE, of Mexico (INEGI, 2022) and the O*Net database of the United States of America (O*NET Program, 2022) were used. Subsequently, two main variables were selected from these databases: namely, the number of employed persons by branch of economic activity, as well as the list of their occupations. Finally, the branch of economic activity, which is identified with a 4-digit code from the North American Industrial Classification System, NAICS (INEGI, 2018), was associated with the occupations related to each of the branches.

From the number of employed persons by type of occupation and branch, the Location Quotient (LQ) indicator was estimated to determine the level of specialization or concentration for each occupation considered within the economic branches, using the National Occupational Classification System, SINCO (INEGI, 2019), of the ENOE. The higher the LQ indicator, the greater the presumed importance of a given occupation within the branch of economic activity, described with the equation:

$$LQ_{z,i} = \frac{\frac{e_{z,i}}{e_i}}{\frac{E_z}{E}}$$

2 The ICI classifies the diversity and sophistication of the productive knowledge required by an industry. It is calculated based on how many other metropolitan areas can develop an industry and the economic complexity of those regions. The ICI captures the amount and sophistication of the knowledge required to develop an industry. More complex industries (which only highly complex regions can produce) include sophisticated machinery, electronics and chemicals, compared to less complex products (which almost all regions, including the least complex ones, can produce) which include raw materials and agricultural products.

3 https://intelligence.weforum.org

where $e_{z,i}$ is the level of employment in occupation z in industry i; e_i is employment of all occupations in industry i; E_z is the employment of that occupation z in all industries and, E is the total employment in all occupations and all industries. The quotient was computed in Excel software.

From the previous analysis, relevant skills for the key occupations are identified from the data bases. An analysis on educational models to foster these skills is performed.

Results

Industrial assessment

The criteria of economic complexity were used to determine the comparative advantage of industries in the region. Figure 4 ranks the industries by comparative advantage for the MAQ from highest to lowest.

The greatest comparative advantage of the region can be seen in personal services, insurance, and aerospace equipment manufacturing.

The ICI of 276 industrial branches registered at the national level in the 2019 Economic Censuses was estimated. At a national level, the most complex industries in Mexico are those within the area of Financial Services. In this way, it was possible to identify the most sophisticated industries for which the MAQ has a high level of competitiveness as compared to most of the country's metropolitan areas. As can be seen in Figure 5, the most complex industries with the greatest comparative advantage are found in the manufacturing sector.

The industries in which the MAQ currently specializes were prioritized, and the manufacturing of automotive vehicle parts stands out as one of the most important industries in economic, technological, and competitive terms for the region.

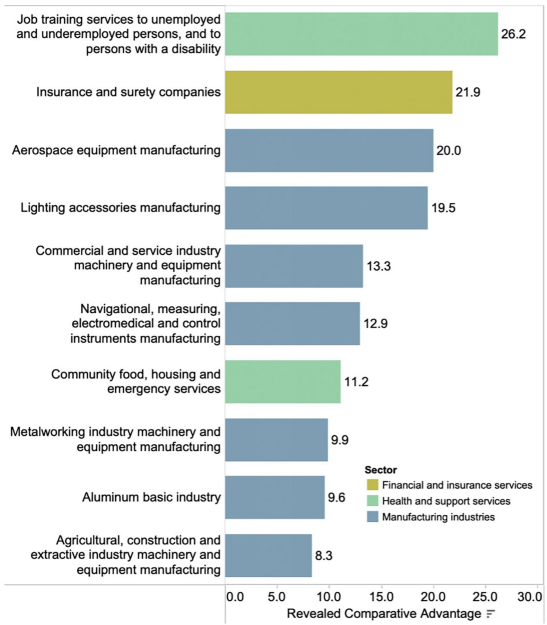

FIGURE 4
Industrial specialization of the MAQ. Own elaboration based on Economic Censuses 2019 (INEGI).

Next, the composite index of economic impact was estimated (Balland et al., 2022). Figure 6 illustrates the results and ranks the industries based on such composite index. Although the industries in the manufacturing sector once again show up in the highest ranks, new industries also appear possible to develop in the MAQ within the sectors of technical and professional services and amass media information. Specifically, the design of computer systems and the development and edition of the system software, programming, application, or mass or packaged entertainment, industries based on the knowledge and capabilities of the creative economy are presented as viable options for the specialization of the innovation district. The following three industries were selected for the educational assessment found later in this paper: 1. software publishing and integrated software publishing and reproduction; 2. electronic data processing, hosting, and other related services; and 3. computer systems design and related services.

In summary, there were two important findings from the industrial assessment: First, the MAQ already showed a high degree of specialization in manufacturing, and the region is known nationally for this. Second, activities related to IT grew quickly between 2004 and 2019. The next obvious question was: which industry selection is most important for an innovation district to specialize in? This is where the Triple Helix model matters because it is not only a technical question. The industrial assessment sheds light on the patterns of industrial growth and shortlists several activities. However, stakeholders and the academia must discuss these shortlisted alternatives to build a collective vision and educational policy to form such human capital that can grasp these new opportunities and these industries ripe. For instance, in the case of the MAQ, it seems plausible to promote IT-related activities, but also to foster the conversion of manufacturing into Industry 4.0 capabilities with Artificial Intelligence (AI) and the Internet of Things (IoT).

Urban assessment

The construction of a district involves the investment of capital and the provision of infrastructure within one or more specific locations in the city. A project of this nature has a regional and metropolitan impact that reshapes urban form, transportation demand, and housing prices in the city. Thus, an innovation district is large enough that it can regenerate and/or socially transform an area of a city, improving or worsening its access to employment, transport, and leisure for the region. In addition to its potential for transforming a center of development the innovation district must also recreate an urban environment that is attractive to the creative class that will join the new labor market that will develop.

The most important trait of the model of urbanization for the Queretaro area is suburban sprawl. Over the last three decades, new, low-density neighborhoods sprouted in the city's outskirts, pushing the urban boundaries further from its center. Moreover, the industrial development of the last 15 years that we referred to in the previous section was one of the drivers of sprawl. Figure 7 compares the urbanized areas in 1991 and 2019, by which they had increased by a factor of 4.

The urban sprawl has reconfigured spatial patterns with regard for the location of people and jobs. Understanding these patterns and spatial-demographic dynamics is very important when choosing the location of an innovation district. We analyzed the changes in the location of people and jobs for the last 2 decades. Figure 8 traces concentric circles every 1 kilometer starting downtown. We used the census blocks from 2000 and 2020 to compare the population change

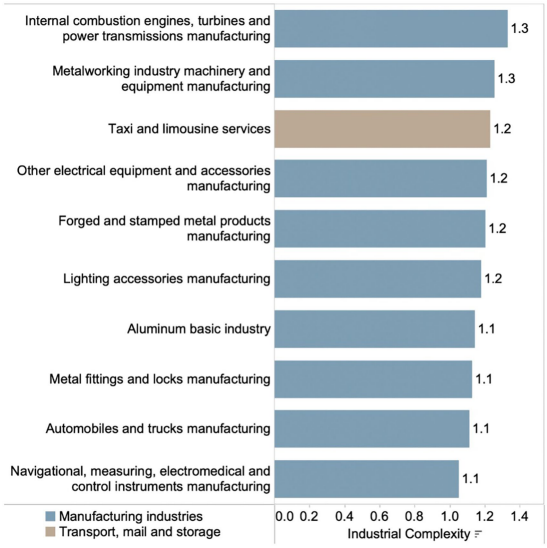

FIGURE 5
Top 10 industries with greater complexity and specialization of the MAQ. Own elaboration based on Economic Censuses 2019 (INEGI).

represented by a concentric circle, and we did the same for the number of jobs between 2000 and 2010. These years were selected because information on employment units was only available after 2010, and because the census data by block were available only after 2000. The concentric circles are useful to trace demographic patterns of internal migration from the center of the city to the suburbs. After this analysis, we repeated this exercise for the elderly and youth as well.

The red circles in Figure 8 show a declining population and a negative balance between 2000 and 2020. The blue circles illustrate the areas with a net growth in total population. The demographic implication of urban sprawl can be seen in the rearrangement of spatial population patterns within the metropolitan area. In terms of population, we observe a loss in the central zone and migration towards the urban periphery. The lack of affordable land and of an adequate housing supply in the central zone are the main causes of this sprawl: young families move to areas with a generous housing supply where their economic hopes and lifestyle aspirations can be met; this mainly happens mainly in the suburbs. The paradox is that the city, which has the best transportation infrastructure and services, is losing population and this is a factor that those selecting the site for an innovation district should consider.

In terms of employment growth, the comparison between 2020 and 2010 shows that the highest density of economic units and

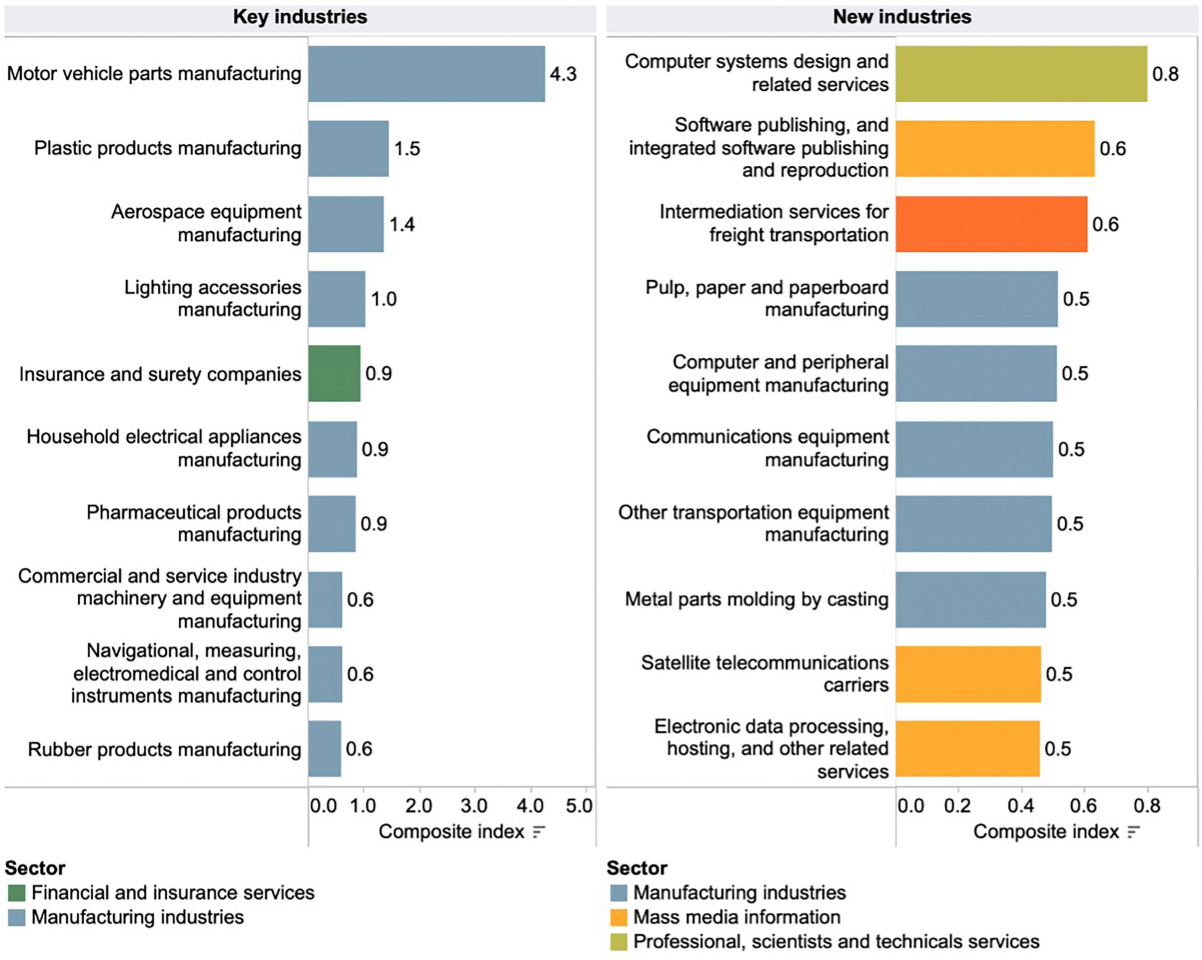

FIGURE 6
Top 10 key new industries of the MAQ. Own elaboration.

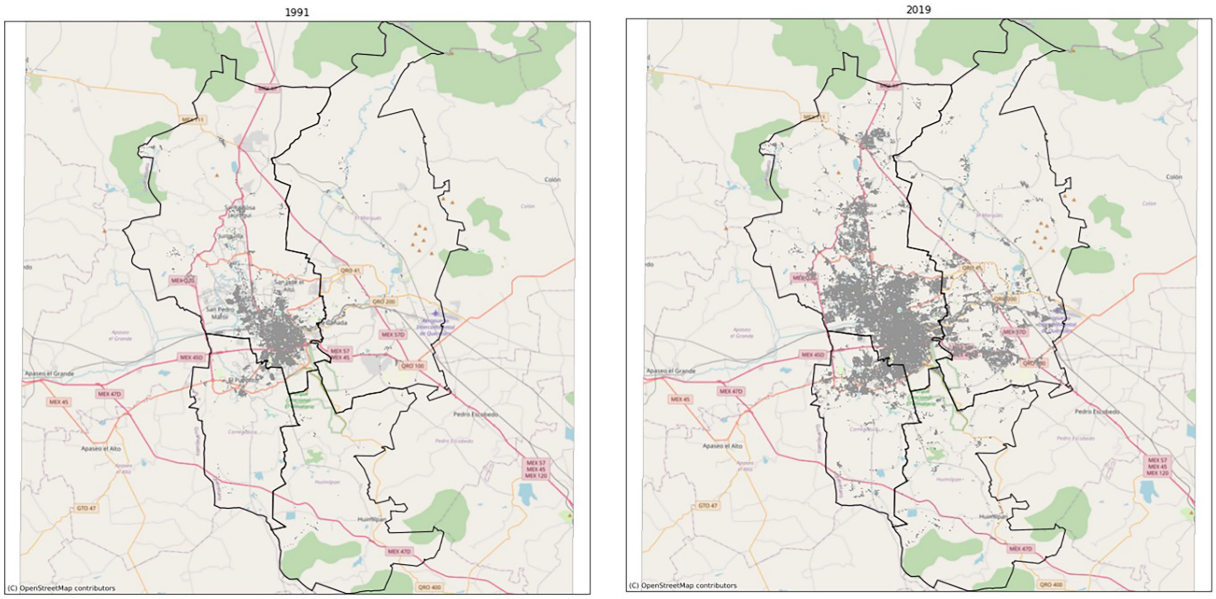

FIGURE 7
Urbanized area in the MAQ. Own elaboration.

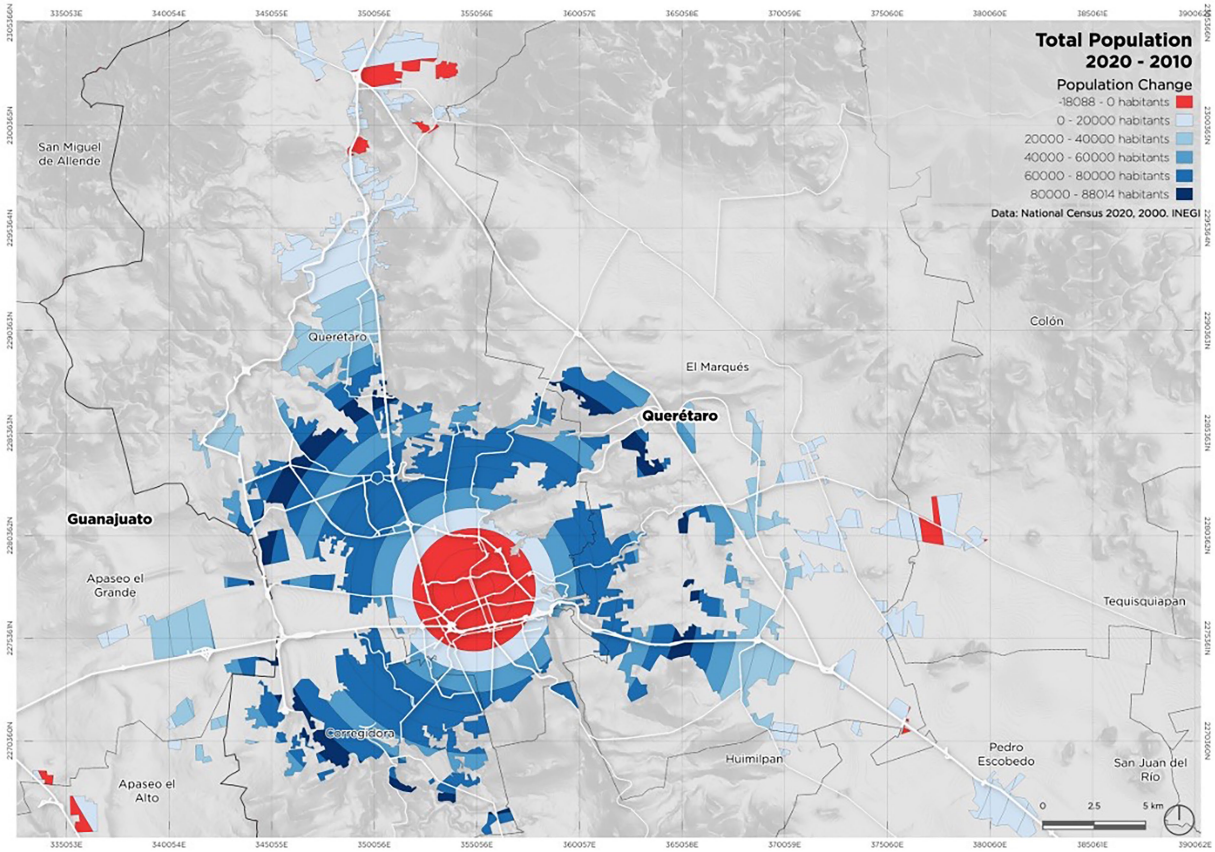

FIGURE 8
Population changes indicated by concentric circles (1-kilometer betweenness) from 2000 to 2020. Own elaboration based on the decennial censuses from iNEGI for 2000, 2010 and 2020 by block.

employment was still in the central zone of Queretaro, that is, in the area located less than 6 kilometers from the historic center. This area coincides with the one that has lost population in the last 20 years. However, job creation in the MAQ has been also gradually deconcentrated from the central zone, generating new urban centralities located in the suburbs. In urban terms, the city is said to

be going through a transition from a monocentric to a polycentric city.

Territorial expansion and the loss of residential density in the central zone are the main traits of urban growth in the MAQ. The central zone retains its commercial attraction because it is the most accessible zone in the metropolitan area. This territorial pattern of sprawl is not sustainable in the long run. Thus, it is desirable to re-densify the central area and promote a community of mixed uses. The central area of the city has the best access to existing services and urban infrastructure such as hospitals, schools, and amenities are already built.

In this context, a critical choice suggested by use of the Triple Helix Model is the selection of the most suitable location for an innovation district, a decision in which the three actors and the community as a whole must be involved. This assessment of urban growth shows that the central area of the city, which has been depopulated but still has amenities, has enormous potential to host an innovation district. This area comprises downtown, but it also includes other neighborhoods that were built in the 1950s and 1960s. It has neighborhoods, amenities, and proximity to institutions of higher education, and is, thus, suitable to host an innovation district and accommodate a creative class that might live in proximity to the district. Other factors, such as available land, the relative location of the site to universities, and the participation of the community, should be considered when making a final choice for the location of the innovation district. This participatory process that involves the urban context in the selection of the site for the innovation district embodies the principles of Knowledge-Based Urban Development.

Up to this point, the industrial assessment has been useful to shortlist a selection of industries with special potential to establish and develop in the innovation district, conditional on the strengths of the region in human capital and industrial profile. Then, the urban assessment analyzed the process of urbanization of the city and discussed the convenience of locating the district into an area having the potential for re-densification and amenity creation in order to grow the human capital for the district. Once the new strategic industries with the greatest potential to thrive in the region were identified, and anchored in the urban context, an educational assessment was done to complete the plan. The objective was to meet the potential demand for specialized workers in new industries, which will require not only the training of new professionals and technicians, but also the possible retraining of current workers from related industries. In the Triple Helix Model, it is important to link these two assessments, industrial and educational, so that they can work together in the reconfiguration or creation of educational programs, professional careers, and continuous training courses. In a city such as MAQ in a developing country, this step is not automatic and requires the active engagement of all the stakeholders.

Educational assessment

The model of Education, Competencies, and Learning for the educational programs of an Innovation District in the MAQ is supported by 4 pillars:

1. Educational Innovation.
2. Skills Development.
3. Digital Transformation.
4. Lifelong Learning.

Figure 9 below shows the fundamental elements of the model from the perspective of the development of basic and transversal competences. The model must meet the requirements of the Fourth Industrial Revolution (4IR), but it must also meet the following 3 criteria: focus on the training of specialized labor and for occupations that are a priority in the technology sector; respect public finances and educational programs for emerging industries; and include STEM skills.

In the ENOE survey, the INEGI (2022) collects quarterly information on the characteristics of the workforce, occupations, labor informality, underemployment, and unemployment. This survey is carried out in 39 representative cities of the 32 states of the country. The ENOE classifies occupations based on the National Occupational Classification System, SINCO (INEGI, 2019).

We computed the Location Quotient (LQ), or the significance of a particular occupation within a branch of economic activity, and now present the results. Three new industries with the greatest growth potential in the MAQ were selected for study based on the outcome of the industrial assessment (see Figure 6). These were: software publishing and integrated software publishing and reproduction; electronic data processing, hosting, and other related services; and computer systems design and related services. For these industries, the most important occupations by economic branch were considered, the equivalence was made with the NAICS of the Economic Censuses to assign the occupations to the strategic industries that resulted from the first stage of the project analysis and the most suitable industries to consider as part of the educational programs of the District of Innovation those indicated in Figure 10, where the corresponding NAICS code is indicated in parentheses. In addition to their importance with regard to specialization, the occupations most related to the video game industries, such as technicians or software developers, were determined as cases of interest in the Queretaro KBUD Innovation District study.

The second source consulted was the O*NET Program (2022), a database that describes the characteristics of occupations and required skills, knowledge, and other features for the types of occupations-codified using the Standard Occupational Classification (SOC) and economic activities noted within NAICS. This information has become a basic tool for both workers and employers because it describes the characteristics of almost 1,000 occupations that cover all economic sectors in the United States in a way that reveals both the skills companies are looking for in various occupations and the skills that will allow them to be competitive in the market. Using this list of occupations and skills, the equivalences were sought, especially for the occupations with the SINCO in order to be able to relate the skills to each occupation. Table 1 includes the possible jobs activities according to the SINCO classification for the three NAICS branches of Figure 10.

To determine the skills required for each of the jobs chosen according to the SINCO classification, an analysis of the databases was carried out and the required skills were determined. Figure 11 shows, as an example, the skills identified for the SINCO #2271.

High-value-added industries and services depend on local human capital with the skills required to enter new labor markets and aspirations for entrepreneurship and innovation. These technical/critical-thinking and entrepreneurial skills can be taught and learned through the educational system and are necessary for the success of an innovation precinct.

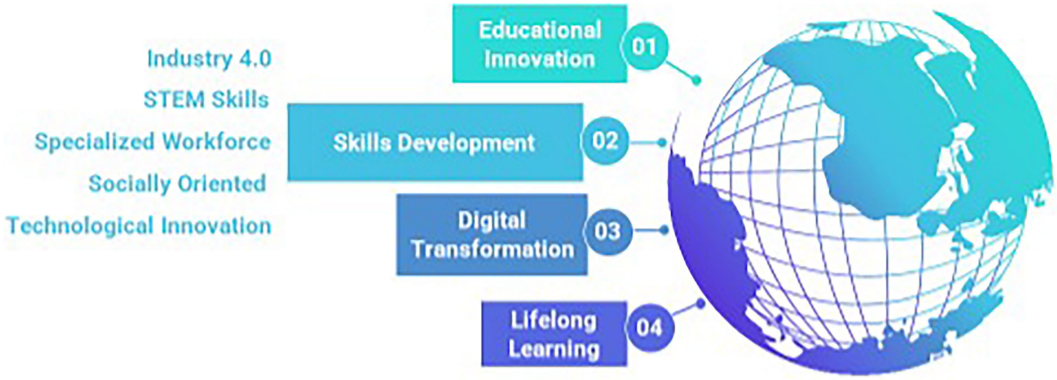

FIGURE 9
Education, Skills, and Learning Model for a KBUD Innovation District. Own elaboration based on the Education 2030 Report (OECD).

FIGURE 10
Examples of branches of the videogames sector according the NAICS. Own elaboration based on NAICS codes of the Economic Censuses.

Innovation district and education 4.0: Framework, characteristics, and technologies

In innovation districts, the training of human capital in skills and abilities associated with Industry 4.0 is essential to meet the hiring requirements of high-value industries and to become competitive entrepreneurs in the new technological markets. Industry 4.0 is defined as digital production having real-time reaction and optimized artificial intelligence systems, which works in a highly self-managed network (Koizumi, 2019). Industry 4.0 is characterized by the consolidated use of emerging technologies, including artificial intelligence, the Internet of Things (IoT), advanced data analytics, cloud computing, virtual and augmented reality, robotic process automation, blockchain, drones, and other digital technologies that can transform work (Martinelli et al., 2021). With the concept of Industry 4.0 advancing rapidly within all aspects of production, jobs and occupations in this sector are constantly changing and will keep changing in the future. Therefore, there is a need for ongoing training to help workers improve those skills and competencies that allow them to continuously learn and use new knowledge to both ensure their own employability and contribute to the development of a sustainable world. It is especially important that Industry 4.0 workers develop a lifelong learning mindset that allows them to easily adapt to changes and transformation, always acquiring and updating the knowledge and skills necessary to perform well in constantly evolving work situations (UNESCO & Institute for Lifelong Learning, 2020).

Traditionally, professionals and technicians working in the technology sector have followed a structured and often rigid path to advance in their professions, so continuing education for these workers has also been associated with structured curricula. The current era of Industry 4.0 requires that upskilling and reskilling ongoing training programs to include the preparation of professionals with regard to such specific topics as: process digitization, 3D printing, artificial intelligence, data analysis, robotics, additive manufacturing and blockchain (World Economic Forum, 2018). A completely new educational model, called Education 4.0, embraces this new form of training. Education 4.0 involves Continuing Education (CE) and Lifelong Learning (LLL) and represents a scenario in which workers must consider continuous training carry out functions based on constantly changing technologies, and improve their skills and competencies to avoid job obsolescence (Chakrabarti et al., 2021).

The World Economic Forum estimates that by 2023, 75 million jobs will be eliminated by the shift from human to machine work--but that a further 133 million new jobs will be created to accommodate ever-expanding digital workplaces (Ratcheva et al., 2020). Even before the pandemic, a strong sense of uncertainty among workers regarding how the workforce would be affected as Industry 4.0 unfolded. Skills gaps continue to be a challenge to success; the biggest impact of this skills shortage in business has been the inability to innovate effectively. Such gaps and the potential limitations they impose will be very relevant for innovation districts. Industry 4.0 not only generates demand for new skills related to new technologies, but also demands new attitudes and temperaments associated with new concepts of work, workforces, and workplaces.

Regarding the concept of *work*, it can be said that Industry 4.0 represents a cognitive revolution, in the sense of changing our understanding of performing tasks and solving problems. This change is eliminating more than 14%, and disrupting 32% of current jobs (Nayak et al., 2022). Roles are being redefined, combining technology with human skills, and incorporating new kinds of skills, abilities, activities, and practices. One of the roles of an Innovation District's continuing education and LLL programs will be to change the way work is handled and to develop the training that a workforce needs in the short term to take on these new roles and assignments.

Industry 4.0 redefines the concept of the *workforce*, and its changing demographics (it has become older and more diverse in recent years) must be taken into account. However, with this approach, the social contract between employees and employers has also been transformed: from the ways to find workers, to the percent of full-time vs. part-time employees, to managed services, to outsourcing, crowdsourcing; the

TABLE 1 SINCO codes and workforce activities for NAICS branches.

SINCO	Workforce activities
2271	Software and multimedia developers and analysts
2651	Technicians in the installation and repair of computer networks, equipment and computer system
2653	Aides and technicians of video recording and reproduction equipment
2654	Audio, sound and lighting engineering assistants and technicians

Own elaboration based on SINCO classification (O*Net).

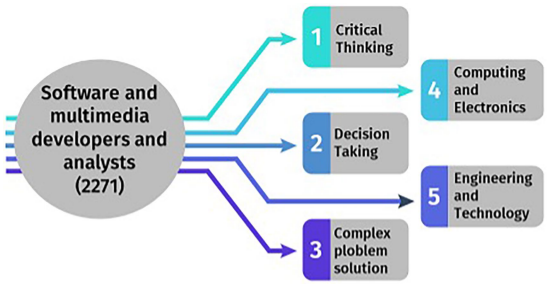

FIGURE 11
Some skills and competencies related with SINCO#2271. Own elaboration based on SINCO classification (O*Net).

presence of alternative workers (currently 35% of the US workforce is in supplemental, temporary, project or contract positions) and finally the novelty that the freelance workforce is growing faster (up to 8.1%) than the total workforce (Schwartz et al., 2019).

Regarding the concept of *workplace*, it should be noted that this concept started changing drastically in March 2020 with the COVID-19 crisis, moving from the requirement that employees work in *physical proximity* to instead working using digital communication, collaboration platforms and/or even with digital reality technologies (World Economic Forum, 2020). These changes were accompanied by the creation of distributed teams and had social consequences: organizations were able to organize different workplace options, from the traditional single workplace to the new, distributed workplace with 100% virtual interaction. As teams became more highly distributed, organizations needed to rethink how to promote workplace culture, maintain efficiency and sustain team connections. In post-COVID times, the Innovation District must work intensely on the design of upskilling and reskilling programs that include the social–emotional and networking skills necessary to continue carrying out this ongoing transformation (World Economic Forum, 2020).

Considering the transformations generated by the substantial changes in the model of the labor force that were mentioned above and taking into account the reports of international organizations such as the Organization for Economic Cooperation and Development (OECD) and the World Economic Forum (WEF), the global challenge is to meet the demands of Industry 4.0 regarding the nature of future work and the skills of the workforce to adequately meet those demands (World Economic Forum, 2020).

One way to ensure that workers are satisfactorily trained with regard to Industry 4.0 requirements is to ensure that the education model of Innovation Districts uses an Outcome-Based Education (OBE) approach (Rao, 2020). For adult education, OBE is an approach since decisions about the curriculum are driven by the learning outcomes that students are required to show at the end of the course: in this way, the final product defines the process (Macayan, 2017). The implementation of OBE requires complementarity between the desired educational outcomes, teaching and learning activities, and assessment methods and practices. The three most significant aspects of OBE are: first, the focus on results; secondly, the curriculum design process that starts from exit-level result and works its way backward; and finally, the responsibility of the institution and the teacher/coach to provide appropriate learning experiences to enable the success of all students (Premalatha, 2019).

With regard to curricular design and implementation, there are several conditions that must be met. These include: where instructional focus is placed; how much, how often, and when time is provided for learning; what learning is expected from whom and how it is rewarded; and how the curriculum is designed and organized. The theoretical framework for the education model for Industry 4.0, Education 4.0, can be identified with two competencies with four learning characteristics that ensure high quality:

Transversal Competencies: Global Citizenship, Use of Technology, Innovation and Creativity, and Interpersonal Awareness.

Learning Characteristics: Personalized and self-paced, Accessible, Inclusive, Collaborative, and Student-driven.

This framework was used throughout the study to propose different implementation schemes of a viable educational model for an Innovation District. Various international organizations such as the Organization for Economic Cooperation and Development (OECD) (Howells, 2018; Hughson and Wood, 2020) and the World Economic Forum (WEF) (World Economic Forum, 2018; Ratcheva et al., 2020) have in the last 5 years published reports related to the emerging technologies of the 4IR, the jobs, and occupations required by the Industry 4.0 labor market, and, finally, the best active learning practices for the development of:

Technical skills, also called STEM skills (Science, Technology, Engineering, and Mathematics). STEM skills are those technical skills that complement higher-order thinking skills and social–emotional skills. The objective of incorporating STEM approaches into the educational programs of an Innovation District is to close the gap between the skills acquired prior to entering the program and the skills needed for the future workplace, as confirmed by professionals from the human resources (HR) departments of major international companies (Nguyen et al., 2020). In the near future, to thrive in their jobs, workers will need to develop a high level of digital fluency and STEM skills. The ability to find innovative solutions to global challenges, including climate change, resource management, agricultural production, health, biodiversity, and declining energy and water sources, requires an interdisciplinary STEM educational approach (Millar, 2020; Deák et al., 2021).

Soft skills: Critical Thinking, Decision Making, etc. In 2012, the Organization for Economic Cooperation and Development (OECD) carried out an important study, which is still widely read, on the analysis of cognitive skills (both basic and higher) to measure possible mismatches between supply and demand in international labor markets (OECD, 2017). In the Program's Adult Skills Assessment Survey, a potential but growing mismatch in needed vs. available cognitive skills becomes apparent: the demand for higher cognitive skills, such as

critical thinking, decision-making, and complex information processing, will grow at double-digit cumulative rates through 2030. Demand for these skill categories is estimated to increase by 19% in the United States and 14% in Europe, according to the forecast carried out (Caratozzolo et al., 2021; Supena et al., 2021); however the supply for these skills is/will be missing because our educational programs need to adapt to teach such new competencies.

Transversal Competencies: Use of Technologies, since technological advances can support in teaching techniques; and innovation and creativity, since these digital skills are the basis for the digital transformation required in upskilling and reskilling (Caratozzolo et al., 2019, 2020; Hiğde and Aktamış, 2022).

Digital skills: Interpretation of images, Management of Multimedia Platforms, Network Management, etc. (CEDEFOP, 2022; Ostmeier and Strobel, 2022).

When designing educational programs for an Innovation District, it is important to offer students an interdisciplinary, personalized, inclusive, flexible, collaborative, student-centered, attractive, and, above all, motivating learning environment. In order to provide quality education in a globally competitive environment, all Innovation District programs must be structured towards the development of 21st-century skills, that is, designed within the Education 4.0 Framework, which explicitly includes increasing the skills, knowledge, and abilities that students/professionals bring from their previous training. In the report *Skill Shift: Automation and the Future of the Workforce*, the McKinsey Global Institute stressed that in the future technology professionals' demand for cognitive skills would shift from basic to higher skills, due to the ongoing consolidation encouraged by Industry 4.0 (McKinsey, 2018). Specifically, the study predicted that the needed transformation of skills with a view to 2030 will mean that the jobs and occupations of the future will require, above all, higher cognitive skills.

With regard to the selection of pedagogical techniques, the instructors who are in charge of the training and updating courses for an Innovation District must consider that the use of a single technique is insufficient to obtain the desired results. For this reason, the role of the District of Innovation instructors will be highly relevant as they will facilitate instruction within student-centered communities of practice, addressing individual concerns and questions, and providing support to maintain focus on complex problems. Education programs designed in an Innovation District have the challenge of preparing professionals to prosper in a world mediated by rapid technological advance, and discerning and then filling gaps between what students need to learn to perform in more demanding competitive and globalized work environments, and what the training and updating programs of the Innovation District offer. According to recent academic reports by Hughson and Wood (2020) and Sgambi et al. (2019). Instructors must choose which among the many cutting-edge teaching techniques available to them will be most appropriate for a given Innovation District. Available teaching techniques/activities include the following three:

Gamification. Gamification is a technique that has gained popularity in the era of digital transformation and is defined as the use of game mechanics in non-game environments. In such environments, participants play and develop needed skills through action-reward (Raju et al., 2021; Hayes, 2022).

Flipped classroom. The flipped classroom technique allows students to learn about the learning material before having contact with the instructors or the systematic information, which allows classroom time to be used for interaction, discussion, and problem-solving with classmates. The model for a flipped classroom can be enriched with materials provided by the digital environment (Strelan et al., 2020; Senali et al., 2022).

Challenge-Based Learning. The Challenge-Based Learning technique is based on experiential learning, which allows students to actively face, and help solve, real-world business situations and industry problems. This "learn-by-doing" approach involves students' interaction with instructors and business partners to solve challenges that allow the students to develop their teamwork skills and deliver products of different complexities (Caratozzolo and Membrillo-Hernández, 2021; Membrillo-Hernández et al., 2021).

To ensure the success of the educational programs in an Innovation District, it is essential to use various cutting-edge educational technologies including the use, design, and implementation of media, web portals, and technological platforms in the service of the educational learning processes (Hernandez-de-Menendez et al., 2020). It is important that the Innovation District have specific spaces earmarked for the development of skills and acquisition of knowledge using cutting-edge technologies and the assistance [OR "guidance" or "support"-?] of instructors with expertise in pedagogy and evaluation, who can implement learning dynamics that motivate the learner and trains them to better meet the requirements of Industry 4.0.

The additional educational technologies described below were originally designed to address the needs and concerns of users and employers within the Education 4.0 Framework and focus on Information and Communication Technologies (ICTs), which are essential for training professionals in specific skills required for the jobs that are targeted (Okoye et al., 2021):

Virtual Environments. The virtual environment technique allows courses to be redesigned based on their use of new communication channels (videoblogs, open classes, e-books, etc.) that are used with activities, laboratory practices (e.g., virtual and augmented reality), simulators, and immersive haptics, which allow students to understand and develop cutting-edge technical skills (Huang et al., 2019; Halabi, 2020).

Podcast and Video Recording. Second-generation podcast recording (audio and video) and screencasting videos are an excellent educational technology option for Generation Z learners. Because these types of platforms are used by young people in their interactions with social networks and for entertainment, they are familiar to students and manage to keep their attention (Hess et al., 2021; Priyadharshini et al., 2022).

Internet-based platforms. The use of internet platforms and other online networks as educational technology allows courses and training to be delivered to a large number of students, without the physical limitation of classrooms. One example of these technologies are the platforms used for teaching MOOCs (Massive Online Open Courses) at no cost to an unlimited number of students. These types of educational technologies also produce options for students to earn micro-credentials and alternative credentials (Sheikh et al., 2021; Liapis et al., 2022).

To ensure the quality of technical education worldwide, there are three international agreements known within the field as *Washington* (for engineers), *Dublin* (for technologists) and *Sidney* (for technicians) These agreements guarantee the mutual recognition among participating

countries (Jadhav et al., 2020). Many countries have adopted the OBE approach for their undergraduate engineering programs after signing the *Washington Accord*. Currently 21 countries are signatories to the *Washington Accord* and another 7 countries (Mexico among them) that have provisional status. These countries offer many programs producing graduates with highly similar and related skills and competencies (Wilson and Marnewick, 2018). Although the *Washington Accord* covers only undergraduate engineering degrees, and graduate engineering programs are not included in the agreement, it is a stand-alone agreement between national organizations that grants external accreditation to higher education programs and signified that graduates have met the criteria for access to the practice for professional engineers. Signatories agree to grant the graduates of each other's accredited programs rights and privileges similar to those available to their own graduates. Through this arrangement, the agreement increases the movement of graduates between signatory jurisdictions and grants them a greater understanding and recognition of their engineering education and accreditation systems.

Educational programs that are implemented within an Innovation District must consider the adequacy of the professional and career preparation of the students, specifying not only the results or skills that the local market demands, but also the possibility of incorporating the worker into the wider global labor market. From this point of view, it would also be important for the educational model to ensure assessment and accreditation of skills and competencies in a framework similar to those of the *Washington*, *Dublin*, and *Sydney Agreements*.

Conclusion and future work

This paper draws from the Knowledge Based Urban Development (KBUD) framework of innovation districts to emphasize the importance of the community and of education policy in the construction of an innovation district. The KBUD is important in our approach to innovation districts because it assumes the importance of the Triple Helix Model for the planning and governance of such innovation precincts, in which targeted education is seen as essential to the success of a project like this. However, the KBUD and triple helix model have one major limitation since it takes for granted the connection between educational institutions and industry that is needed to grow human capital with the soft skills needed to innovate and thrive in an innovation district. The lack of connection might be more relevant for countries with institutional weakness, limited financial resources and a less diversified economy, where connections between education, industry and the urban context for the district might simply not exist. This is where the design and implementation of specific collaboration strategies, and public policies that give them support and legitimacy becomes especially relevant.

Queretaro is one of the industrial hubs in Mexico that served as an example of thriving manufacturing regions that long to plan for and host a thriving innovation district. Our case study demonstrated that the triple helix model can be better sustained by a detailed analysis of the industry sector in the planning process of an innovation district to highlight specific areas of economic opportunity based on special strengths of the region. For instance, Queretaro is already a hub of aeronautical and automobile manufacturing, but the hiring and productivity of the software and ICTs industries have increased largely only in the last 15 years. Our analysis of economic complexity shortlisted the industries with the greatest chance of success. Then an urban assessment helped better understand the challenges needed to generate a potentially productive urban environment --in the context of a sprawling city shaped by processes of informality and inequality--to attract and retain the called creative class.

Finally, Education 4.0 was crafted as a response, within the educational sector, to the needs for new skill sets that the Industry 4.0 demanded. The same concept of Education 4.0 has vast applications in innovation districts to generate the transversal competencies and learning characteristics that are also needed to develop the full potential of the industries that were tagged as critical in the industrial assessment, such as the ICTs in Queretaro. Moreover, the educational literature can contribute enormously to the physical and urban design of innovation districts through its findings and demonstrable experience in implementing educational technologies. It can also suggest designs and configurations the physical for learning spaces that promote student-centered communities that foster soft skills needed for creativity and innovation. For instance, gamification, flipped classrooms, challenge-based learning, virtual environments, podcast and video recording and internet-based platforms can be important instruments, already tested in educational settings, that can contribute enormously to the success of an innovation district. Our case study exemplifies our view regarding the necessity of a deeper collaboration between education, industry, and government within a KBUD framework that is customized for specific spaces and pedagogies. The classic Triple Helix Model proposed in the literature of innovation districts do not reach to this level of detail when addressing the relevance of education for regional economies. However, this is the level of specificity that we believe is essential, and the fields of education, pedagogy and educational technology area all important in any discussion of innovation districts. The main contribution of our research through this case study has been to demonstrate that such a three-pronged approach this is feasible and requires institutions and academia to both play primary roles.

An innovation district makes a society more sustainable--if it is based on a recognition of the interplay of education and technology. Education must be the fundamental engine of a transformation towards innovation and competitive production systems. Educational models using cutting-edge technological tools should complement innovation districts in order to enable the districts to function as extracurricular spaces where, following a specific pedagogical design, technologies that may not be available in other settings can be made accessible or more affordable to students. In this way, an innovation district serves as an incomparable space to deploy the potential and knowledge that a region possesses and apply them to the production of goods and the generation of new knowledge. The case study of Queretaro Innovation District in Mexico provides an example of how human resources can be used for greater transversal and the development of specific skills.

Two are the main limitations of our research. First, to include other case studies of cities from other developing countries than Mexico, that also have a strong industrial base in manufacturing. Second, to translate the mapping of competencies and skills needed for the innovation district into a pedagogical curriculum for higher education. The Triple Helix stakeholders would take part into this definition. We defer these two tasks to future work.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://github.com/gperaza/paper_frontiers_kbud.

Author contributions

RP-L organized the project and assembled the team, proposed the structure of the paper, carried out the literature review of innovation districts and triple helix models, worked in the urban assessment of the case study. GP-M put together the different pieces, structured the conceptual framework, and prepared the first manuscript of the paper. FG-Z carried out the industrial assessment and the location quotient methodology. JM-H participated in developing the theoretical linkage between innovation districts and education. AA-L contributed with the description of educational attainment statistics in Queretaro and reviewing the first draft of the paper. PC provided guidance throughout execution of the project and was the driving force behind the concept of the importance of Education 4.0 in for the success of innovation districts. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Academic parenthood in the United Arab Emirates in the time of COVID-19

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Since the onset of the global COVID-19 pandemic, early research already indicates that the personal and professional impact on academics juggling parenting responsibilities with their academic work has been immense. This study, set in the United Arab Emirates, explores the experiences of academic parents and looks at ways in which various aspects of their professional lives have been affected by the pandemic. Survey data from 93 participant parents indicated that certain elements of research productivity have been reduced during the pandemic, and having to support children with online schoolwork while teaching online themselves has been particularly stressful. Working from home with no dedicated space was a frequent challenge for the academic parents, and this impacted their ability to perform research tasks that demanded quiet spaces, e.g., reading and writing. However, the data also indicated that parents appreciated greater working flexibility, a reduction in commuting time, and being able to be more involved in their family lives. Some indications were perhaps unexpected, such as no statistically significant impact being observed on academic parents' ability to interact with students or peers at their institutions while working from home. The implications of these findings to faculty and institutions are discussed.

KEYWORDS

academic parents, COVID-19, productivity, family responsibility, universities

Introduction

The global COVID-19 pandemic created additional challenges for parents as they attempted to balance working from home with added full-time childcare responsibilities and domestic chores. Research has shown that parents have been less productive than their child-free peers since the start of the pandemic (see, e.g., Myers et al., 2020; Staniscuaski et al., 2021). More specifically, there has been an immense personal and professional impact on academics juggling their parenting responsibilities with their academic work. However, academic parents' experiences from the United Arab Emirates (UAE) are still missing in the literature. Therefore, this study aimed to investigate how academic parents' working lives in the UAE were affected during the COVID-19 pandemic by exploring the changes to their working patterns, daily roles and responsibilities, and how this impacted their ability to manage work.

Academic parenthood: literature review

Juggling responsibilities at work and home

Gender disparities were present in the homes of academics well before the COVID-19 pandemic. Studies have repeatedly shown that female academics perform more household labor than men, sometimes to the detriment of their academic work (e.g., Schiebinger et al., 2008; Rafnsdóttir and Heijstra, 2013). Recent research indicates that the pandemic has increased domestic responsibilities for women (e.g., Minello et al., 2021). Bianchi et al. (2012) showed that having young children at home increases housework for both genders, yet increases the housework for females threefold that of males. Furthermore, Suitor et al. (2001) found that female faculty spent 113% more time on childcare than their male counterparts. This is likely to impact the academic's ability to work quietly on research writing and therefore may impede their research productivity. Fairweather (2002) points out that "each faculty member is expected to be … the complete faculty member – simultaneously productive in both teaching and research" (p. 27). Constantly juggling work responsibilities and family life responsibilities may contribute to a cumulative disadvantage (Bailyn, 2011; Grant and Elizabeth, 2015). Literature strongly indicates that academic parenting struggles can be more significant for mothers than for fathers for a variety of reasons, including practical ones such as pregnancy and maternity leave, but also due to persistent ideas about the caretaking of young children as being a predominantly feminine concern (Fairweather, 2002).

Rosewell (2021) argues that research about the experiences of fathers in the academy continues to lag behind that of mothers; however, it is important to recognize the challenges and barriers faced by all in academia. Academic fathers are unlikely to have their commitment to work questioned in ways that mothers might experience; however, academic parenting appears to present as a barrier to what is referred to as the 'ideal worker norm' where there is an expectation of total dedication to the employer. The "bias against active fathering" (Reddick et al., 2011, p. 6) is perceived as 'choosing' to be an active father at the expense of one's career.

However, institutions have expectations of academic fathers who are research productive, and such men can be marginalized if they are unable to fulfil these expectations (Reddick et al., 2011). Since childcare is so deeply associated with females, it can make it challenging for academic fathers to get recognition too (Minnotte, 2020; Nash and Churchill, 2020). Manager bias may make it difficult for fathers to request flexibility, which may have been necessary at times under COVID-19. Like academic mothers, fathers also experience criticism and penalties for family involvement and, at times, have their dedication to academia questioned (Ecklund and Lincoln, 2016; Sallee et al., 2016; Nash and Churchill, 2020).

Academic parenthood and the pandemic: what could be predicted from what is already known?

Given what is already known about academic parenthood and its impact on academic life, it is possible to predict some likely outcomes for academic parents during this time. Literature often indicates that parents have been less productive than their child-free peers during the pandemic as they face the additional challenge of balancing working from home with full-time childcare responsibilities and domestic chores (see, for example, Myers et al., 2020; Staniscuaski et al., 2021). While some research suggests that this trend existed before the pandemic too, other studies contradict this. For example, Krapf et al. (2017) investigated almost 10,000 academic researchers and did not find any correlation between motherhood and reduced research productivity, in general. However, they discovered that becoming a mother before 30 negatively impacts research output. Moreover, Joecks et al.'s (2014) study of 400 business and economics researchers found that female researchers without children were less productive than female researchers with children. So the research around this question is mixed, though more weighted toward an acceptance of the fact that faculty with caring responsibilities have a more challenging time meeting academic expectations.

This has left many academic parents, particularly those with young children, feeling overwhelmed (Fertig, 2020). Given the well-established gender divide in academic parenting (Santos and Cabral-Cardoso, 2008; Schiebinger et al., 2008; Kan et al., 2011; Klein and Myrdal, 2013; Derrick et al., 2019), academic mothers have had to make the most adaptations to their daily lives (see, for example, Andersen et al., 2020; Nash and Churchill, 2020; Minello et al., 2021). These changes to everyday life have affected academic parents' professional and personal lives, including work priorities, increased childcare requirements, and combining the work/home environment, and they are likely to have long-term consequences.

A study of academic mothers during the lockdown in Italy and the United States found that online teaching was their main working priority, as opposed to other aspects of academic work (Minello et al., 2021). This has encompassed modifying lessons for online learning and the teaching time itself, whether synchronous or asynchronous. Female faculty sometimes tend to have more teaching responsibilities (Viglione, 2020), so it is likely that the finding by Minello et al. (2021) is not uncommon, and the sudden shift to online teaching caused by the pandemic may have affected females, and therefore mothers, disproportionately. Some institutions would already have been using learning platforms prior to the pandemic, but unless they were teaching online, this would have been infrequent or hybrid use, which is quite different from the situation which developed during the pandemic. The focus on teaching during the pandemic often resulted from deliberate institutional decisions and academic policies (Minello et al., 2021), although it is generally seen as a less important element in terms of promotion and tenure, where research is prioritized (Kibbe, 2020).

Domestic responsibilities for women have been increased by the pandemic, in both concrete ways such as supervision and support of children's home learning, and in more subtle ways such as the emotional work of dealing with children and other family members' anxieties (e.g., Fertig, 2020; Power, 2020; Minello et al., 2021). With the shutdown of schools and childcare facilities, women have assumed more responsibility for childcare at home than men (Sevilla and Smith, 2020; Viglione, 2020). Other support systems, such as grandparents, have been unavailable in many cases due to inability to travel distances. Juggling these responsibilities simultaneously with working from home has challenged academic mothers.

Research work requires time, silence, concentration, and inspiration, but these conditions are difficult to find where the space for the academic is not separated from the family, making the

segregation of the roles of parent and academic more challenging (Nash and Churchill, 2020). Indeed, for most academic mothers, the home represents yet another workplace (Hochschild, 1989).

In a study on productivity among academics during the first 2 months of the COVID-19 lockdown in the U.S., faculty with 0–5 year-old children reported significantly fewer working hours compared to all other groups (these were – no children, children in other age ranges). They also completed significantly less peer review work and submitted fewer articles as first author (Krukowski et al., 2021). Fertig (2020) explains that "while drops in productivity during COVID-19 are gendered, maintaining research productivity in absence of childcare has been untenable for all caregivers" (p. 331). There is already empirical evidence demonstrating parents (and women, in particular) being less 'research productive' than men during the pandemic, and there are signs of this disparity across academic disciplines. Women are publishing less than men compared to the same time period in 2019 (Andersen et al., 2020; Oleschuk, 2020; Ribarovska et al., 2021), and female first authorship is also less visible in emerging COVID-19-related literature (Amano-Patiño et al., 2020). A Brazilian study that took place around the same time with 3,345 participants found that parenthood had a significant impact on manuscript submissions, with more childless peers submitting manuscripts than those with children, for both women and men (Staniscuaski et al., 2021). Similarly, a U.S. study (Krukowski et al., 2021) found that female academics' first- and co-authored article submissions decreased during the pandemic quite significantly. This echoes other findings of reduced numbers of manuscript submissions authored by women during the pandemic, especially where women are the first authors (Andersen et al., 2020; Minello, 2020; Viglione, 2020). We note that other studies have shown gender disparities in publishing or general research productivity prior to the pandemic too (e.g., Mueller et al., 2017), but this is likely to have increased during the pandemic, according to the studies mentioned previously. Where academic parents, specifically, were studied, the age of their children was also associated with productivity; there was a negative association between women with at least one child aged between 1 and 6 years old and the submission of manuscripts (Staniscuaski et al., 2021). However, other academics have suggested that some 'silver linings' of the pandemic have been the ability to access research conferences more easily since they are held virtually (Nash and Churchill, 2020), compared to previous situations. This is important, aswWomen are known to often forego networking and research dissemination opportunities that research conferences provide due to childcare considerations and concerns (Dickson, 2019).

These studies into productivity largely reflect research data collected during the first few months of the pandemic. At that time, the pandemic was not predicted to last as long as it has, and people (including academic parents), were doing what they needed to survive, perhaps assuming it was a short-term disruption to their lives. As the pandemic continued, divisions between parents and non-parents may have continued to be exacerbated.

Parents' experiences during COVID-19 in the Gulf region

Parents in the Arab Gulf region, as was the case with parents internationally (e.g., Brown et al., 2020; Cluver et al., 2020), have experienced major challenges amidst the outbreak of COVID-19 and the enforcement of a series of preventive measures. Coinciding with the shift to remote work, quarantine, and social distancing protective measures, the mode of learning in the Gulf region countries switched to online and, at times, to hybrid learning between March 2020 to October 2021. With education being transferred from schools to homes, parents became tasked with supporting their children through their remote learning experiences. A recurring theme in Said et al.'s (2021) study reflected gender differences in domestic and other duties, as well as in attending to the educational needs of children during COVID-19. Their examination of the gender differences was carried out in the United Arab Emirates (UAE), and the disproportionate responsibility placed on mothers as the primary caretakers was consistent amongst participants from different cultural backgrounds. Additional motherly duties expected of mothers included those that pertain to learning from home such as printing resources, setting up timetables, following up on children's work throughout the school day, and ensuring their children's well-being during remote study (Said et al., 2021). The burden was heightened due to accompanying circumstances such as work commitments, social distancing, and increased concern for family and loved ones (Saddik et al., 2021). Consequently, academic mothers in the UAE may have shouldered a heavier burden than childless academics and perhaps academic fathers.

In the UAE, moderate to severe anxiety and worry in working females were reported in association with COVID-19 (Saddik et al., 2021). Working mothers spoke of multiple mental health concerns and pressures of time management that negatively affected their work (Said et al., 2021). However, to our knowledge, only two studies have so far investigated the status and experiences of the academic community in a country in the Gulf region. In Kuwait, depression was reported among university students during the pandemic, reportedly with higher incidence rates among females compared to males (Alsairafi et al., 2021). In Saudi Arabia, the academic community reported experiencing acute mental health disorders including anxiety, depression, and insomnia constantly or occasionally (Alfawaz et al., 2021). A detailed picture of the experiences of UAE academics during the current pandemic is as yet missing.

Study purpose

The overarching purpose of this study was to investigate how the working lives of academic parents living in the UAE were affected during the COVID-19 pandemic. Specific aims were to explore the changes to their working patterns, daily roles, and responsibilities, and how this impacted their work and ability to manage work.

Research questions

1. In what ways have academic parents been affected by the COVID-19 pandemic in their domestic spheres (e.g., additional responsibilities, changes to working environment, etc.)?
2. How, if at all, have academic parents' working lives and productivity been affected by these changes to their working environment, including levels of support (e.g., institutionally)?
3. What differences, if any, are observed between female and male academics for the aspects named in RQ 2?

Methodology

The research study utilized a mixed-methods design to benefit from both quantitative and qualitative features. Specifically, having more respondents answer closed-ended questions permits more objective and generalizable conclusions, yet having the human experience expressed through the subjects' own words allows access to in-depth information to formulate a better understanding of the phenomenon. The research team utilized the literature discussed earlier to self-develop the survey questionnaire. The researchers could not locate appropriate pre-developed tools to adapt, likely due to the UAE's unique contextual nuances and the pandemic being a relatively recent occurrence with limited publications on the subject at the time of instrument creation.

A survey questionnaire (see Supplementary Appendix) containing 39 questions was produced that included 15 demographic questions relating to gender, nationality, the number and ages of their children, marital status, use of domestic help, etc. The remaining survey questions investigated respondents' perceptions of how the COVID-19 pandemic affected their work-life balance and work productivity, and their suggestions to help working academic parents alleviate some of the challenges faced. We defined research productivity in the survey items as involvement in the following facets: academic reading, research proposal writing, grant writing, research data collection, manuscript preparation and submission, publication, and research dissemination (e.g., through conferences). The survey mostly contained closed-ended questions (e.g., multiple choice, Likert scale, etc.). However, three open-ended responses were also asked, including how the pandemic affected aspects of home and work life, what institutions could do better to support their faculty during the pandemic, and ways in which life had become easier due to the changes brought on by the pandemic.

Each item, and construct within which the item was positioned, was carefully discussed by the researching team and debated for its relevance and validity. Since we are a team of seven experienced faculty members from across six different UAE institutions, we had strong contextual knowledge within which to base our discussions and to decide upon items to include or exclude in the survey questionnaire. We also carefully assembled the constructs based on key themes arising from the body of research literature which exists on structural and practical barriers faced by academic parents both prior to, and (according to research which was beginning to emerge at the time of writing) during the pandemic. These themes include practical support structures, children's home learning situations, academic parents' home working environments, family/spousal/paid help/ institutional support, the benefits of interactions with students and colleagues, research and teaching support, work-home boundaries and work-life balance.

We piloted the survey questionnaire with a small group of faculty parent colleagues and made adjustments to survey items based on their feedback.

Even though instruction in tertiary educational institutions in the UAE is predominantly in English, respondents could take the survey in English or Arabic. This provision was for Arabic faculty members who might have preferred to respond to the survey using their mother tongue. To ensure correct translation, the English survey was translated by a bilingual Research Assistant and then back-translated by Arabic-speaking research team members. Using purposive sampling, the survey was sent to faculty by the Research Office or equivalent at eight tertiary institutions in the UAE after gaining IRB approval at each institution since reciprocal IRB arrangements do not exist in the UAE. The data collection period was from approximately March to June 2021. Our survey response rate was close to 30%, a fairly typical response rate for online survey questionnaires (Nulty, 2008).

Research participants

The target population for this research study was full-time academics working in private or public higher education institutions in the UAE who were parents of at least one child under 18 years old living full-time at home with them during the COVID-19 pandemic. The research sample consisted of 93 academics, 61% female and 39% male, with 82% of the survey respondents being expatriates and 18% UAE nationals. Of the 93 faculty, just over half reported holding an academic administrative role in addition to their faculty role. Eighty-eight percent of the participants had a spouse, but just 56% of them reported having childcare assistance from their spouse. While 62% of the respondents employed domestic help for household chores, only 35% hired childcare. Forty-one percent reported that provision of care for children was undertaken predominantly by the faculty parent themselves, while other care options included: spouses (33%), nannies (21%), and extended families (5%).

Data analysis

The quantitative data were first analyzed descriptively for percentages, means, frequency, and standard deviation. We also explored statistically significant relationships between certain variables, such as the provision of a private closed space to work at home, and outcomes such as the level of challenge in teaching and research productivity in relation to the research questions. Finally, ordered logit regression analyses were carried out for these associations. Inferential statistical tests informed whether significant differences existed between academic parents' responses, where a variable was being explored, and whether there were significant differences in participant responses pre- and post-pandemic, among other factors. The open-ended questions were analyzed through a phenomenological lens to create themes and sub-themes, primarily based on the conceptual framework whereby information was coded and grouped.

Research ethics

The risk to participants of responding to the anonymous online survey was deemed minimal. However, because of the possible instability, increased stress, and trauma experienced by individuals due to the pandemic, the research team was aware that some respondents might encounter psychological vulnerabilities while completing the survey. The researchers tried to mitigate possible stressors by carefully reviewing the items for appropriacy and sensitivity with multiple reviewers and reminding participants that

completing the survey was voluntary, so they could stop at any time or skip questions that they did not wish to answer. Another issue was that participating in research takes time that many busy academic parents do not have in excess; therefore, the researchers ensured that the survey could be finished in approximately 15 min through trial runs. Finally, our online data collection method through Qualtrics™ maintained anonymity since the data were collected in one centralized database without email or IP addresses.

Findings

This section reports the results of the responses gathered using the survey instrument. Data on how participants were affected by the pandemic, information about their physical workspaces, number of children, and research productivity are reported here.

Ways COVID-19 impacted academic parents' domestic spheres

More than one-third of the participants (34%) had worked entirely at home since the onset of the pandemic in March 2020, with the remainder experiencing a mixture of home and on-campus work, which had varied over the course of the pandemic. A relatively large proportion of the participants (42%) said that their child or children's school learning situation had been entirely at home throughout the pandemic, with the remainder having children who were educated in varying models of home and school. The participants were asked if they had been personally affected by illness due to COVID-19, and over one-third (37%) stated that either they or their immediate family had had the virus. In addition, slightly less than half (48%) of the faculty had been affected due to issues such as close contact with a positive case and needing to quarantine either because of this or travel.

Support from others in looking after children had varied as a result of the pandemic, with 64% of participants experiencing greater levels of support from their spouses, presumably due to their increased physical presence in the home. A large proportion (82%) of the academic parent participants agreed or strongly agreed that their domestic responsibilities in relation to their children had increased. Close to three-quarters of the sample agreed or strongly agreed that involvement with helping and supervising children's schoolwork and domestic responsibilities other than in connection with children had increased.

Ways COVID-19 impacted academic parents' working lives and productivity

Table 1 presents the levels of ease or difficulty with which academic parents experienced academic life during the pandemic compared to before.

Overall, the responses indicated that most aspects of academic life had become more challenging since the onset of the pandemic. Predictably, aspects that regularly occurred in a face-to-face context (such as engagement in campus events, interacting with colleagues informally, working with colleagues, and carrying out community service) became more difficult. The spontaneous nature of these interactions and subsequent intellectual stimulations was a theme of the qualitative responses too, as this response shows:

TABLE 1 Levels of comparative ease of dealing with aspects of academic life during the pandemic (n=93).

	Easier	Same	More difficult
Preparing for classes	33.3%	32.3%	34.4%
Teaching classes	29.0%	11.8%	59.2%
Finding quiet time for tasks such as reading	24.7%	17.2%	58.1%
Carrying out service to your institution	21.7%	32.6%	45.7%
Carrying out service to your community	17.2%	22.6%	60.2%
Carrying out research	23.9%	22.8%	53.3%
Working with colleagues	18.5%	20.7%	60.9%
Interacting with colleagues informally	12.9%	16.1%	71.0%
Ability to support students effectively	25.8%	22.6%	51.6%
Interacting with students informally	20.4%	20.4%	59.2%
Engagement in campus events	10.8%	10.8%	78.4%
Undertaking professional development	37.6%	22.6%	39.8%

> *I miss being on campus and being around colleagues to discuss research-related stuff.*

This sense of professional isolation extended to relationships between teachers and students. Another qualitative response exemplifies how the participant felt about not being able to connect face-to-face with their students:

> *It has been much more difficult to connect with and understand the needs of students when the only interaction is online, and students never turn on their cameras. Online teaching has left me feeling totally disconnected from them and that has caused stress, knowing that I am not able to address their needs as well.*

Notably, though, around a third of the participants reported finding preparing for classes easier, while a similar proportion of the sample found that class preparation had become more difficult. These findings are corroborated by some of the qualitative data responses, where participants pointed out their preference for remote teaching due to the extra family time it afforded, flexibility, and gain of time spent previously commuting, e.g.,

> *Working remotely may be much better than working in person. There are tasks that can be done virtually without the need to come to campus.*

> *I think online learning is great and should continue to be an option in the future along with remote work for parents, especially of very young children.*

One mother spoke positively about the additional time which working from home had provided to set up her child and herself for the day's online schooling:

> *I got extra time at morning as a mother to take care of my kid and prepare her and myself for the online classes.*

Other parents also enjoyed the extra time at home with their families which the situation of working from home, as well as a reduction in activities in general, created, as these excerpts show:

> *Extra-curricular activities were all canceled so I spent no time driving my daughter to extra classes and waiting for her.*

> *Not having to rush in the mornings – travel time to school and office no longer a factor so kids get additional 'lie in' time not just at weekends.*

Other respondents were less positive about their online experiences. They felt that the responsibility of doing this while managing home responsibilities had created stress and often left them feeling ill-equipped to teach remotely due to "exhaustion and the lack of sufficient resources." Some academic parents articulated the sense of a "loss of work and home time balance due to the pandemic" and struggled to maintain clear delineations and boundaries between work and home, e.g.,

> *Because we spend most of the day in front of the screen, there is some kind of overlap between personal, family and professional life.*

The omnipresence of domestic help in the UAE, as in most Gulf countries, and the support in the home that this provides many academic parents was a theme in some qualitative responses. Two examples are provided here:

> *lt helps so much to have a nanny. The nanny culture and domestic help culture has helped the UAE a lot during the pandemic.*

> *Yes, I am not rushing out the door in the morning and am able to spend more time with my son. I am also better able to see any issues that arise with his nanny.*

We conducted statistical analyses of the items in Table 1 in order to compare the levels of ease or difficulty with which academic parents (males and females) experienced academic life during the pandemic compared to before. We used ordered logit regression to compare these responses based on gender, but found no statistically significant differences between males and females in all aspects of academic life presented in Table 1 (see Table 2 for this analysis).

Physical workspace

Table 3 shows the participants' physical working space provision in the home. This was important as we hypothesized that this might have a direct bearing on the likelihood of being able to work effectively in the home, which is used in analysis later.

Since access to a private, closed workspace was an important consideration for participants, we used ordered logit regression to compare these responses from Table 3 to those in Table 1. However, we found no statistically significant differences between these two groups of academic parents (those with private closed space and those without) in all aspects of academic life presented in Table 1.

We hypothesized that the relative proximity of children while the faculty parents were working at home might be important, given the possibility of interruptions to work. Over half of the participants had children present or near them while working, and almost 70% reported having been distracted or interrupted as a result, a rather startling statistic. Around 12% of the participants said they were responsible for their children while they were teaching their online lessons, while approximately one-third said their spouses were also accountable for the children and 31% reported that a helper, nanny, or family member, was also responsible (these options were not limited to one only, and participants could choose as many options as applied).

Number of children

We considered that the number of children faculty parents have living with them at home might influence the degree of challenge,

TABLE 2 Comparing the academic experiences of faculty parents based on gender (n=93).

Aspects of academic life	*B*	SE	Wald	df	Value of *p*	1/exp(B)
Preparing for classes	−0.06	0.39	0.03	1	0.872	1.07
Teaching classes	−0.19	0.42	0.21	1	0.647	1.21
Finding quiet time for tasks such as reading and preparing for lessons	−0.21	0.42	0.25	1	0.616	1.23
Carrying out service to your institution	−0.14	0.40	0.13	1	0.723	1.15
Carrying out service to your community	0.23	0.42	0.30	1	0.582	0.79
Carrying out research	−0.28	0.41	0.47	1	0.495	1.33
Working with colleagues	−0.66	0.45	2.19	1	0.139	1.93
Interacting with colleagues informally	0.00	0.46	0.00	1	1.000	1.00
Ability to support students effectively	−0.53	0.41	1.67	1	0.197	1.70
Interacting with students informally	−0.57	0.43	1.75	1	0.186	1.77
Engagement in campus events	0.01	0.51	0.00	1	0.983	0.99
Undertaking professional development	−0.72	0.40	3.18	1	0.075	2.05

Female was set as the reference category.

musing that parents with only one or two children might experience the challenges of academic life as more manageable than those with three or more. A relatively large proportion of participants have one or two children living with them, while 33% have three or more.

Further analyses (ordered logit regression) were carried out to investigate the possible effect of the number of children faculty parents have living with them (one or two, three or more) on each aspect of faculty life noted in Table 1. The assumption of homogeneity of proportional odds was first assessed. For each aspect of academic life, the value of p associated with the −2 log-likelihood test was greater than 0.05, which indicated homogeneity of regression coefficient across the three response categories (easier, same, more difficult). The results presented in Table 4 showed there were statistically significant differences between faculty parents with three or more children and those with one or two children in three aspects of academic life, including preparing for classes, teaching classes, and interacting with students informally. The odds of faculty parents with three or more children considering preparing for classes to be easy was 2.64 times that of faculty parents with one or two children, a statistically significant effect, Wald $\chi^2(1) = 5.29$, $p = 0.021$. Regarding the teaching classes aspect, the ordered logit regression model was also statistically significant, Wald $\chi^2(1) = 4.48$, $p = 0.034$, the odds of faculty parents with three or more children considering teaching classes to be easy was 2.53 times that of faculty parents with one or two children. Similarly, the odds of faculty parents with three or more children considering interacting with students informally to be easy was three times that of faculty parents with one or two children, a statistically significant effect, Wald $\chi^2(1) = 6.42$, $p = 0.011$.

TABLE 3 Participants' physical working environment in the home (n=93).

	Percent
Dedicated private, closed space	52.8
Dedicated space which is not private nor closed	33.7
No dedicated workspace	13.5

Research productivity

Faculty were asked to reflect on the relative priority they placed upon research compared to teaching. The percentages of the sample who prioritized research over teaching prior to the pandemic were approximately similar (10 before and 12% during). However, those who prioritized teaching over research had increased compared with before the pandemic (49% before and 60% during). Table 5 shows how the pandemic affected the participants' perceptions of aspects related to research productivity.

Hypothesizing that those who had private closed workspaces to work at home might find these aspects of academic life less challenging, we used ordered logit regression to analyze differences between these groups of parents, but there were no statistically significant differences between the two groups ($p < 0.05$). Further ordered logit regression were carried out to investigate the possible effect of faculty having children beside them (yes/sometimes, no) on each aspect of research productivity noted in Table 5. It was found that there was a statistically significant difference between these groups of parents in one particular area of research work – academic reading, Wald $\chi^2(1) = 5.80$, $p = 0.016$, the odds of faculty parents who do not have their children beside them when teaching online from home considering academic reading to be more productive was 2.8 times that of faculty parents who did have their children beside them.

We then analyzed the research productivity outlined in Table 5 to compare faculty parents with one or two children living with them and those with three or more, using ordered logit regression, and found no statistically significant differences between these two groups of parents in aspects of research productivity. In other words, research productivity did not appear to be linked to the number of children living at home with faculty.

TABLE 4 Comparing the academic experiences of faculty parents based on the number of children they have living with them at home (n=93).

Aspects of academic life	n		M		SD		t	df	p
	One or two	Three or more	One or two	Three or more	One or two	Three or more			t-test is significant (p<0.05)
Preparing for classes	61	30	1.85	2.27	0.79	0.83	−2.31	89	0.023
Teaching classes	61	30	1.57	2.00	0.85	0.95	−2.17	89	0.033
Finding quiet time for tasks such as reading and preparing for lessons	61	30	1.64	1.77	0.84	0.90	−0.67	89	0.507
Carrying out service to your institution	61	29	1.70	1.93	0.76	0.84	−1.27	88	0.206
Carrying out service to your community	61	30	1.49	1.77	0.70	0.90	−1.60	89	0.112
Carrying out research	61	29	1.66	1.86	0.79	0.92	−1.10	88	0.276
Working with colleagues	61	29	1.51	1.76	0.79	0.79	−1.41	88	0.162
Interacting with colleagues informally	61	30	1.33	1.63	0.63	0.85	−1.94	89	0.056
Ability to support students effectively	61	30	1.67	1.93	0.83	0.87	−1.39	89	0.168
Interacting with students informally	61	30	1.48	1.93	0.74	0.87	−2.61	89	0.011
Engagement in campus events	61	30	1.26	1.47	0.58	0.82	−1.38	89	0.171
Undertaking professional development	61	30	1.93	2.13	0.89	0.86	−1.01	89	0.314

More than half of respondents (52%) stated that since the pandemic began, support with their research from their institution had decreased. This is an important figure, and we can use this as a basis to review the qualitative responses. While grant funding by internal and external sources may have been curtailed during the pandemic for some, one participant commenting on the research conflict explained that even though she actually had greater access to grant funding, the challenges she was facing in her teaching meant that she was not in a position to avail them:

> *Research grant options at my institutions have increased. However, I am teaching four different courses in one semester to students who open the computer and are not really there.*

Support with one's teaching was mostly articulated through practical offerings of IT help with technical difficulties, providing teaching and learning platforms, making professional development courses about online teaching available, and informal professional development support. For those participants who voiced experiences of not feeling supported by their institutions, these were often due to workload – increased class sizes and consequently increased marking, etc., or the lack of support from an individual line manager. Participants expressed frustration about the perceived lack of understanding their management had about the challenges of teaching online, as these responses show:

> *Top management thinks that teaching online is easy. Most of them do not teach even one class, so they do not know what it is like.*

TABLE 5 Participants' perceptions of changes to aspects of research productivity because of the pandemic (n=92).

	Less productive	Unchanged	More productive
Academic reading	51.9%	29.1%	19.0%
Research Proposal Writing	52.2%	23.9%	23.9%
Grant securing	58.1%	30.6%	11.3%
Research data collection	53.6%	26.1%	20.3%
Manuscript preparation and submission	47.1%	28.6%	24.3%
Publication	47.7%	30.8%	21.5%
Research dissemination (through conference presentation, seminars etc.)	59.7%	22.2%	18.1%

Comparing female and male academics' reported research productivity

Table 6 presents academic parents' (males and females) perceptions of changes to aspects of research productivity because of the pandemic. No statistically significant differences between males and females were found in all aspects of research productivity presented in Table 5.

Faculty health and well-being

Table 7 presents the quantitative findings of participants' sense of their health, well-being and work-home balance, and generally indicates that all areas have been negatively impacted since the onset of the pandemic.

Echoing this pattern in the quantitative data, one participant responded:

> *During the lockdown/school from home period, I found my responsibilities in all areas growing significantly, often to the point of overload and at the expense of my health.*

Some also expressed concern that fears over safety, e.g., the sufficiency of COVID protocols during the pandemic, were not taken seriously enough by institutions, with mixed experiences of support for this and for student and faculty well-being, e.g.,

> *Focus should be on mental wellbeing instead of academics during the pandemic. This is an issue that is not being addressed in primary nor tertiary education levels.*

Discussion and implications

While academic parents were dealing with a sudden shift in teaching delivery mode and being away from their classrooms, offices and resources, they were also faced with supporting children undergoing similar changes. Although many academic parents in the UAE employed help for housework, some specifically for childcare, 82% of participants agreed or strongly agreed that they had experienced increased domestic responsibilities. Almost two-thirds of participants also reported greater levels of support for looking after children from spouses, yet three-quarters of participants still agreed or strongly agreed that they were more involved with helping or supervising their children. This could be due to other childcare provisions including extended family being no longer available or the academic parent having an increased presence in the home leading to more involvement in domestic tasks, even if they may have had a finely tuned routine and division of labor prior to the pandemic. This is supported by other studies, which showed that academics (females particularly) at home during the pandemic had to take on many tasks that had not previously been their responsibility (Yildirim and Eslen-Ziya, 2021). Over one-third of respondents reported being personally affected by illness, with either themselves or their immediate family contracting the COVID-19 virus, giving the research team a useful insight into the situation faced by participants. Any illness for oneself or a family member is likely to impact the ability to work negatively,

TABLE 6 Comparing academic parents' perceptions of changes to aspects of research productivity because of the pandemic based on gender (n=92).

Aspects of academic life	*B*	SE	Wald	df	Value of *p*	1/exp(B)
Academic reading	0.06	0.41	0.02	1	0.884	0.94
Research proposal writing	0.55	0.40	1.82	1	0.177	0.58
Grant securing	0.09	0.40	0.05	1	0.821	0.91
Research data collection	−0.16	0.40	0.15	1	0.699	1.17
Manuscript preparation and submission	0.55	0.40	1.82	1	0.177	0.58
Publication	0.22	0.40	0.30	1	0.587	0.80
Research dissemination (through conference presentation, seminars etc.)	0.62	0.41	2.25	1	0.134	0.54

Female was set as the reference category.

but an illness that is relatively new and without a known cure at the time of data collection is likely to cause additional mental and emotional burdens.

Given changes to working life, the additional stress of supporting children through the pandemic and online schooling, and dealing with the virus itself, it is no surprise that aspects of academic life became more challenging. More than half of the participants reported that teaching their classes, finding quiet time for tasks such as reading and preparing, engaging in campus events and community service, and interacting informally with colleagues had become more difficult for them. The faculty response to the survey question regarding their well-being indicated that a high proportion had felt this aspect of their lives had suffered. Perhaps this was partly related to missing the human interactions afforded on campus and the stimulation of colleagues' conversations. Possibly these interactions and conversations release stress, providing a sense of normalization which was then missing for the participants. A significant number (58.1%) of participants also reported facing more challenges in interacting with students informally, and the stress caused by feeling disconnected from students was a common theme in the qualitative responses. A large proportion participants also reported a lack of support from institutions in terms of both research and academic tasks – this is something which institutions would do well to analyze and identify key areas of support lacking, since we can see from the qualitative responses that it adversely affected many participants and in some cases caused a direct chasm between academics and administration. While we did not specifically ask participants about their perceptions of institutional support in relation to their health, well-being, and work-home balance, given that at least 60% of respondents reported that these aspects had deteriorated during the onset of the pandemic, it would be interesting to investigate what, if anything, institutions had done in this regard, and how it was perceived by faculty, particularly parents. Interestingly, no significant differences were found between the perceptions which female and male parents had of difficulty or ease with life during the pandemic compared to before. This was perhaps surprising, given what is known about the often profound differences between female and male academics' experiences (see for example Mason et al., 2013; Sallee et al., 2016), and as discussed earlier, the impact that these gendered disparities often have on research productivity. One possible explanation could be that the common practice of having paid help to support with household tasks, chores, childcare in the UAE could have mitigated some of the stress and workload differences between the genders. It is also possible that a larger sample would have shown some disparity, but for this group we did not observe this.

Academic parents having a dedicated, closed, private workspace was hypothesized to support the effective completion of academic tasks; however, our analysis showed no statistically significant differences between parents who did or did not have such spaces. This may indicate that simply having access to such a private workspace did not mean that the faculty was actually able to avail the benefits of that space, perhaps being so taken up by other tasks such as supervision of schoolwork and increased domestic responsibilities. Alternatively, interruptions from their children being so prevalent might have meant that they were not able to take advantage of it in any case.

While the percentages of faculty prioritizing research productivity over teaching did not substantially change, their prioritizing teaching over research during the pandemic did. Presumably, this was in part as a result of the changed teaching mode and having to prepare resources and build courses on unfamiliar platforms, for example. This type of 'urgent' task tends to mean that research can take a 'back seat' in the list of a busy academic's priorities but doing so means that research productivity would likely decrease. Indeed, previous research supports our analysis (see, for example, Fertig, 2020; Myers et al., 2020; Staniscuaski et al., 2021) in that more than half of the participants perceived that they had become less productive in research (using various indicators such as writing proposals, securing grants, collecting data, preparing, submitting, and disseminating research). We were also interested in finding out whether the challenges to research productivity were exacerbated by faculty having stated that a child or children were seated close beside them while they worked. We were somewhat surprised to discover that in all but one of the tasks, academic reading, no statistically significant difference between the groups was found. This could be related to academic parents overcompensating by 'working overtime' to meet their professional research responsibilities even during trying times. The majority reported that the pandemic negatively impacted their health, well-being, and work-home balance. We did not specifically ask faculty to state their academic rank, and it is possible that there would have been differences in research productivity (and impact on one's academic work in general) between these groups. We suggest that future studies with

TABLE 7 Participants' health, well-being, work-home balance (n=90).

	Less/ decreased/ diminished	Unchanged	More/ improved/ increased
Personal health and well-being	68.9%	17.8%	13.3%
Ability to maintain boundaries between work and home	70.0%	20.0%	10.0%
Work-life balance	66.7%	17.8%	15.5%

a larger sample size could include this question in their survey questionnaire since different ranks may have disparate expectations of research productivity.

Nonetheless, around half of all participants reported they were less prolific in all aspects of research productivity due to the pandemic. Given that the effects of the pandemic are still ongoing at the time of writing, these findings are likely not constrained to the period under study. Furthermore, given that the majority of our survey participants were female, this could have significant consequences for future promotional prospects and pathways for female academics, echoing previous findings (see, for example, Alon et al., 2020; Nash and Churchill, 2020; Wenham et al., 2020). With this recent decrease in scholarly visibility, women are less likely to be invited to speak at conferences or to serve in other academic roles, such as manuscript and grant reviews. Since women already face bias in these areas (Helmer et al., 2017; Witteman et al., 2019), these combined factors will lead to a quantifiable decline in publications and grant submissions from women. As these are the currency of academia (Kibbe, 2020), the career trajectories of academic mothers may be adversely and disproportionately affected by the effects of the pandemic (Alon et al., 2020; Wenham et al., 2020) and may have promotional pathways derailed or postponed as a result. Controversially, Nash and Churchill (2020) have argued that "COVID-19 provides another context in which universities have evaded their responsibility to ensure women's full participation in the labor force" (p. 1). There have been some calls for institutions to attempt to level the playing field by altering promotional pathways, changing grant calls, extending 'tenure' periods, etc. (Oleschuk, 2020). It remains to be seen how higher education institutes in the UAE respond in support of academic parents.

There was also no statistically significant difference between the number of children living with academic parents in how these challenges were perceived. Possible reasons for this could be that in larger families, older children might already be accustomed to looking after younger children and, in particular, helping them with schoolwork, thus compensating for more children in a house where a faculty member is attempting to work. There may also be well-established routines within a large household, dating from before the pandemic and partly established by the schools with the online lesson schedule. Larger families may also be more likely to have more domestic help, like a live-in nanny. For all faculty members, it is possible that the presence of children actually mitigated remote working troubles as they may have desired to provide good role modeling during working hours (no leisurely surfing!).

Conclusion

Our study has highlighted the juggling act of academic parenting and has shown that the pandemic has created situations of both challenge and ease for those in the dual role of an academic and a parent. While the survey data suggested that academic parents felt that some aspects of their research productivity were reduced during the pandemic, the data also indicated no statistically significant impact on academic parents' perceived ability to interact with students or colleagues at their institutions while working from home. Based on these findings, it is imperative for institutions to take into account the ability of faculty to fulfil their professional obligations from home, especially post-pandemic, since their children will most likely be in school or daycare. Therefore, moving into a post-pandemic era, many academic parents would like flexible work conditions to remain at their institutions, predominantly supporting a hybrid model that combines the advantages of working from home and on campus. While flexible working options can lead to greater equality, it is vital to ensure that they do not lead to more ingrained traditional gender roles in the family or workplace whereby the expectations are that men use the time to enhance their work performance (Lott and Chung, 2016) and women take on additional family responsibilities (Hilbrecht et al., 2008). However, with justice and professionalism in mind, flexible work options may afford academic parents the freedom they need to balance their work and home life better while perhaps reducing their stress levels and improving their happiness and well-being, thus, possibly leading to increased work productivity and satisfaction, enhanced academic reviews and improved equity. It is our hope that the study findings can support work to reduce the burden on female academics as institutions work to strengthen attempts for equity and improvement in all aspects of faculty life, including evaluations for promotion.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Emirates College for Advanced Education IRB. The patients/participants provided their written informed consent to participate in this study.

Author contributions

MD as study PI was responsible for developing the study concept and research design, and contributed to and oversaw all sections of this manuscript. JM contributed to the literature review, wrote the methodology section, contributed to the discussion section and was responsible for final proof-reading and revisions. RA carried out the

data analysis and contributed to the findings section. MM contributed to both literature review and discussion section of the manuscript. MA, DE, and PT contributed to the literature review. All authors were involved in planning the study methodology and development of the data collection tool.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer PRC declared a shared affiliation with the author JM to the handling editor at the time of review.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.952472/full#supplementary-material

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EdTech in humanitarian contexts: whose evidence base?

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This study reports on the design and development of a methodological toolbox prototype for evaluating EdTech deployed in the contexts of fragility and crisis. The project adopted a bottom-up approach: training EdTech users in participatory action research approaches was followed by a comprehensive mapping of problems in the Azraq refugee camp that might be addressed through the chosen EdTech installed in a local Makerspace. Students as researchers used a developmental evaluation approach to deepen their understanding of evaluation as a concept and as a process and proceeded to match the results of their Azraq camp problem-tree analysis with evaluation questions related to the EdTech tools available in the Makerspace. The study concludes with a proposed methodological toolbox prototype, a set of approaches and processes that include research capacity building in fragile contexts, and user-led evaluation that emphasizes the notion of evaluation as a learning process driven by those designed to benefit from EdTech in fragile contexts.

KEYWORDS

EdTech in humanitarian contexts, developmental evaluation, accountability to affected populations, localization, PAR

Background

"EdTech is a tool that needs to be constructed with principles of pedagogy in mind" (Tauson and Stannard, 2018, p. 8). While early responses to the challenges imposed by the COVID-19 pandemic focused on technology, attention shifted quickly to pedagogy and engagement as the key determinants of keeping the learning going (Vegas, 2020). IRC (2022) defines EdTech as the application of a tool that combines hardware, software, educational theory, and practice, which promotes learning. Kucirkova (2022) contends, however, that EdTech and companies have become bigger but not necessarily more educational. According to Hirsh-Pasek et al. (2022), education lags behind digital leaps, which allows technology rather than educators to define what counts as an educational opportunity. IRC (2022) leverages the six Cs first introduced by Hirsh-Pasek et al. (2022) to describe the characteristics that make EdTech truly educational: Collaboration, Communication, Content, Critical Thinking, Creative Innovation, and Confidence. Tauson and Stannard (2018) deplore the extraordinary lack of evaluations and impact studies of EdTech in emergency settings and how challenging it had been to represent the views on EdTech of those living in humanitarian contexts due to the paucity of research carried out in those settings in general, and the complete absence of relevant cost-benefit analyses. The promise of EdTech to produce change at scale in humanitarian and development contexts has not

materialized (Rodriguez-Segura, 2022). Literature reviews of usability studies of EdTech (Lu et al., 2022) make no mention of humanitarian and development contexts and focus more on the ease of use of technologies, rather than on their specific relevance to the context in which they were used. Lu et al. (2022) emphasize that no standard evaluation tool exists for assessing usability with all of the studies included in their meta-analysis employing a study-specific observation or questionnaire protocol. The gap in evaluation approaches for EdTech is therefore not limited to humanitarian and development contexts, although the significant funding gaps in Education in Emergencies (EiE) should have encouraged (Geneva Global Hub for Education in Emergencies, 2022) more systematic analyses of how investments in EdTech in emergencies impact humanitarian contexts and youth in displacement.

Very little of published research in EdTech has been led by researchers living in contexts of forced displacement (Tauson and Stannard, 2018), and the literature offers only occasional mention of participant-led monitoring and evaluation (Davies and Elderfield, 2022). As decolonization has taken root in humanitarian and development contexts, extractive research led by Global North institutions is increasingly and rightly questioned on ethical grounds (Haelewaters et al., 2021). When considering EdTech, there continues to be considerable emphasis on all education initiatives being designed to contribute to meeting national curriculum requirements for primary and secondary school students and ensuring that at higher education levels, students reach the same learning outcomes verified through formal, yet modified assessment procedures. As the COVID-19 pandemic has abated, universities have relaunched, promoting the advantages of online and hybrid learning, while primary and secondary schools have returned to the classroom, with modifications. There are numerous discussions on catch-up strategies to achieve scheduled learning outcomes; some countries, such as Kenya, decided to simply skip an entire school year and had everyone repeat. There continues to be the talk of school reforms, education reforms, and higher education reforms, but only scant inquiry into learning itself, insufficient questioning of education models, or of the delivery channels that are designed to ultimately serve the same purpose as education was designed to serve prior to the pandemic. The focus appears to remain on delivery channels and the corresponding tools to deliver learning and content, without questioning either the learning or the content, or paying close attention to what kind of EdTech and how its deployment affects youth in displacement (UNICEF-Innocenti, 2022). Compilations of how digital technologies accompany youth from learning to earning document promising practices (UNICEF, 2021) but focus more on digital technology in humanitarian and development contexts in general, rather than on EdTech, and do not include clear references on user assessment.

With the entire world as an EiE context during the COVID-19 pandemic, EdTech was seen as key to overcoming the gaps in learning, resulting from schools and universities closing their doors, and the initial response to physical isolation was thus emergency remote teaching. This only exacerbated inequities already present in education systems worldwide, as few countries were able to respond by furnishing their learners with the needed devices, while others, including those living through other types of emergencies, were quick to return to the lowest levels of technology, with educational radio making a major comeback (Muñoz-Najar et al., 2021).

The project we report on in this study was launched prior to the onset of, but implemented during the COVID-19 pandemic and it was conceived for humanitarian contexts from the start. The project output was to design and develop a methodological toolbox for evaluating EdTech deployed in contexts of fragility and crisis and to identify evaluation questions related to the context and location in which EdTech was used with a view to informing policy and practice surrounding EdTech in humanitarian contexts.

Monitoring and evaluation approaches in humanitarian contexts encounter challenges in developing reliable indicators and in meaningfully capturing the important parameters of interventions. ALNAP's *Guide to Evaluating Humanitarian Action* (Buchanan-Smith et al., 2016) lists six challenges to reliably evaluate projects: constrained access to where a project is implemented; lack of data, where data quality is either very poor, irrelevant, unavailable, with no baselines recorded, which is particularly difficult in protracted emergencies; rapid and chaotic responses in the absence of a theory of change whenever the program was implemented rapidly; high staff turnover as projects are often of short duration and key informants are difficult to come by; and data protection, as well as ethical considerations regarding data collection within a do-no-harm framework.

In considering the above, the activities identified to design the EdTech methodological toolbox prototype included the co-design of a participatory, youth-led, research methodology that would be part of an evolving methodological toolbox to assess the potential of EdTech tools in humanitarian contexts. Leveraging the potential of forcibly displaced youth is an integral part of the Grand Bargain's spirit of a coordinated approach to community engagement and participation (IASC, 2017). It emphasizes the inclusion of the most vulnerable and promotes sharing and analyzing data to strengthen decision-making, transparency, and accountability in humanitarian contexts. The Inter-Agency Standing Committee (IASC), the United Nation's humanitarian coordination mechanism, is home to the Grand Bargain, a commitment of currently 66 signatories—donors, UN member states, NGOs, UN agencies, and the Red Cross movement—that originated at the World Humanitarian Summit 2016. Workstream 6 focuses on the Participation Revolution and promotes the inclusion of people receiving aid in making decisions that affect their lives (IASC, n.d.) and defines effective "participation" of people affected by humanitarian crises as "put[ting] the needs and interests of those people at the core of humanitarian decision making, by actively engaging them throughout decision-making processes." This revolution "requires an ongoing dialogue about the design, implementation, and evaluation of humanitarian responses with people, local actors, and communities who are vulnerable or at risk…" (IASC, 2017). Similarly, the Inter-Agency Network for Education in Emergencies Minimum Standards include Community Participation as Standard 1 (INEE, 2010): "Community members participate actively, transparently, and without discrimination in analysis,

planning, design, implementation, monitoring, and evaluation of education responses."

In line with these recommendations and standards, the methodological framework chosen for this research is Participatory Action Research (PAR), which is collaborative in nature and focuses on gathering information that can be used for change on social issues by those who are affected by those issues and encouraged to take a leading role in producing and using knowledge about it (Pain et al., 2012). PAR offers a democratic model of who can produce, own, and use knowledge and is thus greatly adaptable to the contexts in which it is applied.

The implementation context

Designed originally as a project with three implementation sites, Lebanon, Jordan, and Djibouti, the fallout of both political and health emergencies in Lebanon and Djibouti left Jordan as the only remaining project site. This clearly dealt a blow to the ambition of significantly strengthening the evidence base. Having to choose between rescheduling the entire project and continuing the implementation in Jordan's Azraq refugee camp, the authors decided to modify the original terms of reference to adapt to a double emergency as follows: Syrian refugees living in the Azraq camp as an already protracted crisis, coupled with that of the pandemic that exacerbated already existing humanitarian challenges. Expertise gained by one of the authors in other refugee contexts through systematic programming to build social-emotional learning competencies further strengthened the resolve to continue the project in the Azraq camp and to build on a foundation that had been laid through the relevant course and project work over the preceding 18 months. During that period, a new learning hub for tertiary education had been completed in Azraq's Village 3 where two HP Learning Studios had been installed (Global Citizen, 2018) as EdTech solutions.

The Azraq camp in Jordan, nestled in a remote desert plot approximately 100 km east of Amman, opened in 2014 to receive refugees from the Syrian Civil War; its population has remained stable at approximately 40,000, of whom 60% are children, with families living in an estimated 9,000 shelters (UNHCR, 2022). Over 11,000 children are enrolled in formal schooling in 15 camp schools. There are no tertiary education institutions on-site, and only 8% of the total working-age population hold work permits for Jordan, with another 10% employed by UN agencies and NGOs in the camp's incentive-based work scheme as paid volunteers.

Addressing the deliverable of a methodological toolbox prototype to assess the potential of EdTech tools in humanitarian contexts, this project site was chosen based on the prior engagement of refugee students with EdTech within projects related to Makerspace. This was to ensure shared interest/knowledge, opportunities, and relationships, the three parameters identified by the Connected Learning Alliance as key to meaningful and powerful learning, whether digital, blended, or face-to-face (Connected Learning Alliance, 2020).

Azraq refugee camp in Jordan had benefited both from programming on the HP Learning Studios, consisting of a Sprout Pro by HP and including an HP 3D Capture Stage, a business-size printer, a charging cabinet, and 15 laptops tailored to different education levels. Additionally, two editions of a development engineering course offered by Purdue University had been rolled out, followed by the setting up of an engineering projects interest group and an engineering facilitator training course (de Freitas and DeBoer, 2019). The foundation engineering class, *Localized Engineering in Displacement,* was designed to challenge students to apply engineering skills to solve local problems. Purdue's DeBoer Lab leveraged the affordances of the HP Learning Studios, given that the learning outcomes envisaged by the HP Learning Studios and the engineering in displacement course showed considerable overlap. The HP laptops and modeling software (HP Sprout) aligned with the engineering course curriculum. The laptops were versatile and compatible with all the software used to program and visually sketch circuits for microcontroller setups that students used in their prototypes. Students in the Azraq camp had thus learned to collaborate, explore, innovate, and test real solutions, taking advantage of the variety of technologies afforded by the devices of the HP Learning Studio.

Participants in the engineering course had worked on the design of spaces in preparation for their role in shaping the construction of the new Learning Hub in Azraq's Village 3, thus contributing to the design of a common space in their community using insights from observation and interviews. Projects built on the design thinking process were explored in the HP Learning Studio training course and introduced themes of inclusive design, accessibility, and equity. Together, then, the HP Learning Studio approach and that of Localized Engineering in Displacement, both identified and addressed real-world problems; they encouraged participants to work in teams to solve these problems and explore, test, and evaluate multiple possible solutions on their own. In short, the Azraq refugee camp offered the capacity to pursue the development of the methodological toolbox for EdTech assessment.

The methodological EdTech tool(box)—prototype as the main outcome of the project

First, we describe the methodological toolbox in detail (Figure 1), followed by a description of how it was developed, tested, and verified for humanitarian contexts. We then synthesize and discuss the implications of the toolbox for evaluating EdTech solutions for protracted displacement contexts and conclude with recommendations regarding the involvement of forcibly displaced youth in monitoring and evaluation.

BetterEvaluation (2022) approach served as the basic framework for the evaluation process chosen for this project; it sets out the different steps and provides a timeline along which these need to be implemented. The methodological toolbox contains the following: capacity building through training in Participatory Action Research (PAR) as a process, with more specific tools of bottom-up problem-tree analysis facilitated by mind-mapping, qualitative data analysis of reflections (iterative) and outputs (evaluation questions), and an open developmental evaluation approach to selecting evaluation questions and implementing the final evaluation phase as outcomes.

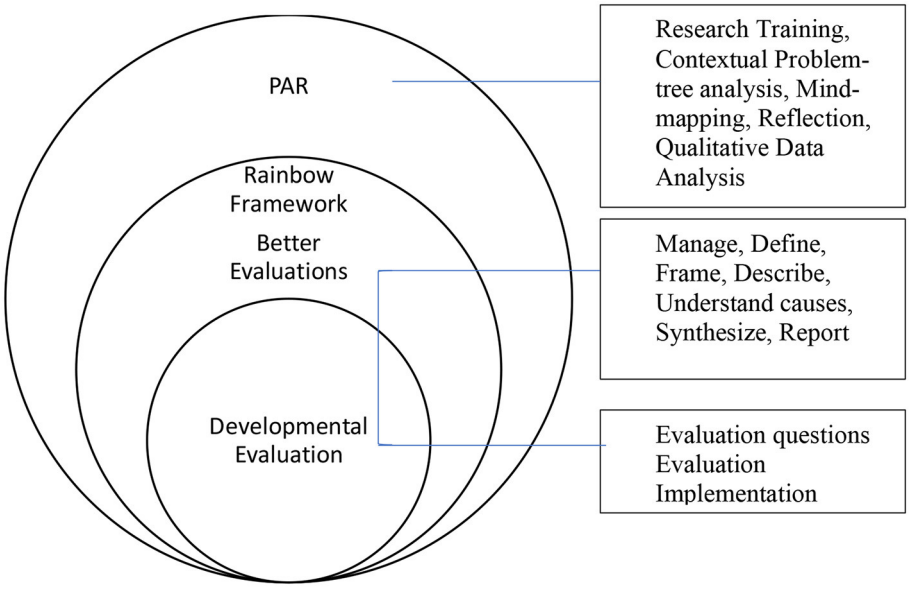

FIGURE 1
The EdTech tool(box)—Prototype.

BetterEvaluation as an overarching framework

The Rainbow Framework (BetterEvaluation, 2022) provides a systematic approach to Monitoring & Evaluation (M&E) in that it organizes the different M&E methods and processes into tasks and task clusters that facilitate application. These task clusters are labeled as follows: Manage, Define, Frame, Describe, Understand Causes, Synthesize, and Report & Support Use. This framework is part of the Global Evaluation Initiative that supports efforts aligned with local needs, goals, and perspectives.

Managing an evaluation involved agreeing on how decisions would be made for each task cluster of the evaluation. This involved understanding and engaging stakeholders, establishing decision-making processes, deciding who will conduct the evaluation for the tool we were to develop, what resources we had available, and how we would secure them, defining ethical and quality standards, documenting the process, developing planning documents for the evaluation system, and building the capacity to assess whether indeed a tool developed using this approach could be used in different complex contexts.

The challenge was defining what was to be evaluated and how it is supposed to work. While the HP Learning Studio itself could have lent itself as the EdTech to be evaluated, its installation had not been linked to any specific outcome. This meant that no assumptions were made *a priori* about what the evaluation tool was to measure or what it would look like, there was no theory of change and hence no traditional logic frame to inform the build phase of the project. It was thus important to identify an evaluation approach, which did not require these traditional M&E components, that was flexible and could be implemented in low-resource environments involving the ultimate users/beneficiaries of EdTech as the drivers of the build phase. They would constantly learn and adapt their developments to new levels of knowledge and understanding of the context in which the tool was built. This led us ultimately to identify the developmental evaluation approach as optimal for the humanitarian contexts in which the tool would be developed and later used.

TABLE 1 Types of evaluation questions (Adapted from BetterEvaluation, 2022).

Appropriateness	To what extent does the program address an identified need? How well does the program align with priorities identified by youth, agencies, and the government?
Effectiveness	To what extent is the program achieving the intended outcomes, in the short, medium, and long term? To what extent is the program producing worthwhile results (outputs, outcomes) and/or meeting each of its objectives?
Efficiency	Do the outcomes of the program represent value for money? To what extent is the relationship between inputs and outputs timely, cost-effective, and up to the expected standards (INEE MS, Sphere)?

Framing the boundaries of the evaluation represented a key task cluster, as it included identification of intended users, deciding on one or all of the evaluation purposes, accountability, knowledge construction, and improvement, specifying the key evaluation questions (Table 1), and eventually also determining what success might look like. This task cluster represented a major component of the methodological toolbox prototype as can be seen from the description below of activities and outputs. Synthesizing data from the evaluation to document the merit of an EdTech and reporting on the findings in ways that are useful to the intended users completed the series of tasks within the BetterEvaluation Framework.

Participatory action research training

As the remit for this project was the development of an evaluation tool(box) for EdTech and as the program within which this project was embedded was a Higher Education in Emergencies program, we wanted to proceed within the framework of a participatory approach and therefore needed to start with training researchers/evaluators in humanitarian contexts where EdTech was to be used and ultimately evaluated. Starting with the skill-building approach ultimately allowed for observing how this empowers forcibly displaced youth, the ultimate beneficiaries of EdTech in the refugee camp, to design a tool that would genuinely evaluate educational technology in a complex and changing environment, such as a humanitarian context. Our choice among evaluation frameworks was guided by our vision of refugee empowerment within the larger localization framework of the 2016 World Humanitarian Summit (IASC, 2017).

Potential researchers were recruited during the *Management* phase of the project. Outreach by one of the engineering course graduates was initiated to recruit participants through purposive sampling in what came to be called the *HP Research Group*, linking the project to the installation of the HP Learning Studio. A total of eight participants joined the project (three female, five male; age range 19–35; all Syrian refugees living in the Azraq refugee camp, Azraq, Jordan), supported by two humanitarian interpreters with a background in engineering and research. All of them had graduated from secondary school, and some were enrolled in formal or non-formal higher education programs offered in the Azraq refugee camp or by local universities. The level of English proficiency was mixed, requiring educational interpreting during the on-site seminars on participatory research and when the group was meeting in the Learning Hub where the HP Learning Studio had been set up. To facilitate communication, a dedicated forum on a messaging app was set up in which the interpreters also participated to ensure sharing of information across the entire group. The messaging forum was active for a total of 288 days (678 messages, 11,645 words, 64 media files made up mostly of project photos, and 35 documents. The analysis was based on the *Chatvisualizer* output).

Participants received detailed printed information and subsequently reviewed it during the first onboarding workshop, regarding the objectives of the project. It was made clear that this research project did not provide academic credit, but that individual participants would receive confirmation of their participation in the project. It was then decided at a later stage that participants would co-author the present academic paper and that this would represent evidence of the competencies they had acquired on this project.

Participants nominated one of their female peers, a graduate of the Localized Engineering in Displacement and the engineering projects course, who also had participated in the initiation course to the HP Learning Studios and was active in designing and developing engineering projects. As on-site project lead, she would be in charge of local coordination and decision-making as well as liaison with the management of the Learning Hub. She supervised the document production process, coordinated on-site meetings, ensured that assignment deadlines were respected, and kept supplies well stocked.

Building research capacity was accomplished through a bespoke blended course module designed by the project lead from the University of Geneva, launched with an on-site workshop in the Azraq refugee camp and continued virtually using the participatory action research (PAR) framework (Pain et al., 2012; KT Pathways, 2022). The course module walked project participants through the typical and recurring stages of a PAR project such as planning, action, and reflection, followed by evaluation. More specifically, the topics covered through the eight phases of the course module involve research design, ethics, knowledge and accountability, research questions, working relationships and information required, and the evaluation of reflection processes as a whole.

At the end of the capacity-building phase of the project, participants had learned about different kinds of research, knew how to distinguish between researcher-led and community-led research projects, had decided that the project course would fall into the category of community-led inquiry, and proceeded to define the EdTech tool on which their evaluation toolbox project would focus as a Makerspace.

Developmental evaluation

As there was no *a priori* intervention to be evaluated and in light of the complexity of the humanitarian context, developmental evaluations (Patton, 2010, 2012) emerged as the most appropriate tool to be added to our methodological toolbox. They are designed for complex systems, for innovation spaces where the indicators are not known, where we do not know where to find them, but where the objective is to create them through approaches that are flexible and adaptable, that respect local culture, identify, and build on existing knowledge, that design for learning over time, that support the application and adaptation of new knowledge to local contexts, and that establish true partnerships for mutual learning (BetterEvaluation, 2022).

With traditional evaluation models, evaluators create logic models that include well-defined and preferably SMART indicators (Sandhu-Rojon, 2017) to clearly measure outcomes and ultimately impact. In developmental evaluation, however, it is appropriate to start without well-defined goals and objectives if we find ourselves in new territory where the goalposts might be moving and where we are confronted with "wicket problems, where we don't know the solutions" (Patton, 2012), where the key is to find out what works and what does not, rather than following established pathways to change, and where continuous adaptive learning is key. The developmental evaluation framework captures that learning in real time. The focus is therefore on innovation and adaptation to emergent and complex situations. Patton (2006) lays out the differences between traditional and developmental evaluation along eight parameters, a comparison that provided helpful guidance and corroboration of the innovative approach to evaluation this project was taking.

According to Dozois et al. (2010), there are no established or fixed ways, or templates for going about a developmental evaluation. One of the key differences highlighted by Simister (2020) between traditional evaluation, which is often carried out primarily to demonstrate accountability to donors or government

TABLE 2 Differences between traditional and developmental evaluations (adapted and expanded from Patton, 2006).

	Traditional evaluation	Developmental evaluation	The rationale for the use of developmental evaluation in humanitarian contexts
Purpose	Supports improvement, summative tests, and accountability.	Supports the development of innovation and adaptation in dynamic environments.	Adaptability to unpredictable contexts
Roles and relationships	Positioned as an outsider to assure independence and objectivity.	Positioned as an internal team function integrated into the process of gathering and interpreting data, framing issues, surfacing, and testing model developments.	Meets criteria for Participation Revolution in humanitarian action and INEE Minimum Standard: Community participation
Accountability	Focused on external authorities and funders based on explicit and pre-ordinate criteria.	Centered on the innovators' values and commitment to making a difference.	Emphasizes accountability to vulnerable populations
Options	Rigorously options-focused, traditional research, and disciplinary standards of quality dominate.	Utilization-focused options are chosen in service to developmental use.	Emphasizes local knowledge production and respects contextual assets
Measurement	Measure performance and success against pre-determined goals and SMART outcomes.	Develops measures and tracking mechanisms quickly as outcomes emerge; measures can change during the evaluation as outcomes emerge.	Adaptability to dynamically evolving humanitarian contexts
Evaluation results	Detailed formal reports; validated best practices, generalizable across time and space. Can engender fear of failure.	Rapid, real-time feedback; diverse, user-friendly forms of feedback. The evaluation aims to nurture learning.	Strengthens the "Action" part of Participatory Action Research; ensures that results are returned to the affected population
Complexity and uncertainty	The evaluator tries to control design implementation and the evaluation process.	Learning to respond to lack of control; staying in touch with what is unfolding and responding accordingly.	Shifts from a focus on controlling all risks to enabling vulnerable populations to develop skills to manage uncertainty
Standards	Methodological competence and commitment to rigor, independence; credibility with external authorities and funders; analytical and critical thinking.	Methodological flexibility and eclecticism, adaptability; systems thinking; balanced creative and critical thinking; high tolerance for ambiguity; open and agile; teamwork and people skills; and ability to facilitate rigorous evidence-based perspectives.	Supports a system approach engaging all stakeholders equally instead of building unsustainable donor-dependent project-cycle-based parallel systems

agencies, and developmental evaluation is that the latter is focused primarily on learning in order to improve performance within the project or program being evaluated. Table 2 illustrates the key differences between traditional and developmental evaluation and highlights the relevance of the latter for humanitarian contexts.

Operationalizing the EdTech toolbox

In this section, we provide concrete examples of how each of the tools was operationalized by the group of student researchers following the task sequence of the Rainbow Framework and present examples of the output.

Putting the rainbow framework in place

The management phase

The HP Research Group set up the HP Learning Studio combined with the EngStarter and additional materials as the Makerspace, reflected on possible users, invited a pilot group of users, observed their use of the space, and then created an outreach flier. Users reached through this recruitment phase, which was organized according to guidelines established for outreach in humanitarian contexts, and then came into the Makerspace. The HP Research Group mapped the users, observed what they were interested in doing in the Makerspace, and documented their own observations and reflections as part of the PAR course assignments. Throughout these first six phases of the PAR course, the group had undergone iterative cycles of Action–Reflection–Action–Reflection by way of sixcourse assignments, with an additional two scheduled for the last phase of the course, which overlapped with the operationalization of the methodological EdTech toolbox prototype.

Participants shared their insights into what they had learned throughout the first six phases of the PAR course module. A thematic analysis (Braun and Clarke, 2006) of their contributions, posted on the messaging forum, identified the following key concepts: cooperation, social change, assessing community needs, working as a team, building knowledge, dividing tasks among team members, and stakeholder participation. Key concepts were then returned to the group with each member contributing an example of at least one of the concepts (cf Supplementary material). Participants were now equipped with the necessary skills to carry out contextual problem-tree analyses, use specific tools, such as mind-mapping (Genovese, 2017), design short surveys, collect and analyze data, and reflect on their practice.

In addition, the group also mapped the users' interests over the course of 3 months for a total number of users in the Makerspace over the project period of 256. This provided input to a second

TABLE 3 Areas of interest mapping.

Activity	Areas of interest	Social-emotional dimension
IT	Computer skills	personal
IT	Searching the internet	personal
IT	Searching and reading reference material	Personal/study
IT	Design on Sprout	Personal/community
Engineering	Landscape design	Contributing to community space
Engineering	Recycling/circular economy	Personal and community
Study	English	Personal
Meeting friends	Life skills	Personal and community/socializing/coping skills

thematic analysis of the different project ideas users produced (plastic art, computer skills, Arabic calligraphy, hydroponics, time-bank project to swap expertise, using recycled materials to make toys, learning English, developing expertise in distance learning, etc.) and was subsequently organized by the group by area of interest as shown in Table 3.

The definition phase

The group had thus arrived at the critical stage of *defining* what is to be evaluated (Table 4). They now knew enough about the Makerspace as the EdTech tool they would evaluate, about youth as users of the Makerspace in the Azraq camp, and about their interests and preferences, to be able to advance to identifying the "what is to be evaluated" before formulating research and evaluation questions. In keeping with the bottom-up approach, participants were introduced to tools rather than given theoretical lectures on designing research and evaluation questions. Through videos and facilitated readings, the group learned mind mapping and proceeded to design their problem tree (Chevalier and Buckles, 2019), a fairly involved and time-consuming process, which produced rich information and insights into the needs of the Azraq camp inhabitants and their community.

All group members worked on the identification of the main topic, the trunk of the tree, using the problem-tree or situational analysis tool (Chevalier and Buckles, 2008) that is widely used in participatory research to map problems, their causes, and needs. Two group members then teamed up to identify the topics that would become the branches (Figure 2), and all branches were then combined and presented as the completed tree (Figure 2).

Framing the evaluation phase

The group had thereby developed a very comprehensive picture of the needs of the Azraq camp community and how these needs were related to each other and was ready to relate the affordances of the Makerspace to solving these needs; in short, they were ready to evaluate how the Makerspace and its EdTech as installed in their camp could actually solve problems of camp residents that they had identified through their problem-tree analysis.

They then proceeded to the next step of the project: defining evaluation questions, i.e., if and how the EdTech of Makerspace could contribute to solving community problems. In that, the group was guided by three key question types (cf Table 3), with output summarized in Table 5.

Description and causal allocation phase

Based on the Azraq camp problem tree, the group produced a large number of potential evaluation questions (cf Table 5).

The synthesis phase

In a second iteration, the table became the input for in-depth group discussions as to which of these were evaluation questions linked to the potential uses of the Makerspace as an example of EdTech, and how this type of EdTech could serve the needs identified by the HP Research Group and the users of the Makerspace. Table 5 summarizes the selection of evaluation questions linked to the Makerspace as EdTech and provides examples of how, with the EdTech embedded in the Makerspace, solutions could be generated by the users. The addition of potential solutions in response to the evaluation questions identified by the researchers was to test the contextual relevance of the evaluation questions.

Meeting the criteria for developmental evaluation in humanitarian contexts

The comparison between traditional and developmental evaluations and the latter's relevance to humanitarian contexts is summarized in Table 2 above. Moving to the last task of the Rainbow Framework, and in light of the fact that pandemic-related restrictions and cost-cutting had not yet allowed for carrying out evaluations in the camp, participants decided to repurpose the last phase of the BetterEvaluation framework and describe the impact of designing and using new tools to evaluate EdTech in humanitarian contexts. To this end, the research group engaged in reflection on how the overall framework and the different tools met the needs of forcibly displaced youth and their communities. Had the Rainbow Framework and developmental evaluation together with the tools of Participatory Action Research responsibly supported Core Humanitarian Standards

TABLE 4 List of evaluation themes produced by the research group.

Problem tree branch	Evaluation themes and related data collection questions
Residence	• What is the camp population? • How many housing units are there in the camp? • What are the pros and cons of housing and housing in the camp? • What is the role of the High Commissioner in securing housing? • How can a housing solution be found, if any?
Transport	• What are the places that are visited frequently (hospital-market-camp center....)? • Which means of transport would you prefer to move inside the camp (by foot, bicycle, rudimentary transport vehicles, and public transport)? • If a public means of transportation is available, what is the frequency that you propose should be provided (a quarter of an hour, half an hour, or an hour)? • What is the virtue of having a permanent line passing all vital points in the camp? • Does it prefer to go to every village? • What is the acceptable tax on the passenger within the camp? • What is the period of time that you prefer should be covered by transportation (starting time and stopping time)? • Is the provision of specialized seats for people with disabilities necessary in this vehicle? • What do you think of the availability of transport on demand (by mobile phone)?
Water	• How much water does the camp consume in 1 month? • Why is tap water not suitable for drinking? • How much drinking water does the camp need for 1 month? • Can we manually filter the non-drinking water in the camp? • How can we do that? • How can Makerspace help us? • How can we reduce the wastage of water? • How can we make the transportation of water to the shelter easier?
Education	• Do you feel that the current way of educating children fully prepares them for the needs of the 21st Century in this camp? • What do you feel would be the most exciting or effective learning environment? • How could your child's school be better for your child and all children? • How often do you talk with your child about school and about what he/she is learning? • What is your plan of action when your children do not learn?
Communications	• For what purposes is the internet needed? • Is the quality of the internet good enough to satisfy all requirements in the camp? • And if not, how could we contribute to making it meet all requirements? • Why does the camp need a strong network? • What is the importance of the internet for the people in the camp? • How does the internet in the camp support the students and help them with their studies? • What are the disadvantages of a bad network? • How can we improve the quality of the network in the camp and find solutions by using Makerspace? • How can we increase the awareness of the youth about the overuse of the internet and its disadvantages? • Why do so many people not have balance or data on their phones? • What are the reasons for the bad network in the camp?
Jobs	• What is the role of society toward the problem of not having enough work opportunities? • How can organizations provide work opportunities for everyone? • What is the average income required for each family? • How many people can work in the camp? • How many people are currently working? • How many individuals should work in each family? • How can working outside the camp reduce the number of unemployed? • Can we form small projects? • Who should support small projects? • How does the increase in the number of unemployed affect society?
Electricity	• How much electricity does the electricity field produce in the camp? • What is the average daily consumption of electric energy in the camp? • What are the most important causes that lead to the extravagant use of electrical energy? • What are the effects on society due to the wastage of electricity? • What are the effects on the individual as a result of extravagant use of electrical energy? • How can we reduce the wastage of electrical energy in the camp? • What is the role of the local community in treating the wastage of electrical energy?

(CHS Alliance, 2014)? Traditional evaluations are almost always initiated by outside consultants to ensure impartiality. However, accountability to affected populations requires deeper and more sustained community engagement that goes beyond participation in interviews, surveys and focus groups. While fear of negative feedback from communities, lack of resources, and competing priorities are often cited by humanitarian actors as reasons for choosing traditional and donor-facing evaluation approaches, community participation ensures access to affected populations and their resources, makes assistance more efficient and speeds up recovery (CHS Alliance, 2014). Putting crisis-affected youth at the center of a humanitarian response also yields important (social)

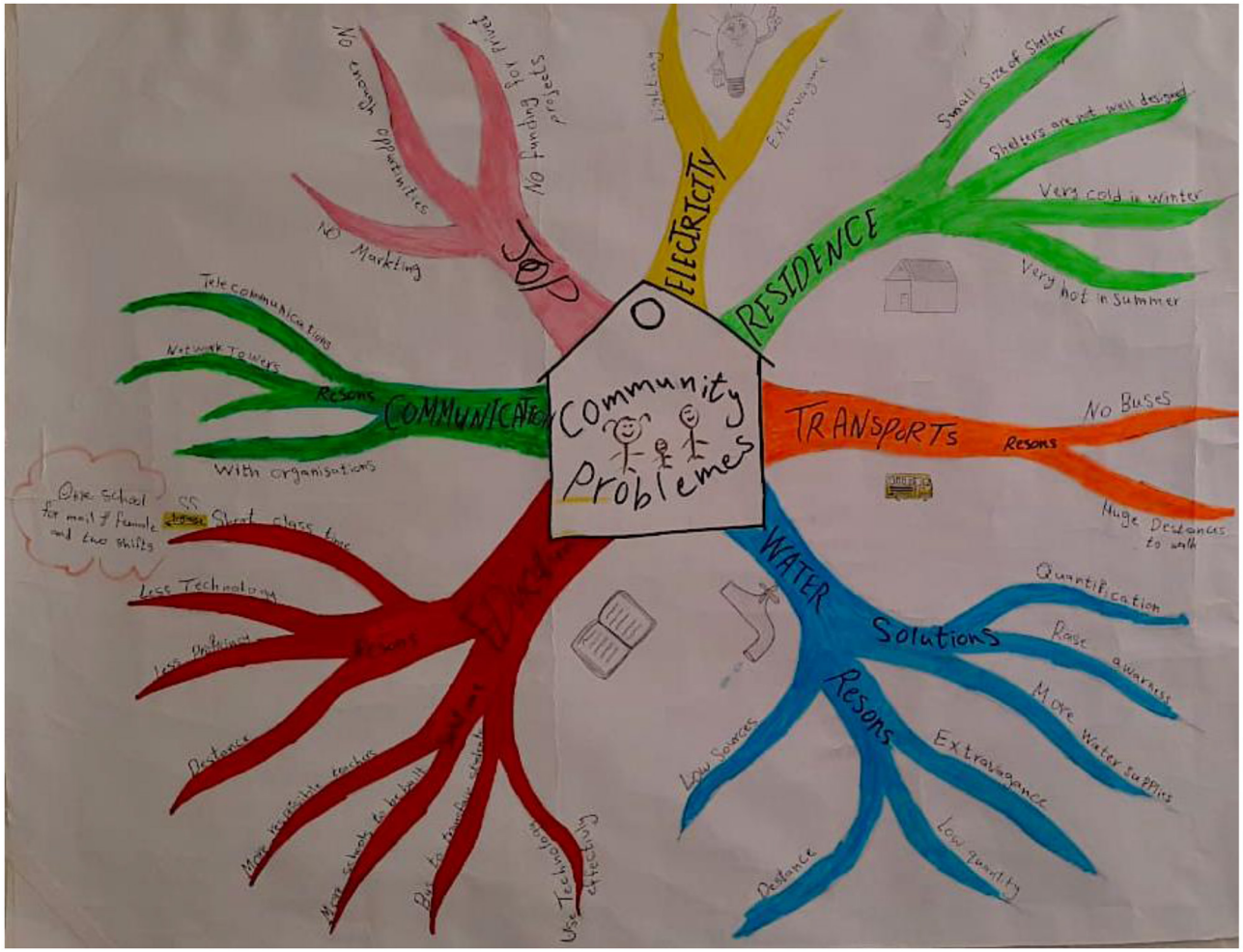

FIGURE 2
Completed map transformed into a problem tree with seven branches (clockwise from the top: residence, transport, water, education, communication, jobs, and electricity).

protection benefits and contributes to their self-reliance (Holmes and Lowe, 2023).

From the key criteria listed for developmental evaluations and their application in humanitarian contexts, this project had adapted to the needs of an unpredictable camp context, emphasized community participation, local knowledge production, and respect for contextual assets; it had put vulnerable youth in charge of "Action" and through detailed analyses of needs in their camp, it enabled them to exercise accountability to their community. The project illustrates how it met the criteria for Participation Revolution in humanitarian action and the INEE Minimum Standard for community participation as referenced above.

Reporting impact

The last phase of the Rainbow Framework (BetterEvaluation, 2022) provides for reporting on the impact and on developing recommendations that support the future use of the evaluated EdTech. In Phase 3 of the BetterEvaluation framework, participants produced a number of evaluation questions related to the potential use of the EdTech involved in this project and demonstrated how participatory approaches could produce a comprehensive contextual understanding of the impact a particular EdTech could have on the humanitarian community where it was implemented. The final selection of evaluation questions and implementation of the remaining phases of the BetterEvaluation framework for this particular EdTech remained subject to funding and restrictions related to the pandemic.

As the focus of this study is on the design and development of methodological tools, we, therefore, propose a meta-analysis of the process, the program of activities, and the impact these have on the community, in particular on the group of student researchers. To this end, personal reflections on the project and its implementation were requested from each group member. There was no prescribed format; participants could choose video, audio, or narrative, as well as samples of the creations at the Makerspace. A total of 12 comprehensive files were submitted anonymously and subsequently analyzed by the project lead using thematic analysis based on Braun and Clarke (2006). Submitted video and audio files were first transcribed for analysis. Inductive and semantic coding

TABLE 5 List of evaluation questions and suggested answers produced by the HP Research Group.

Residence:
How can a housing solution be found, if any?
The equipment in Makerspace can be used to redesign shelters or at least make some adjustments to the shelter design.
Transport:
How can the provision of specialized seats in vehicles for people with disabilities be accomplished?
We can make use of the equipment in Makerspace in the process of designing special vehicles and seating options that accommodate people with different types of disabilities.
Water:
How can we make the transportation of water to the shelter easier?
A suitable solution is to put a water faucet in every shelter (water distribution times need to be defined of course in order to reduce water wastage). We can design a blueprint for the camp's water network using Sprout and do the necessary calculations on the laptops. We can supplement this by building a prototype of the faucet and the network using the materials included in the EngStarter kit (e.g. K'NEX).
Education:
How could it be better?
It can be improved if we supplement formal instruction with informal learning using the laptops that allow us to access more learning materials that are suitable for children and also easy to use for their parents; at the high school or university level, the Makerspace technology supports the design of better class presentations, helps engineering students create prototypes, and allows students to save their work for off-line use as the internet is always unstable. This increases students' desire to explore and learn new things, follow their interests, and motivates them to complete their education in the best way.
Communications:
How can we improve the quality of the network in the camp and find solutions by using Markerspace?
We can use the Makerspace technology to map connectivity in the different villages at different times of the day to better understand the load on the camp's network and work out recommendations as to how different users could be given priority at different times so as not to overload the system. Internet access in the Makerspace helps us communicate the results of our research to the community.
Jobs:
Can we form small project teams?
We can take advantage of the Makerspace infrastructure, exchange ideas, form a team, design small projects using the Makerspace EdTech tools, and then present these to interested NGOs looking for solutions to problems they have identified (hydroponics project, for example).
Electrical:
How can we reduce the wastage of electrical energy in the camp?
We can use Sprout to design a light sensor that turns lights off automatically in the daytime and turns them back on when it gets dark. The Makerspace plays a big role in providing a space to search for solutions and share ideas and design processes that actually solve real problems in our community.

was used to then develop first-cycle codes; these 25 codes were then grouped into five themes with duplicate codes or near duplicates eliminated, and during a subsequent third sweep through the qualitative data, a total of 83 items distributed across the five themes were identified.

Table 6 provides an overview of the process from the first-cycle coding to the grouping into salient themes to the second-cycle coding and quantification, with percentages of second-cycle codes allocated to each theme (cf. Appendix for sample quotes).

Synthesis and discussion

Understanding evaluation as a concept and as a process was challenging for recent high school graduates with little background in the social sciences. This required balancing the building of foundational knowledge of specific accepted scientific approaches and minimal interference with locally informed approaches, and also preserving a degree of fuzziness and messiness that would support bottom-up innovation that did not follow a received innovation design process. The developmental evaluation framework provided considerable flexibility for the participants to scope ideas, follow up with collaborative inquiry, observation of the Makerspace users, and scope of evaluation questions while remaining entirely embedded in the reality of the humanitarian context of their community and for which the use of EdTech tools was to be evaluated. Emerging from an education system that did not prioritize independent, creative, and critical thinking, these recent high school graduates were ideal participants in that they were not entirely set in their ways of learning and exploring their environment. This supported trial-and-error learning, being receptive to feedback, opening up to new and diverse ideas, and gaining confidence in their abilities to contribute to science. As a learning opportunity, this project allowed them to acquire 21st century skills and contributed greatly to social-emotional learning during the pandemic. "What is important is that we develop a culture of evaluation, in which mistakes are seen as learning opportunities and learning as a major source of growth and development" (Feinstein, 2006, p. 8).

TABLE 6 Project impact codes and themes.

First-cycle Codes	Themes	Second-cycle Codes	Count/%
1. Active creator 2. Benefits me as a person	1. Time	Free time Fun time	4/**4.8%**
3. Benefits my studies 4. Communication skills	2. Relationships	Knowing people (social) Teamwork Trust	12/**14.5%**
5. Community problems 6. Creativity 7. Empowerment 8. Find solutions 9. Free time 10. Fun time	3. 21st century skills	Communication skills Find solutions IT skills Present ideas Problem solving Research skills and tools	28/**33.7%**
11. IT skills 12. Knowing people (social)	4. Social skills	Making a difference Understanding community problems Understanding social issues	16/**19.3%**
13. Learning 14. Making a difference 15. Present ideas 16. Pride 17. Problem solving 18. Research skills 19. Research tools 20. Self-confidence 21. Self-discovery 22. Teamwork 23. Time 24. Trust 25. Understanding social issues	5. Personal development	Creativity Learning Personal benefits Pride Self-confidence Self-discovery	23/**27.7%** 83/**100%**

From a methodological point of view, the different tools that make up the toolbox prototype are responsive to the Grand Bargain Commitments regarding local ownership of projects and processes, appropriate to the context in which they will be used, effective in that they produce usable results, and efficient in that they do not require lengthy training. The prototype as a whole is greater than the sum of its parts, i.e., its individual methods and tools. And yet, even the selection of individual tools may likely generate important insights and learning opportunities that are participant-led and community-embedded.

As noted in the background section, there is scant evidence of EdTech in emergency situations (World Bank, 2016). The project reported on in this study seeks to contribute to the creation of evidence regarding EdTech interventions in fragile contexts through the design of a methodological toolbox prototype, by and for forcibly displaced youth living in fragile contexts. The project built on principles that included a clear understanding of low-resource humanitarian contexts, that EdTech is a tool and not the solution, that we need to start with the problem and not the technology, and that the human factor is critical to impactful EdTech applications (Tobin and Hieker, 2021). The proposed methodological toolbox prototype was designed with refugee youth aged 18–35, but the framework and tools can be easily adapted for use by secondary school students, and even upper-level primary school students can engage in participatory research initiatives. The EdTech to be evaluated for implementation need not be an entire suite of IT tools, as was the case with the HP Learning Studio, as the toolbox approach lends itself readily to participatory evaluation for low-resource humanitarian contexts of stand-alone tools, such as educational apps and learning management systems.

Conclusion

Raluca et al. (2022) conclude a recent policy brief regarding EdTech use during the global pandemic as follows:

> "What we know less about is whether distance learning and EdTech can help offset [these] negative consequences…A core constraint, however, is the availability of local data and information to inform this decision-making. Without an operating footprint of schools to channel information up and down, policymakers have to be realistic. They are likely to have less information than what is normally available from weak education management and data collection systems, meaning they will be unable to optimize their decisions." (Raluca et al., 2022, p. 3).

Years of emphasis on more evidence-based approaches to learning in fragile contexts have largely oriented the focus to applying the "gold standard" of research methods, RCTs, and other quasi-empirical methods, to constructing this evidence. The guide to assessing the strength of evidence in education

(Building Evidence in Education Working Group, 2015) follows a similar pattern, relying on the understanding that evidence is constructed using the accepted scientific method as usually applied in Western research centers and higher education institutions where controlling variables and methodological finesse are an integral part of the research enterprise and where research output generally does not directly affect people's lives. When such approaches are exported to fragile contexts they invariably set up a power differential between those who are studied and those who are doing the research (Fox et al., 2020). This approach, however, is increasingly questioned by those whose voices are supposedly included in the research, but who are at best enumerators, collecting data on variables and indicators to whose identification they had never contributed, and which will inform research and evaluation questions that they themselves rarely learn about. As the research and evaluation results are only occasionally returned to the population under study, this type of extractive research is increasingly questioned (Bastida et al., 2009; Cordner et al., 2012) not only on ethical grounds (Kouritzin and Nakagawa, 2018) but also in terms of validity and reliability of its results. If including refugee voices is limited to their participation in focus groups and KI interviews—the selection is often co-determined by their level of proficiency in the language of the researcher(s)—it is difficult to claim that the quality of the evidence warrants its consideration for policymaking that directly affects the studied population. It is thus not surprising that so much of EdTech in humanitarian contexts remains unused or not used as intended and that potentially valuable uses remain unidentified. This usually leads to more studies using the same traditional research and evaluation approaches being commissioned and which largely produce more of the same results.

In this project, we invested considerable effort in being and remaining grounded (Strauss and Corbin, 1994), digging into the toolbox of research methods that would be compatible with empowering young people to become evaluators and researchers, giving them enough time and opportunity to build their skills, for using their voices and breaking new ground not by inventing new research methods, but by combining respected methods in ways that would ultimately contribute to a responsible methodological toolbox for use in humanitarian contexts. Setting the approach within a highly respected evaluation framework (BetterEvaluation, 2022) was initially a risky departure from our grounded approach, but the *Rainbow framework* stood the test and proved to be a valuable guide and roadmap that also ensured the interface to more traditional evaluation approaches with which the humanitarian community would be more familiar and thus perhaps improving chances for acceptance of the project's outcomes.

While building the methodological toolbox took time and benefited from available resources locally, the resulting prototype responds to the demands of efficiency in humanitarian contexts: the user does not need to go through all the stages in the same in-depth way but can prioritize certain stages and invest more resources where considered appropriate. No two humanitarian contexts are alike. The resource base can be extremely varied, and a one-size-fits-all approach is thus ill suited for fragile contexts. Each context merits to be studied by those who live in it and are the intended beneficiaries of EdTech. EdTech innovators should constantly ask themselves if they have correctly identified the "customer's pain point" (Atwater, 2022), "it's easy to fall in love with a solution first and back into the problem it solves. In a crisis, we make fewer mistakes in the choice of the problem, and we do a much better job about picking solutions." Much of EdTech is designed as a solution without a profound understanding of the problem, worse yet, it is designed *as* a solution, rather than as an open-ended, fuzzy, and messy tool that lets the ultimate users decide on its use and usefulness. Thus evaluating EdTech needs to be user- and context-driven and the process of learning how to evaluate EdTech might turn out to be at least as, if not more important than the outcome, strengthening both our accountability to youth in fragile contexts and our engagement as higher education actors to contribute to operationalizing the Grand Bargain commitments.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study involving human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants in accordance with the national legislation and the institutional requirements.

Author contributions

KA coordinated the junior researchers RAlh, RAlS, AA, AH, BB, MHA, and MMA in the refugee camp during research training and research implementation. BM-M provided the research training and framework, compiled and analyzed the data, and wrote the article. All authors contributed equally to this study.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix

This produced the following rich output of (unedited) examples:

Output from follow-up assignment:

Building knowledge: We have developed the skills of members (using the place) and expanded their awareness in many areas, including teaching them how to use advanced computers (Sprout).

Social change: By working in the Makerspace and following up on place users, we have noticed a lot of harmony, cooperation, and exchange of ideas, despite their different cultures and social groups, this is a goal that we have achieved and a great achievement.

Hope this works!

Stakeholders: They are the people directly related[sic] and affected, and the involvement of stakeholders in the research helps in gathering information and helps to define the needs of the local community. They are generally people in the community (and part of them are users of the place).

Division of tasks: We divided the tasks among the team members according to the skills and experiences of each member of the team, for example, when we featured the brochure, Mohamed Al-Hamoud, with the assistance of Rawan Al-Maher, designed the external pictures of the publication. Ahmed and Ali were tasked with writing the content in both languages. Arabic and English, Rowan and Bashar were tasked with spelling and final design on the laptop, which was the task of Kawkab and Muhammad al-Qadri.

Community needs assessment: Through our follow-up of the place, users, their sharing of ideas, and through discussions, we were able to determine the needs of the local community. For example, the youth in the camp need to learn the English language in order to study and work. Another example: People here need plants, but the soil is not suitable for cultivation, so the idea of a hydroponic project was born.

Cooperation between the members of the group: Since the beginning of the course, I and the members of the group were sympathetic at the beginning. We distributed the tasks to the members according to the skill of each individual. Some of them had the task of entering data on the laptop, and some of them had to register what we needed of[sic] materials. Also, they cooperated in distributing publications in the centers. In addition, we had to determine the content and form of the publication.

Working as a team: We were always in contact with each other, either through periodic sessions or via WhatsApp, cooperating and helping each other to complete tasks in[sic] time and coordinating among us. For example, when we distribute brochures in the camp, we worked as a team and each member helped.

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A social accountable model for Iranian dentistry sciences education system: a qualitative study

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Introduction: Social accountability is a new paradigm in dental education and a sort of cultural change. This study is an attempt to elaborate on the process of social accountability in the Iranian dentistry education system.

Materials and methods: This study was carried out as a qualitative work based on a grounded theory approach. The participants were selected through purposive sampling and took part in deep semi-structured interviews, and data saturation was achieved with 14 interviews. The main interviews were private, and face-to-face interviews were held on different occasions (morning and afternoon) in a quiet and decent environment. The interviews were held by the author and voice-recorded with the permission of the interviewees. Data analyses were performed through the Strauss–Corbin method along with the interviews.

Results: The results indicated that the process of social accountability featured three stages: antecedents, mechanisms, and outcomes consisting of 619 codes, 16 subcategories, and 7 categories. Updating the curriculum, qualified students, appropriate educational environment, appropriate educational technology, monitoring and feedback throughout educational activities, proper interaction with society, and accountability to society's needs were the main categories in the study. The concept of proper interaction with society was the core variable.

Conclusion: The results indicated that the process of social accountability has major and effective requirements in the antecedent, mechanism, and outcome stages, and it has a good performance in fulfilling the current needs of society for dentistry services. However, to meet potential needs, it needs special attention and programming.

KEYWORDS

dentistry education, accountability, society, qualitative study, Iran

Introduction

Dentistry education is one of the most expensive programs for medicine students. The educational system needs to prioritize social needs as one of its top priorities (Walker et al., 2008). Comprehending the needs of society in a dentistry education system with a society-centered approach leads to deeper learning and experiences for the students (Brondani et al., 2020). Being accountable to society's needs has received a great deal of attention over the past few years in many branches of science and dentistry in particular (Sanaii et al., 2016).

Social accountability in dentistry education can be seen as a society-centered approach that, along with a detailed and comprehensive examination of society in the dentistry field (Philibert and Blouin, 2020), introduces educational and health policies in the health sector based on the needs of society (Petterson and Shea, 1972; Lindgren and Karle, 2011). Toward implementing such policies and programs, a variety of prevention levels are emphasized by the health system. Eventually, the objective of such a system is to prepare graduates who can provide services to their society (Dehghani et al., 2014). To achieve social accountability, we need to concentrate on the health requirements of society in three fields: social responsibility, responsiveness, and accountability (Abdolmaleki et al., 2017a). Social responsiveness means attempting to recognize needs and problems in society, while social accountability also includes introducing efficient programs to deal with the problems and needs in an efficient way (Salehmoghaddam et al., 2017).

There have been studies on dentistry education and social accountability (McAndrew, 2010; Rohra et al., 2014; Batra et al., 2015; Chen et al., 2015). Social responsiveness in dentistry education is an important and purposeful issue in higher education in health (Batra et al., 2015), and the graduates need to develop adequate skills along with the knowledge to meet the needs in society for dentistry services with commitment and practical approaches (Chen et al., 2015). Therefore, it is essential to pay more attention to the needs of society and responsiveness toward such needs in the policies of the dentistry education system (Batra et al., 2015). To understand the implementation of a society-centered education in the educational system and the way of implementing social accountability in dentistry education in particular, there is a need to monitor and validate educational systems and programs in a continuous manner (Chen et al., 2015). Accountability in dentistry education is a process with diverse fields and intrinsic and extrinsic factors (Abdolmaleki et al., 2017b). To examine different social processes, qualitative studies with a grounded theory approach can be fruitful (Speziale and Carpenter, 2011). Grounded theory research is a study with a naturalistic approach that examines social interactions and processes in a real environment (Corbin and Strauss, 2008). Compared to medical education, in which social accountability is seen as a serious matter, the emphasis on social accountability has received limited attention in other educational fields and majors (Armstrong and Rispel, 2015). Therefore, the objective of this study is to elaborate on the social accountability process in the dentistry education system using a qualitative method based on a grounded theory approach.

Materials and methods

Design

The study was carried out as a qualitative study using the grounded theory method (Speziale and Carpenter, 2011).

Abbreviations: MSc, Master of Science.

Setting

The study environment was a dentistry school and affiliated educational clinics. The school admits postgraduate dentistry students in master's programs and started its activity 12 years ago with 10 educational departments including Pediatric Dentistry, Oral Diseases, Oral Radiology, Oral Pathology, Oral and maxillofacial surgery, Restorative Dentistry, Orthodontics, Endodontics, Periodontics, and Dental Prostheses. More than 50 faculty members work in this school, and every year more than 60 students graduate from this school with a master's degree in dentistry.

Participants

The participants in the study were all faculty, students, and dentists with an education or therapeutic experience in dentistry. Using the purposive sampling method, the participants who met the inclusion criteria entered the study. Being interested in participation, knowledge about the topic, key informant, and having the ability to speak and fill in the informed consent form was other inclusion criteria. With 14 interviews, data saturation was achieved, and throughout the data analysis methods, 2 participants were selected for theoretical sampling.

Data collection

The main data-gathering method in this study was a semi-structured deep interview using open-ended questions. The main interviews were private, and face-to-face interviews were conducted at different hours of the day (morning and afternoon) in a place convenient for the participants. The interviews were conducted by the second author and voice-recorded with the permission of the participants. In addition, memos and note-taking were used throughout the interviews to record tone of voice, accent, smiles, and pauses. The interview time duration depended on the participant's energy. The mean time of interviews was 50 to 70 min on average. To facilitate data gathering, guiding questions were used. The validity of the guiding questions was confirmed by the content validity method and using the opinions of seven medical scientists and researchers familiar with qualitative research.

Guiding questions:

1. How can dentistry education meet the needs of society?
2. What are society's needs that dentistry education experts need to take into account?
3. What are the measures needed to add accountability to dentistry education?
4. What factors affect social accountability in the dentistry education system?
5. What are the steps to make the dentistry education system socially accountable?

Data analysis

Strauss and Corbin's method was followed for data analysis (Corbin and Strauss, 2008). The main stages of this method are open coding, axial coding, and selective coding. To this end, the recorded voices from the interviews were listened to several times and then transcribed using Word Office 2016. The transcribed interviews were read twice and open-coded. The codes were selected from words and sentences in the interview scripts. All the interviews were analyzed immediately after the interviews along with the next interviews. Afterward, the authors started to study and compare the extracted codes continuously to determine similarities and differences. The codes with similar features were categorized into one category. Categorization was conducted through axial coding. The continuous process of comparing codes and rearranging them among categories along with adding new codes based on similarities and differences was continuous throughout the data analysis stages. Continuous comparison of codes and themes along with categorizing and organizing new codes resulted in the formation of codes and themes. In addition, memos were used in data analyses. To integrate, purify data analysis, discover main themes, achieve the core variable, and discover the relationship between themes, storyline writing was used.

Rigor

To make sure of data rigor, Guba and Lincoln's four measures were used (Speziale and Carpenter, 2011). The authors spent long hours in the research environment to win the trust of participants and gain a reliable perception of the research environment. Data analysis results were confirmed by the participants' focus group meetings to make sure that the authors had a correct perception of the participants' ideas and thoughts. In addition, a wide range of participants in terms of age, gender, work history, and type of service were selected to increase the credibility of the findings. As to conformability, researchers' ideas and perceptions were bracketed, and the principles of no bias were observed in data gathering, analysis, and dissemination of the findings. In addition, university professors and researchers familiar with qualitative research and the topic were consulted. To control the dependability and stability of the findings, the interviews were transcribed and coded independently by three researchers. The findings were provided to other members of the research team and other experts to make modifications if needed. In addition, some of the interview scripts were reviewed by supervisors. To make sure of transferability, a rich description with details about the environment and participants was provided along with the demographics of the participants. In addition, numerous direct quotations were used in the Results section.

Results

In total, five general dentists (at least 3 years of experience and at most 7 years of experience as general dentists), six faculty board members (three associate professors and three assistant professors with at least 5 years and at most 9 years of experience), and three senior dentistry students were interviewed. In addition, 16 private interviews and 1 focus group interview were held, and throughout the data analysis phase, a general dentist and a senior dentistry student were recruited as theoretical sampling.

After the completion of interviews and simultaneous analyses, 7 categories, 16 subcategories, and 619 codes were obtained. Table 1 lists the categories and subcategories and the steps of social accountability in the dentistry education system based on the results of interview analyses.

TABLE 1 Categories and subcategories.

Process section	Categories	Subcategories
Antecedents	Updating the curriculum	The need to revise based on the new needs of society
		Proper course layout based on the prerequisites
		Purpose-oriented curriculum
	Qualified students	Interest in the career
		Potential talent and ability
	Appropriate educational environment	Expert, committed, and skillful workforce
		Physical environment to meet the needs of students
		Updated educational and treatment equipment
Mechanisms	Appropriate educational technology	Purpose-oriented theoretical education
		Client-centered clinical education
	Monitoring and feedback throughout educational activities	Evaluating and giving feedback on theoretical science
		Evaluating and giving feedback on practical skills
	Proper interaction with society	Concentration on the needed clinical services
		Early interaction with society
Outcomes	Accountably to society's needs	Covering the potential needs of society
		Covering the actual needs of society

Categories and subcategories

As illustrated, the process of social accountability in dentistry education in Iran features three stages: antecedent, mechanism, and outcomes. Each one of these stages also contains categories and subcategories.

Updating the curriculum

The category contains three subcategories as follows:

The need to revise based on the new needs of society

This subcategory is based on the data derived from the clients' statements and emphasizes the need to pay attention to the day-to-day needs of society in different fields and reconstructive needs in particular. The university professors stated, *"What people want from dentistry is beauty dentistry, which is only briefly mentioned in the curriculum, while the students need more knowledge about such dentistry services…".*

> *"There are good content in the curriculum; however, the society had new demands so that along with basic education, advanced content and the needs of society should be covered as well…".*

Proper course layout based on the prerequisites

The majority of participants believed that the specialized courses should be made available with priority and observation of the prerequisites. One of the professors said, "*Some courses contain highly specialized and advanced content, which need basic courses as prerequisite. For instance, while students are not familiarized with radiology, they need to pass courses that need diagnosing teeth decay…".*

Purpose-oriented curriculum

The participants' statements indicated a need for constant revision of the curriculum and a purpose-oriented layout of the courses. One of the dentists stated, "*there were challenging and useless courses in the curriculum, while the portion of useful and critical courses was very small…".*

A professor added, "*The current curriculum is not designed based on the new needs of society and it needs to become purpose-oriented through timely revision based on the new needs in society…"*

Qualified students

The category contains two subcategories as follows:

Interest in the career

Based on the interviews, it was found that the number of students who are interested in dentistry is declining, which is due to the good financial expectations in a dentistry career. Students are admitted based on rank in national admittance exams, and the main motivations for students to choose this major are good financial opportunities and income in the future.

The professors believed that "*even in the first year, the students are eager to know the income and money they can expect for providing each new service they learn…". "In the early stages of training, the students are only concerned about beauty treatments and skills that can create more income. They are not interested in skills related to oral health…".*

Potential talent and ability

The participants emphasized that potential talent and ability in students were the key factors in training capable dentists. One of the professors noted, "*Many of the students entering the program are very talented and smart; unfortunately, however, instead by concentrating on learning and self-empowerment, many of them seek opportunities to earn more income after graduation…".*

Suitable educational environment

The category contains three subcategories as follows:

Expert, committed, and skillful workforce

The participants believed that given the importance of clinical education in dentistry, it is imperative to have skillful, committed, and capable instructors. Students noted that "*There are only a few good instructors in the school, and the rest are newly graduates who are not familiar with teaching skills…".* Another student added, "*The majority of newly recruited instructors do not have the skill or intention to teach students…".*

One of the instructors mentioned, "*Unfortunately many of the instructors are not interested in their job and they only work as a faculty board member to fulfill their obligatory services…".*

Physical environment to meet the needs of students

The participants believed that the physical space was not enough for that number of students. One of the newly graduated dentists noted, "*There are too many students and a few patients and dental units and none of us were able to master the skills expected in the curriculum…".*

One of the professors mentioned, "*There are too many students in clinical courses, and we cannot work with all students and teach all the skills to them…".*

Updated educational and treatment equipment

All the participants mentioned the need for adequate modern equipment to meet the new needs and advances in science. A professor noted "*We need adequate new equipment and tools to implement the curriculum and extra material that the students need to meet the new needs in society. This a problem almost in all dentistry schools in the country…". "The equipment is outdated even in the schools located in the capital city let alone the schools located in other smaller cities…".*

Educational technology

The category contains two subcategories as follows:

Purpose-oriented theoretical education

The participants believed that using proper educational technology and concentrating on the needs of society and providing content that empowers students more efficiently were key factors in accountability-oriented education. One of the professors said, *"Us teachers need to also focus on the educational needs of society in the educational process in addition to the curriculum…"*. Another participant added, "*Teachers need to follow specific framework and objective and in this case is to improve the knowledge needed by dentistry students…"*.

Client-centered clinical education

All the participants noted that education must take into account the needs of clients and make the student realize that the key point in clinical activities is the client's needs and preferences. One of the professors noted "*Interacting with the patients and accepting them along with their cultural concerns are highly important in clinical education. Students need to learn to pay attention to patients' opinions in providing clinical care…"*.

One of the dentists added, "*Teachers in the clinics only perform the primary measures and ask the clients to visit their own clinic for more specialized services…"*.

Evaluating and giving feedback on educational activities

The category contains two subcategories as follows:

Evaluating and giving feedback in theoretical science

Evaluating and giving feedback in theoretical education was one of the key issues emphasized by all participants. One of the professors noted, "*Educational processes need to use evaluation methods that suit the education and give feedback to students based on the evaluations…"*.

One of the graduates said, "*All we did was to memorize the material and since the questions were based on the textbooks, we were able to gain top scores…"*.

Evaluating and giving feedback on practical skills

All the participants highlighted that measuring students' performance in clinical courses and giving feedback to them highly affected education outcomes. A professor noted, *"There are too many students in clinical courses and it is not actually possible to evaluate skills of all students. In fact, there is no time for evaluation and giving feedback…"*.

A graduate added "*Unfortunately, there were too many of us in clinical courses and it was not possible for us to practice clinical measures on patients as needed. There was a limited time and the instructor was too busy to evaluate us or give us feedback…"*.

Proper interaction with society—Core variable

The category contains two subcategories as follows:

One of the main categories that interacted with other categories and was considered the core variable was proper interaction with society, which comprised two subcategories.

Concentration on the needed clinical services

All participants believed that the dentistry services needed in society must be covered in the program. A professor noted, "*the instructors need to be in contact with society to find out what type of dentistry services are needed most and cover such needs in their teaching…"*. A student added "*the majority of instructors only cover some of the cases and complications in the clinic of school. Some others, however, have their own clinic and invite us over to learn those services that are not provided in state-run clinics…"*.

Early interaction with society

The participants emphasized that students should enter clinical fields as soon as possible after entering the program. Through this, they can understand the needs of society for specialized services and interact properly with society. A professor noted "*students can spend more time in clinical setting and interacting with people if they enter clinics sooner in the program. Through this, they can have a better understanding of people's needs and prepare themselves to answer such needs…"*.

Accountability for the needs of society

The category contains two subcategories as follows:

Covering the potential needs of society

Data analysis indicated that without proper infrastructure and due to non-purposeful programming, the dentistry profession has failed to keep up with the growth of dentistry science around the world. Since it has failed to predict the potential needs of society, it has failed to prepare itself for them. Professors said, "*Giving the low salary given to the faculty board members, the majority of professors seek more revenue by opening their own clinic, which consumes all the time that are supposed to spend on studying and researching…"*. *"Dentistry schools are in charge of developing dentistry science, while because of limited budget, they cannot keep up with the world in terms of equipment. Therefore, there is also a gap between us and the needs of society…"*.

Covering the actual needs of society

The participants highlighted that the knowledge transferred to dentistry students and graduates can cover the actual needs of society, and the shortcomings are limited to reconstructive dentistry and some special services that are highly expensive and not covered by medical insurance. A professor noted, "*there are shortcomings in the curriculum about reconstructive services needed*

by the society. Still, it covers all the current needs of society for dentistry services…". "Taking into account the number graduates in general and specialized fields, we can say that the current needs of society for dentistry education are covered…".

Storyline

The process of social accountability in the Iran dentistry education system is composed of three parts: antecedent, mechanism, and outcomes. It starts with curriculum design, and factors, such as qualified students and proper educational environment, are the main variables in the antecedent stage with a notable effect on the process. With properly designed and arranged factors in the antecedent stage, positive effects on the process that activates the mechanisms can be expected. The process mechanisms include educational technology, evaluation and feedback in education, and proper interaction with society. In the case that the antecedents are designed properly and the mechanisms demonstrate the required efficiency, the process can meet the actual and potential needs of society (Figure 1).

Discussion

The social accountability process in the dentistry education system was elaborated qualitatively and using a grounded theory approach. As the results showed, the process features three steps of antecedent, mechanism, and outcomes in a conceptual model with 7 categories and 16 subcategories.

Factors such as updating the curriculum, competent students, and a proper educational environment were antecedent factors with a profound impact on the process. The curriculum needs to be updated regularly given the latest needs of society for dentistry services and reconstructive dentistry in particular. In addition, the curriculum content should be designed in a purpose-oriented manner and arranged based on priorities. Daher et al. (2012) conducted a study in Brazil and found that a curriculum based on the needs of society can provide dentistry students with valuable experiences; however, failure to update the curriculum based on the needs of society can lead to unwanted outcomes. Kassebaum et al. (2004) also showed that changes and innovations in curriculum relative to the needs of society were essential for dentistry students and had positive effects on their learning. Witton and Paisi (2021) found that creating society-based learning opportunities in the dentistry program provided the students with better learning and interaction opportunities. To elaborate on the findings, given the continuous progress of medical sciences and dentistry in particular, it is important to stay updated and consistent with changes in society. In addition, there is a need to create better coordination between different disciplines based on the new findings and changes in society to meet the changing needs of society. The outcomes of this coordination should be reflected in the educational process. To this end, we need to create a proper educational environment including recruiting committed and efficient faculty board members and admitting talented and interested students. Blouin and Philibert believed that educational evaluation in the educational environment of instructors, equipment, clinical and theoretical education environments, and educational processes were methods to empower disciplines to meet the needs of society (Philibert and Blouin, 2020). Olsson et al. (2021) showed that a society-oriented curriculum in dentistry education can help students answer the needs of society. Therefore, such a curriculum not only ensures deep learning in students but also makes them more accountable to society (Brondani et al., 2020).

Factors such as educational technology, evaluation and feedback in educational activity, and proper interaction with society affected the process under study. The findings indicated that a proper interaction with society as the core variable was connected with all categories with a direct impact on the process. Purpose/clinical-oriented education, using standard evaluation and assessment methods, and proper and timely interaction with society can be the outcomes of the variables in the antecedent stage. The variables in the process, when supported well by the variables in the antecedent stage, can cover the needs of society. Other studies have also emphasized the educational process, educational technology (Philibert and Blouin, 2020), and proper interaction with society (Strauss et al., 2010). Brondani et al. (2020) found that giving efficient feedback and purposeful evaluation to students based on a society-oriented curriculum can empower the students to be socially accountable. To explain the findings, early, proper, and dynamic interaction of students with society in all disciplines and curricula can train more responsive and social-oriented students. Through such an educational environment, good planning to develop a society-oriented curriculum, and using updated educational technologies, we can expect training empowered and society-oriented graduates.

As the results showed, the dentistry education system was socially accountable to some extent given the shortcomings in the curriculum, education system, student admittance system, and faculty board member recruitment, that is, the system has managed to meet the current needs of society and because of the said shortcomings, it has failed to answer the potential needs of society. Chen et al. (2015) found that dentistry education needed to answer the needs of society, but in practice, it had failed to do so because of the ruling mindset of the graduates who believe oral and dental health should be the priority of society. To be properly accountable to the needs of society, dentistry education needs to detect the requirements and variables in the process and introduce a proper program for them. Several studies have also highlighted the requirements of the process such as curriculum (Kassebaum et al., 2004; Yamani and Fakhari, 2014; Emadzadeh et al., 2016), a decent environment (Kassebaum et al., 2004; Emadzadeh et al., 2016; Ventres et al., 2018), and educational technology and evaluation (Philibert and Blouin, 2020; Olsson et al., 2021). Therefore, the social accountability process in medical education has prerequisites known as antecedents that are considered the foundations and basis of this discipline, and the main mechanism in the process that determines the variables affecting the process and results in the main outcomes of the process, i.e., fulfilling actual and potential needs of society as to dentistry. In this regard, we always need to interact with society efficiently and in a timely manner to cover the cultures, expectations, and preferences of the main communities in society.

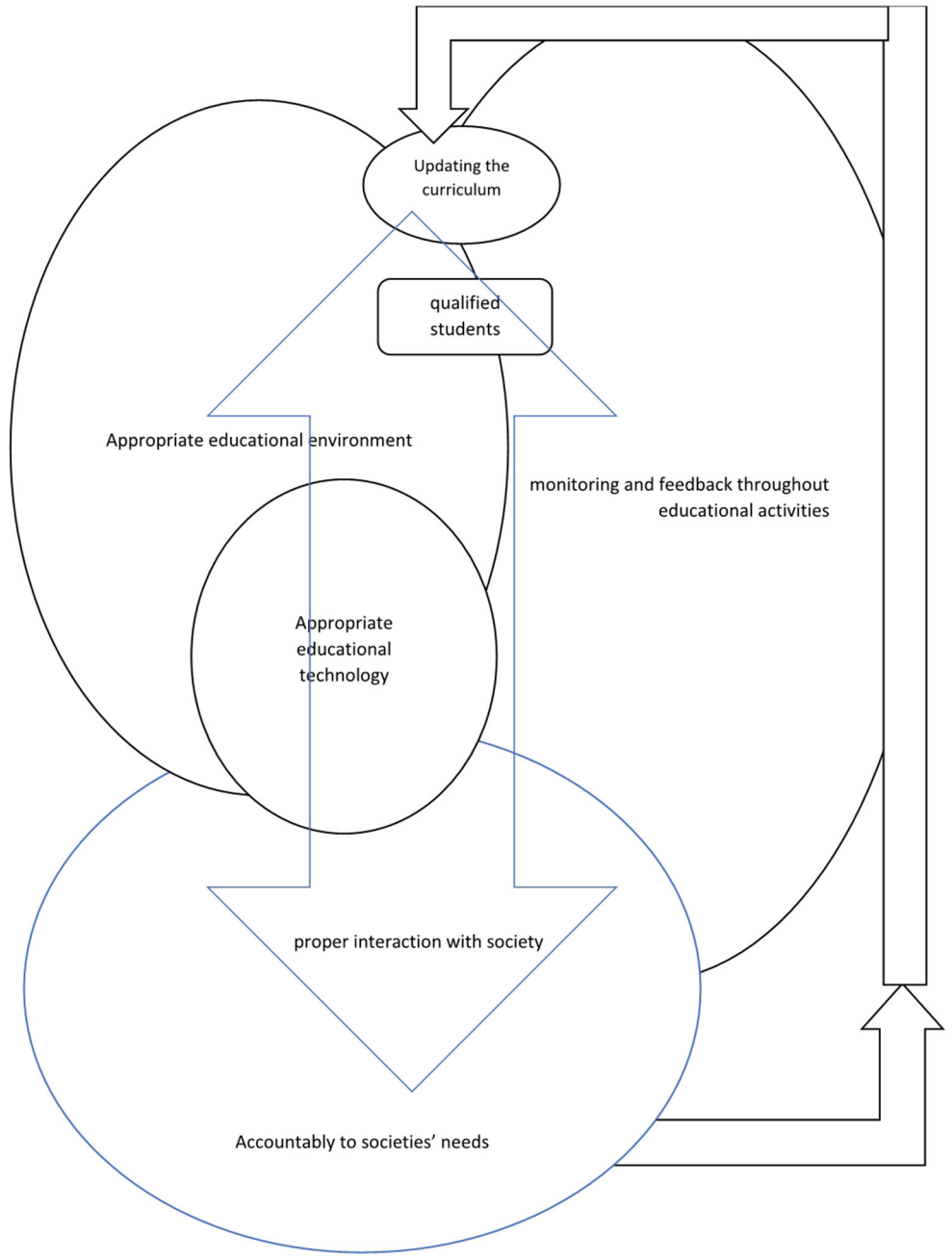

FIGURE 1
Conceptual model of social accountability for the Iranian dentistry sciences education system.

Study limitations

One advantage of the study was the qualitative approach followed in a real environment, which gave a realistic picture of the process under study. Unfortunately, because of the COVID-19 pandemic, the selected participants refused to participate in the interviews for approximately 1 year until the prevalence of the virus was controlled for some periods in Kermanshah City, Iran, and the participants agreed to attend the interviews. Given the situation, selecting the participants and conducting the interviews took more than 1.5 years, which was due to the closure of schools and the reluctance of the participants to attend the interviews.

Conclusion

In summary, the results showed that the process of being accountable to society's needs in dentistry education featured three stages: antecedents, mechanism, and results. The process also included 7 categories and 16 subcategories in which proper interaction with society was the core variable. The results indicated

that the process has been successful in covering the actual needs of society for dentistry services, but it needs improvements and better planning to cover the potential needs of society.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by IR.NASRME.REC.1397.2554. The patients/participants provided their written informed consent to participate in this study.

Author contributions

MI and AJ contributed to designing the manuscript. AJ, MI, PN, FR, and MD collected the data. Data analyses were performed by AJ and MD. The final report and manuscript were written by AJ, PN, and MI. All authors participated and approved the manuscript, design, read, and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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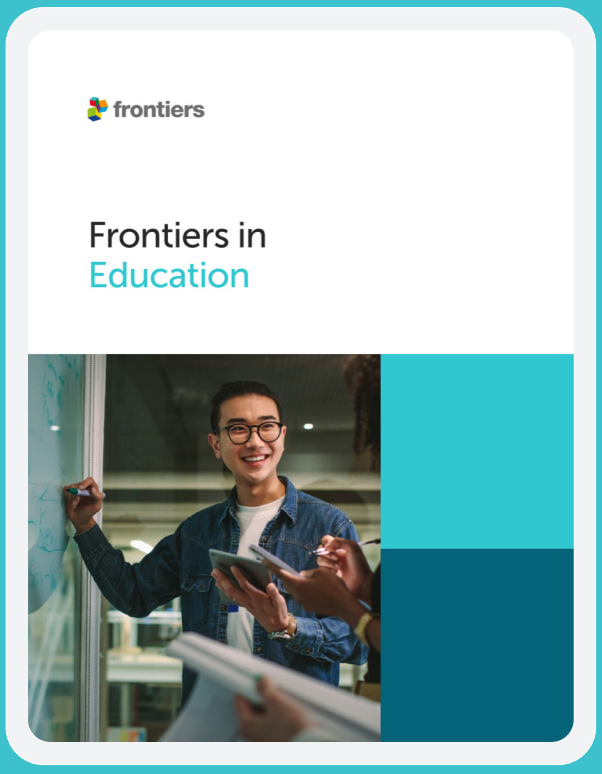

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