Research article

Empowering STEM educators in cross-cultural higher education contexts: professional development strategies for sustainable workforce readiness

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Abstract: In the context of the internationalization of higher education, the development of STEM education increasingly relies on teachers' adaptability and professional competence in cross-cultural environments. This study aimed to empower STEM educators in cross-cultural settings and improve the sustainability of teachers' professional development (PD) by exploring how STEM teachers in Sino-Overseas Joint Education Programs (SOJEPs) experience PD within multicultural teaching contexts, exploring their integration of local educational needs with international pedagogical frameworks to enable sustainable teaching transformation. Grounded in Guskey's PD model and Hofstede's cultural theory, this qualitative study adopted grounded theory analysis for data collected by semi-structured interviews, institutional documents, and classroom observations from six STEM teachers in SOJEPs at an internationalized Chinese university. The findings reveal that STEM teachers in SOJEPs encounter challenges such as language barriers, pedagogical conflicts, and limited intercultural sensitivity. Although most teachers engage positively in PD activities, the transformation of training into classroom practice is hindered by factors like institutional constraints and student learning cultures. However, some teachers develop effective strategies, such as bilingual project-based learning, curriculum standard integration, and reflective teaching practices, demonstrating their evolving roles as cultural mediators and curriculum co-designers. A conceptual model—the Teacher Cross-Cultural Growth Pathway—is proposed to illustrate the dynamic process between PD engagement and cross-cultural adaptation. The study underscores that effective PD must be context-sensitive, culturally responsive, and career-oriented to truly support pedagogical

transformation in SOJEPs, calling for the construction of integrated support systems that link PD to sustainable cross-cultural teaching, global competence, and employment outcomes.

Keywords: intercultural competence, STEM Education, teacher professional development, sustainable teaching innovation, transnational education

1. Introduction

In the context of accelerating globalization, STEM (science, technology, engineering, and mathematics) education has been increasingly recognized as a key driver in advancing the Sustainable Development Goals (SDGs). According to UNESCO's Education 2030 Agenda, STEM education not only enhances young people's scientific literacy and innovative capacities but also lays the foundation for cultivating talent capable of addressing complex global challenges [1]. As one of the essential pillars of 21st-century education, STEM education is undergoing a profound shift—from content transmission to a stronger emphasis on problem-based learning, critical thinking, and global competence [2,3]. This transformation underscores the need to align teaching practices with sustainability-oriented educational goals while preparing a workforce ready to contribute meaningfully to a knowledge-based global economy.

Against this backdrop, Sino-Overseas Joint Education Programs (SOJEPs) have emerged as a vital pathway for advancing the internationalization of higher education in China and nurturing globally competent talents [4,5]. With the increasing implementation of internationalized higher education initiatives in China, STEM education has evolved into a more culturally diverse and globally embedded pedagogical ecosystem [6]. However, this integration process is far from seamless. Cultural discrepancies, conflicting pedagogical beliefs, and divergent curricular goals have posed significant challenges to cross-cultural STEM instruction [7,8].

Cross-cultural STEM education refers to science, technology, engineering, and mathematics teaching conducted in multicultural settings, involving instructional interactions among teachers and students from diverse cultural systems, educational philosophies, and linguistic backgrounds. Its core lies in integrating global perspectives with local teaching needs, emphasizing cross-cultural understanding, cross-linguistic communication, and the development of global competence [9,10]. In the context of SOJEPs, this concept involves not only the localization of international curricula but also the adaptation of teachers' roles and pedagogical innovations within cross-cultural environments.

Teachers, as the key facilitators in the instructional process, are often the first to confront these issues. They are expected to preserve contextual adaptability to the local educational system while effectively incorporating international best practices, thereby achieving a coherent blend of localization and internationalization [11]. Particularly within SOJEPs, teachers are no longer mere transmitters of knowledge but are repositioned as cultural mediators, innovative practitioners, and advocates of sustainability-oriented education [12]. This expanded role demands a higher level of professional competency, cultural sensitivity, and ongoing development. Supporting teachers in this transformation—enabling them to thrive in cross-cultural environments, enhance pedagogical adaptability, and develop global teaching competencies—has become a critical priority for both educational researchers and policymakers [13,14].

Professional development (PD) serves as a critical pathway for enhancing teaching quality and

building educators' capacity to adapt to ongoing educational reforms. In the context of cross-cultural STEM education, PD is particularly vital, as it enables teachers to navigate intercultural complexities while designing effective and inclusive pedagogies [15,16]. Through systematic training, reflective teaching practices, and culturally responsive support mechanisms, teachers can develop both intercultural understanding and pedagogical adaptability. This dual capability empowers them to address local learners' needs effectively while aligning with global standards for high-quality education [13,14]. Nevertheless, empirical research on how STEM teachers engage in PD within the framework of SOJEPs remains scarce. Limited attention has been given to the strategies through which these educators achieve meaningful integration of localized pedagogical goals with international teaching philosophies, particularly within the fast-changing terrain of globalized higher education [17,18].

2. Literature review

2.1. Integrating STEM education with Sustainable Development Goals (SDGs)

Since the early 21st century, STEM education has evolved beyond its initial focus on content knowledge transmission toward an emphasis on interdisciplinary integration, real-world application, and global competence development [19,20]. With the growing global urgency around sustainable development, the United Nations' SDGs have provided both direction and impetus for transforming STEM education into a vehicle for fostering not only scientific literacy but also civic responsibility and problem-solving capacity [21]. In this context, higher education institutions are increasingly viewed as critical arenas for cultivating globally competent, sustainability-oriented innovators. STEM courses at the tertiary level are expected to not only enhance students' technological competencies but also develop their capacity to address complex, real-world challenges—such as climate change, social inequality, and sustainable infrastructure [22,23].

Recent studies have highlighted the urgency of integrating sustainability themes—including ecological design, resource management, and climate action—into STEM curriculum design [2,24]. This perspective, often referred to as *sustainable STEM education*, emphasizes the need for pedagogies that promote systemic thinking, value-based decision-making, and interdisciplinary learning [25]. Crucially, research stresses that teachers play a central role in realizing this pedagogical transformation. They are not merely deliverers of technical content but architects of future-oriented learning environments [26]. As key change agents, STEM educators must develop the capabilities to integrate sustainability into lesson planning, engage students in critical reflection, and promote cross-disciplinary connections that mirror the complexity of global issues [27,28].

Hence, teacher PD must encompass training in systems thinking, interdisciplinary curriculum design, and socio-environmental responsibility to ensure STEM education aligns meaningfully with the SDGs. Without such pedagogical innovation and capacity-building, efforts to integrate sustainability into STEM education risk remaining superficial or fragmented [29].

2.2. Key elements and transformative roles of teacher PD

Teacher PD is a core mechanism for improving educational quality and responding to educational transformation [30]. According to Guskey's five-level model of teacher PD, teacher growth should evolve from participation and learning to changes in instructional practice, improvement in student learning outcomes, and ultimately, transformation of the organizational culture of education [31,32].

Particularly in STEM education, teachers are required to constantly update their pedagogical beliefs, acquire new technological tools, and understand the sustainability-oriented teaching objectives, all of which demand continuous, systematic, and contextually relevant PD support [13,33,34].

Effective PD for STEM teachers typically demonstrates the following key characteristics: (1) practice-based and problem-oriented learning; (2) collaborative and reflective professional learning communities; (3) integration of the cultural and institutional contexts of specific teaching environments; and (4) focus on impact evaluation and experience sharing [31,34,35,36]. In recent years, research has also increasingly focused on the "cultural adaptability" of PD programs—how, in cross-cultural settings, training content and delivery methods can be adjusted to fit teachers' cultural contexts in order to foster cognitive transformation and changes in instructional behaviors [37,38].

Moreover, the internationalization of education has introduced new demands on teacher PD. On one hand, teachers are expected to develop multilingual teaching skills, understand international curriculum standards, and possess intercultural communication competencies [39,40,41]. On the other hand, they must also be capable of integrating these global competencies with national education policies and the specific needs of local students, thereby forming effective localization strategies. This transformation cannot be achieved through isolated training sessions but requires the construction of a sustainable support ecosystem, including leadership support from school administrators, collaborative platforms among peers, and policy-driven mechanisms [30,32,42].

2.3. Cross-cultural teaching challenges and adaptation strategies in SOJEPs

SOJEPs are typically established through collaborations between Chinese universities and foreign institutions and are officially approved by the Ministry of Education of China [43]. These programs are often housed in universities with strong internationalization strategies and heavily rely on bilingual instruction and international curriculum accreditation. As of February 2025, there are a total of 1979 approved SOJEPs across China, covering undergraduate and above levels, reflecting their extensive role in promoting the internationalization of China's higher education [43]. These programs include various models such as dual-degree and joint cultivation. Students are required to meet the curriculum requirements of both the Chinese and foreign institutions, and the instruction team is jointly composed of members from both sides [44].

SOJEPs represent a significant form of internationalization in China's higher education. Through collaboration with overseas universities in curriculum design, faculty deployment, and the integration of teaching resources, these programs aim to offer students an educational experience that combines local characteristics with global perspectives [45,46]. However, in the implementation process—especially in STEM courses—SOJEPs frequently face complex cross-cultural teaching challenges [47,48].

One of the primary issues is the difference in pedagogical philosophies. For instance, Western educators often emphasize enlightened learning and the development of critical thinking, while Chinese educators are more inclined toward systematic knowledge transmission and exam-oriented instructional organization [49]. Such conceptual divergences may lead to inconsistencies in understanding course objectives and misalignments in instructional approaches. Furthermore, differences in classroom language use and communication styles may create misunderstandings between teachers and students from different cultural backgrounds. These may be caused by not only language barriers but also variations in non-verbal communication situations, which can lead to

discomfort and confusion in the teaching-learning process [50,51].

Studies suggest several effective strategies to cope with these cross-cultural teaching challenges, including culture-oriented PD, bilingual instructional design, team teaching, and teaching observation-feedback mechanisms [52,53]. Among these, intercultural teaching collaboration and reflective dialogue between faculty members are considered crucial pathways to facilitate mutual professional understanding and cultural adaptation [54]. However, most existing research continues to focus on student-level intercultural adjustment or curriculum design, while empirical investigations into how instructors achieve cultural adaptation and professional growth remain limited—particularly in the STEM field, which features high levels of integration and technological complexity [55,56].

2.4. Research gaps and significance

Although extensive research has explored sustainable transformation paths in STEM education and effective strategies for teacher PD [2], and growing attention has been given to teaching adaptation in cross-cultural educational contexts, systematic studies focusing on how STEM teachers navigate the integration between localization and internationalization within the context of SOJEPs remain limited [57]. In particular, regarding PD, although teacher identity formation has been widely explored in general education contexts [58], there remains a lack of focused research on how STEM teachers develop, negotiate, and transform their professional identities in cross-cultural joint education programs. In particular, in SOJEPs, where teachers must navigate hybrid institutional cultures and reconcile divergent pedagogical norms, more contextualized and empirical investigations into identity reconstruction and pedagogical innovation are still needed [59].

Furthermore, existing research rarely examines teachers' experiences of cultural adaptation in combination with the institutional arrangements, curriculum design, and administrative mechanisms of specific educational programs [60,61]. This disconnect between theory and practice has constrained the capacity of policymakers and training providers to design systematic support strategies for STEM teachers [62].

Therefore, the aim of this study is to address three specific gaps identified in the current research. First, it focuses on SOJEPs as educational platforms where internationalization and localization are highly integrated, analyzing how STEM teachers adapt to intercultural teaching environments. Second, it integrates Guskey's model of teacher PD with Hofstede's cultural dimensions theory to construct a multi-level analytical framework for understanding teacher transformation [63,64]. Third, it adopts a multi-method qualitative approach, including interviews, classroom observations, and document analysis, to systematically examine teachers' practices in blending local and international pedagogies and to propose actionable policy recommendations [65,66].

The core aim of this study is to deepen the understanding of teacher PD in cross-cultural STEM teaching environments and to provide practice-based recommendations for education policymakers, university administrators, and institutions. These recommendations are intended to strengthen the support system for teachers and improve the quality assurance mechanisms in SOJEPs.

3. Theoretical framework

This study aims to explore how STEM teachers within the context of SOJEPs integrate localized

and internationalized instruction during their PD. To gain a deeper understanding of teachers' developmental trajectories and cultural adaptation mechanisms in cross-cultural contexts, this research adopts Guskey's [63] five-level model of teacher PD and Hofstede's [64] cultural dimensions theory as the theoretical foundation, constructing a framework that intersects teacher development with intercultural adaptation [31,64].

Guskey's model comprises five critical levels: participants' reactions, learning, organizational support and change, use of new knowledge and skills, and student learning outcomes. The model emphasizes that teacher growth is a systematic, hierarchical process, particularly suitable for analyzing how teachers apply professional learning to practice and improve instruction with organizational support [30,63]. In the context of SOJEPs, STEM teachers face dual challenges: aligning with international pedagogical standards while responding to local educational policies and the cultural needs of students [57]. Therefore, teacher development is not merely an update of knowledge and skills but a process of reconstructing intercultural cognition and teaching identity. Guskey's framework helps understand this developmental trajectory from emotional responses and cognitive transformation to behavioral change in pedagogy [59].

Meanwhile, Hofstede's cultural dimensions theory addresses how cultural backgrounds shape individual behaviors and perceptions, through dimensions such as power distance, individualism vs. collectivism, uncertainty avoidance, masculinity vs. femininity, long-term vs. short-term orientation, and indulgence vs. restraint [67]. Within SOJEPs, teachers often face intercultural recognition mismatch regarding teaching styles, classroom interaction norms, or curriculum goals, resulting from differing cultural expectations [60]. Understanding these dimensions facilitates teachers' adjustments in instructional behaviors, intercultural communication, and relationship building in more inclusive learning environments [61].

Integrating Guskey's model with Hofstede's theory provides a dual-path framework to illuminate teacher development in SOJEPs: on the one hand, through formal professional learning and pedagogical enhancement; on the other, through developing intercultural awareness in diverse cultural settings. This integrative framework enables a systematic analysis of teacher growth from cognition to practice and serves as the theoretical foundation for proposing targeted, context-sensitive support strategies. Based on this framework, the study investigates teachers' PD and cultural adaptation in cross-cultural settings, offering practice-oriented recommendations derived from empirical findings.

Against this backdrop, this study aims to investigate how STEM educators in SOJEPs negotiate professional growth within cross-cultural teaching environments, focusing on the fusion of local educational imperatives and global instructional paradigms. Specifically, the study explores how PD pathways support sustainable transformation in teaching practice and promote intercultural competence. The central research questions guiding this study are:

1. What are the main teaching challenges faced by STEM educators in cross-cultural environments?

2. How do teachers integrate localized and international teaching philosophies within the collaborative framework of SOJEPs?

3. Which PD strategies are most effective in facilitating pedagogical transformation and capability enhancement?

4. What types of policy and support mechanisms can effectively improve teachers' intercultural

teaching competencies?

By employing a multi-method qualitative approach—including in-depth semi-structured interviews, document analysis, and classroom observations—this study seeks to illuminate both the growth trajectories and barriers experienced by teachers in intercultural educational settings. The findings will provide empirical insights for higher education policymakers and professional training providers, offering practical recommendations to enhance teacher development and educational quality in a sustainable manner [35,42].

4. Methodology

4.1. Research design

The study adopted a grounded theory qualitative research design to gain an in-depth understanding of how STEM teachers within SOJEPs respond to cross-cultural teaching challenges and integrate localized and international pedagogical approaches during their PD. Grounded theory emphasizes generating theory from empirical data, where researchers develop theoretical frameworks through a systematic process of open coding, axial coding, and selective coding [68]. In this study, data collection integrated classroom observations, semi-structured interviews, and document analysis. This design provides robust empirical support for understanding mechanisms of teacher development and pathways of cultural adaptation in diverse educational environments.

4.2. Participants and samples

The participants in this study are six STEM teachers from SOJEPs based in Chinese internationalized universities. These teachers are bilingual (Chinese and English) and have attended PD programs organized internally by the university or through external institutions [30]. The sample size was determined based on the principle of data saturation—where no new themes or insights emerged from additional interviews—indicating that sufficient depth and diversity of perspectives had been captured [69]. The six teachers represent various STEM disciplines such as computer science, materials science, and engineering, and possess substantial hands-on experience in cross-cultural instruction, curriculum design, and student engagement [60].

To ensure diversity and representativeness, the sample was balanced across several key dimensions: gender, years of teaching experience, and international teaching background. Details of the participants are presented in Table 1 below.

Table 1. Demographics of the respondents.

Teacher	Gender	Age	Instruction major	Teaching years	International experience
T1	M	41	Industrial engineering	12	Overseas study
T2	F	40		7	Visiting scholar
T3	M	44	Computer sci-tech	9	International exchange
T4	F	38		10	Overseas training experience
T5	F	42	Material science	7	None
T6	M	34		3	Overseas work experience

4.3. Data collection

This study integrates three types of data sources to establish a triangulation mechanism [70], aiming to enhance the credibility of the data and the explanatory power of the findings [71]. The details are shown in Table 2 below.

Table 2. Triangulation of data collection.

Data source	Data content	Process in details
Semi-structured interview	• The cultural and instructional challenges faced by STEM teachers in SOJEPs. • Their attitudes toward PD activities, level of participation, and perceived outcomes. • How teachers integrate local and international elements into their actual teaching. • Teachers' expectations for future PD policies and support mechanisms.	Each interview lasted approximately 60–90 minutes, and the entire process was audio recorded and transcribed. Prior to the interviews, written informed consent was obtained via email to ensure compliance with research ethics.
Document analysis	Relevant training documents, instructional design materials, and course evaluation reports related to STEM teachers were collected and analyzed, including: • Teacher development manuals or training handouts. • Teachers' personal teaching reflection journals. • Course syllabi and assignment briefs. • Periodic self-evaluation reports submitted by the teachers.	The document analysis aimed to capture evidence of teachers' knowledge construction and practical application during PD activities, and to further validate the transformation processes revealed in the interview data.
Classroom observation	One class session per teacher was selected for non-participant classroom observation, with a focus on: • The actual implementation of teaching strategies (e.g., bilingual instruction, culturally comparative guidance, integration of international case studies). • Patterns of teaching interaction (questioning techniques, feedback mechanisms, teacher-student language interaction). • Student responses and levels of engagement.	Observation data were recorded using a structured observation sheet to support the analysis of teachers' specific instructional practices. (The observation form sample is provided in the appendix.)

4.4. Data analysis

The study employed the grounded theory approach [68] to analyze the collected qualitative data. This method emphasizes generating theory from data and is particularly suitable for exploratory research, especially in understanding teachers' developmental processes and experiential mechanisms within specific educational contexts. The analysis followed three key stages:

1. Open coding: Interview transcripts, observation notes, and document materials were analyzed line-by-line to identify key segments related to challenges faced by teachers in cross-cultural teaching, coping strategies, and conceptual tensions, from which initial labels were generated.

2. Axial coding: Through constant comparison and categorization, the initial concepts were synthesized into higher-level categories such as pedagogical integration, PD participation patterns, cross-cultural adaptation mechanisms, and development pathways.

3. Selective coding: With teachers' cross-cultural adaptation and professional growth as the core category, all related categories were integrated to construct a theoretical model of teachers' cross-cultural growth pathway.

Throughout the process, Nvivo12 software was used for coding management to ensure the systematic structure of theory generation and logical consistency of data interpretation.

4.5. Credibility and confirmability

To enhance the credibility and transparency of the data analysis process, this study incorporated "peer debriefing" and "partial member-checking" strategies during the coding and theme categorization stages [72]. The specific procedures are as follows:

1. Peer debriefing: The researchers invited two doctoral peers with expertise in education and qualitative research to participate in the regular feedback process during data analysis. After each round of coding, the researchers submitted the preliminary coding framework and representative segments to the peers for blind review. The discussion focused on aspects such as "whether the concept definitions are clear", "whether the coding logic is consistent", and "whether there are any interpretive biases". Based on the feedback, the researchers adjusted some ambiguous or overlapping coding labels.

2. Partial member-checking: After the initial analysis phase was completed, the researchers invited three out of the six participating teachers to take part in the subsequent feedback process. Using interview summaries and coding outlines as the basis, the researchers sought the teachers' feedback and any additional comments. The three respondents expressed strong agreement with the analysis results.

During the analysis process, the researcher maintained a reflexive stance to avoid preconceived judgments and strived to understand participants' cognition and behavioral choices within their own contextual frameworks [73]. By implementing these procedures, the study enhanced the credibility and confirmability of the interpretation process, ensuring a deeper analysis while reducing the risk of subjective bias that may arise from a single researcher's perspective.

5. Findings

Through in-depth interviews, classroom observations, and document analysis involving six STEM teachers engaged in SOJEPs, the study identified four core findings: (1) key challenges in intercultural teaching, (2) participation in and outcomes of PD, (3) representative cases of localization—internationalization integration strategies, and (4) a model of teachers' intercultural adaptation and professional growth. These findings are presented in detail below.

5.1. Challenge identification: Language barriers, pedagogical conflicts, and cultural sensitivity gaps

The primary challenge faced by STEM teachers in SOJEPs was the asymmetry in language

proficiency. Although all participants were capable of delivering content in English, difficulties remained in articulating subject-specific terminology, managing classroom interactions, and interpreting student feedback. As Teacher 3 noted:

> *"I can deliver the content in English without a problem, but when students ask deeper questions, I start to feel nervous—worried that I can't explain it clearly."*
> (T3)

A second common issue involved pedagogical conflicts. Some teachers expressed that overseas curricula emphasized critical thinking, project-based learning, and inquiry-oriented instruction, whereas traditional Chinese teaching focused more on knowledge transmission and precise problem-solving. This divergence created fundamental differences in classroom structure and assessment practices. As Teacher 1 shared:

> *"The foreign partner wants us to inspire more discussion, but my students are used to lectures—once I ask a question, no one dares to respond."(T1)*

Moreover, differences in cultural sensitivity were evident in teachers' responses to multicultural expressions. Several teachers (T2, T6) admitted to lacking sufficient understanding in areas such as gender and communication styles, which sometimes led to misunderstandings or awkward silences in class. These challenges collectively undermined teachers' classroom confidence, student engagement, and overall achievement of course objectives.

5.2. Participation in and outcomes of PD: Positive attitudes, limited transformation

Most teachers had participated in PD activities offered by either their institutions or international partners, including pedagogical workshops, intercultural communication seminars, online modules, and internationally recognized certification programs. Overall, teachers showed a positive attitude toward these trainings, commonly describing them as helpful in "broadening horizons", "recognizing gaps", and "exposing new models", (as cited from interview responses). These direct quotes highlight teachers' reflections on how PD contributed to their awareness of pedagogical diversity and cross-cultural teaching practices.

However, the transformation of training outcomes into classroom practices remained limited. Teachers frequently cited constraints such as time pressure, rigid curricular requirements, and low student receptivity as barriers to implementing innovative teaching approaches. As T5 explained:

> *"During the training, I found the cases inspiring, but once I returned to my own class, various constraints made me revert to the usual way of teaching." (T5)*

Similarly, T2 noted:

> *"I wanted to introduce group-based discussion like they showed us, but my students were not used to that. They stayed silent, and it felt awkward. So I gave up after a few tries." (T2)*

Upon analyzing teachers' PD engagement and perceived outcomes, the study identified three elements that contribute to improving the effectiveness of PD:

1. Peer support mechanisms: Informal learning groups or inter-institutional communities allow

teachers to support each other contextually and share practical experiences. Several teachers emphasized the importance, as T1 shared:

> *"I often discuss teaching ideas with a colleague who also teaches a joint program course. We try out things together and adjust based on what works. It helps a lot not doing this alone." (T1)*

2. Reflective practice mechanisms: Structured reflective tools, such as regular teaching logs or observation-based feedback, help internalize training content. Some participants described how structured reflection helped them internalize PD content. For example, T4 said:

> *"After each class, I started writing a short reflection—not required, just for myself. It helped me see what went well, what didn't, and sometimes I would remember something from the training and try it again differently." (T4)*

3. Blended PD design: A combination of online and offline delivery, combining global capabilities with industry, with longitudinal follow-up enhances content retention and facilitates classroom application. Evidence from training reports and post-workshop reflection documents suggests that teachers benefited well from PD programs. T6's PD reflection form notes:

> *"The video module was useful, but the most beneficial part was the follow-up sharing session. Listening to colleagues' experiences in applying strategies gave me ideas for adapting my own course plan." (PD Reflection Report, T6)*

These findings underscore that while PD activities are generally well-received, the presence of contextual support mechanisms is essential to bridge the gap between learning and implementation. Without these elements, even motivated teachers may struggle to implement pedagogical change in restrictive environments.

5.3. Integration strategy cases: Project-based learning, bilingual teaching, and standards alignment

In response to intercultural challenges, some teachers demonstrated self-adjustment and integrative capabilities, developing pedagogical strategies that align both with local practices and international expectations. These strategies mainly manifested in the following three areas:

5.3.1. Project-based learning for deep understanding

Teacher T6 guided students in a class on "China's Green Energy" to conduct cross-group collaborative research, requiring them to write reports in both Chinese and English and to design solutions aligned with the United Nations Sustainable Development Goal (SDG). This approach cultivated students' global perspectives while preserving local contextual applications.

> *"Through this project, students started to realize that we can also discuss international topics using local cases." (T6)*

5.3.2. Bilingual teaching for multilingual and cultural integration

Teachers commonly adopted a "bilingual segmentation" approach: English was used to explain

core concepts, while Chinese was employed in discussions and feedback to enhance comprehension and participation. T1 even encouraged students to take notes in their mother tongue and then translate them into English for presentations.

5.3.3. Alignment with teaching standards and localization of assessment tools

Some teachers integrated international curriculum benchmarks with domestic standards, blending evaluation dimensions and assessment methods. For instance, Teacher 2 combined China's engineering education accreditation criteria with the U.S. STEM Rubric to design a hybrid grading scale.

6. Discussion

The study reveals the pathways through which STEM teachers in SOJEPs handle intercultural teaching challenges, as well as the dynamic features of how they localize and internationalize teaching strategies through PD. The findings highlight teachers' practices in responding to cultural differences and deepen our understanding of how PD facilitates both cross-cultural teaching adaptation and curriculum innovation. Furthermore, the study extends the theoretical scope of PD within the context of educational internationalization. Based on these, the following discussion details three dimensions, as follows: (1) the mechanisms of teachers' cross-cultural adaptation and PD transformation; (2) the connection between PD and employment-oriented curriculum design; and (3) the co-constructed pathways of localization and internationalization in teaching practices.

6.1. From conceptual engagement to practical transformation: How PD facilitates intercultural teaching adaptation

This study found that STEM teachers participating in PD activities generally expressed positive attitudes toward "internationalized teaching", yet the actual transformation of training knowledge into classroom practices faced significant obstacles. This aligns with Guskey's [63] five-level model of PD, which conceptualizes teacher growth as a progressive spiral through stages of reaction, learning, behavioral change, organizational support, and student outcomes. However, in the context of SOJEPs, while teachers reported considerable benefits during the "learning" phase, their transition to "behavioral change" was often hindered by many constraints (as illustrated by T5 and T2).

These findings resonate with Desimone's framework for effective PD, which emphasizes content focus, active learning, sustainable duration, and group cooperation. The peer support mechanisms, structured reflection, and blended design mentioned by respondents reflect concrete manifestations of Desimone's model components, particularly "group cooperation" and "continuous learning". For example, T1's collaborative teaching practices and T6's use of reflective logs illustrate how teachers explored strategies through informal learning communities—an idea closely aligned with Borko's theory of "communities of practice".

Moreover, the effectiveness of PD was moderated by the surrounding teaching culture. For instance, T6's integration of SDGs into instruction demonstrates how teachers are attempting to merge global perspectives with local issues. This process of "cultural bridging" echoes Banks' constructivist theory of cross-cultural teaching [74], which emphasizes the evolving role of teachers as cross-cultural mediators.

6.2. Connecting teacher PD with the labor market: How international curriculum standards influence employment-oriented teaching

The study also found that some teachers, influenced by PD, proactively integrated international curriculum assessment standards with domestic accreditation systems to explore a "dual-track" instructional model (as in the case of T2). This approach not only enhanced the external alignment of the curriculum but also supported the development of students' employability skills.

This finding aligns closely with the OECD's research [75] on the growing connection between global education and labor market trends. The OECD emphasizes that teachers, as "capacity enablers", should possess the ability to align instructional goals with professional competences. In this study, several teachers applied international perspectives gained through PD to design their instructional content toward real-world job requirements—illustrating this role transformation.

Moreover, the British Council [76] argues that future education in engineering and technology should emphasize the convergence of global competence and industry needs, which supports this study's recommendation for blended PD design.

6.3. The dynamic process of integrating localization and internationalization: Emphasizing the co-construction model of "Local Identity + Global Competence"

Teaching practices within SOJEPs demonstrate that localization and internationalization should not be viewed as opposing forces, but rather as components of a mutual integration model (as illustrated in T6's project-based learning case and T1's bilingual teaching strategy). This aligns with the "Glonacal-Agency-Heuristic" proposed by Marginson and Rhoades [77], which emphasizes that in transnational educational collaborations, local educational agents must actively adapt and re-contextualize external pedagogical models in accordance with local cultural dynamics.

Through cross-linguistic mediation, thematic course re-structuring, and flexible assessment design, teachers not only strengthened students' cultural identity but also advanced the development of their global competence. This pedagogical shift enhanced students' critical thinking, collaborative skills, and multilingual communication abilities—all core components of the "global competence" in the PISA assessment framework [14].

Furthermore, the evolving role of teachers—from knowledge transmitters to "cultural mediators" and "curriculum designers"—also supports Schweisfurth's theory [78] on teachers' agency in adapting to global education reforms.

Overall, this study, through interviews, classroom observations, and document analysis, verifies the key role of PD in enhancing STEM teachers' cross-cultural teaching abilities and provides empirical insights into the "localization-internationalization" integrated educational model. Teachers are no longer traditional knowledge transmitters, but constructors and mediators in the flow of global educational cultures. Therefore, future teacher PD programs should further evolve into a comprehensive support system that is grounded in teaching context, centered on cultural sensitivity, oriented toward career development, and characterized by international collaboration [13,79].

7. Conclusions

This study focuses on the teaching practices of STEM educators within SOJEPs, examining the key cross-cultural challenges they face, their strategies for integrating teaching approaches, and their

PD pathway. The findings reveal that although teachers generally hold a positive attitude toward internationalized teaching, their pedagogical transformation is often constrained by institutional limitations, student response, and curriculum requirements. Effective PD for teachers relies on peer support, a reflection mechanism, and blended PD designs to facilitate the transition from conceptual understanding to practical application. Moreover, teachers are gradually shifting from knowledge transmitters to "cultural mediators" and co-constructors of curriculum, achieving a bidirectional integration of local and global elements in their instruction. This study contributes to the theoretical understanding of STEM teaching in global education contexts and emphasizes that teacher PD should be a dynamic, adaptive process that bridges global competence with local educational realities.

Based on the findings of this study, and drawing from Guskey's five-level model of teacher PD and Hofstede's cultural dimensions theory, a conceptual framework—the Teacher Cross-Cultural Growth Pathway (see Figure 1)—was developed to illustrate the interactive process between teacher PD and cultural adaptation.
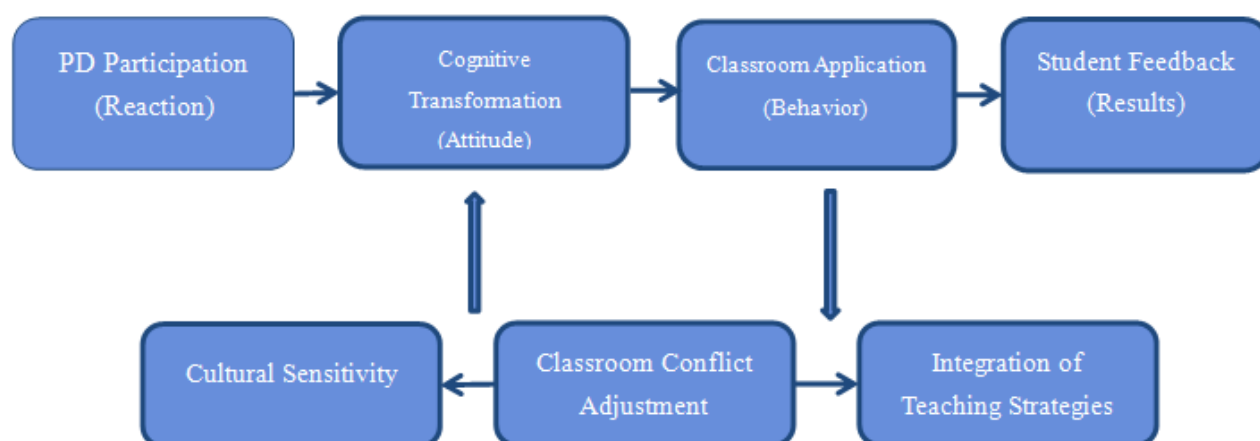

Figure 1. Teacher cross-cultural growth pathway.

This model demonstrates how teachers undergo progressive changes in cognition, attitude, and behavior after participating in PD activities, while gradually enhancing their cross-cultural sensitivity and instructional integration capacity in cross-cultural teaching contexts. The model serves as an integrated representation of Guskey's five levels—reaction, learning, organizational support, practice, and student outcomes—aligned with Hofstede's strategies for managing cultural differences. The "growth pathway" not only captures the developmental trajectory of individual teacher' cross-cultural teaching competence but also highlights how PD contributes to the transformation of their professional roles. It thus provides a theoretical foundation for designing future PD support systems that are more culturally adaptive and contextually grounded.

8. Limitations and recommendations

Although this study reveals the development trajectories and cultural adaptation mechanisms of some STEM teachers in SOJEPs through a multiple-case qualitative approach, there are still certain limitations. Future research can expand in the following two areas:

8.1. Diversification of research subjects

This study focuses on six teachers from a Chinese internationalized university. Future research could include teachers from vocational colleges, private universities, and even overseas partner institutions to enhance the comparative perspective and theoretical generalizability.

Teachers from different academic backgrounds (e.g., humanities and social sciences, medical education) could be introduced to explore the differences and path characteristics of cultural integration across various disciplines.

8.2. Vertical deepening of research methods

It is recommended to conduct long-term follow-up studies to observe changes in teachers' capabilities over 3 or 5 years, further revealing the effects of PD at different stages of their careers.

A combination of quantitative surveys and qualitative follow-up interviews could be employed to enhance the overall explanatory power of the study and provide more valuable policy recommendations.

Author contributions

Cuiyun Wang: Conceptualization, Methodology, Formal Analysis, Writing original draft and the revised manuscript; Norlizah C. H.: Supervision, Methodology, review and validation; Mokhtar Muhamad: Supervision, Methodology, review and validation; Shuran, Zhang: data analysis, review and validation. All authors have read and approved the final version of the manuscript for publication.

Use of Generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare that there is no conflict of interest in this manuscript.

Ethics declaration

Ethical considerations were rigorously upheld to safeguard the rights and welfare of participants. Respondents were informed about the study's purpose, assured of confidentiality, and made aware that their participation was voluntary.

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