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How to Improve the Sustainability of University-Industry Collaboration? A Case Study Based on an Integrated Circuit Engineers Training Program

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Abstract

Background: Over recent decades, significant resources and attention have been invested in promoting University-Industry Collaboration (UIC), with the successful implementation of such partnerships remaining a persistent concern. In particular, the long-term nature of students training presents a unique challenge for teaching-focused UIC, where ensuring the sustainability of collaborations beyond their initial success remains a complex issue.

Purpose: Confronted with the insufficient motivation of industries to sustain their involvement in teaching-focused UIC and the relatively vulnerable position of universities in these partnerships, this study aims to explore how to effectively enhance the sustainability of teaching-focused UIC.

Method: This study adopts a case study approach centered on the Integrated Circuit field, examining an engineering doctoral program at a leading university in China. Using an integrative implementation framework for UIC, we explore effective strategies employed in this case to enhance the sustainability of UIC across four dimensions: institutional, relationship, output, and framework.

Results: Government support acts as a key driver in establishing UIC, while training outcomes are essential for sustaining these collaborations. Universities can enhance industry motivation and foster long-term partnerships by adopting strategies such as bridging boundary organizations, corporatizing large-scale infrastructure, and developing student evaluation criteria that align with enterprise needs.

Conclusion: The findings address the limited attention given to teaching-focused UIC in existing studies and shift the research focus from successful implementation to the sustainability of such collaborations, offering both theoretical and practical insights into UIC research and contributing to the enhancement of engineering students' practical skills.

Keywords: University-Industry Collaboration, Teaching-focused Collaboration, Sustainability, Engineering Education

1 Introduction

In the context of the transformation of the knowledge production model [1], universities are increasingly expected to fulfill a "third mission" beyond research and teaching—establishing links with knowledge users and facilitating technology transfer. Achieving this mission is challenging for universities alone, necessitating collaboration with external organizations, particularly industry [2], [3]. At the same time, industries seek partnerships with universities to access advanced knowledge, cutting-edge technologies, expensive research infrastructure, and high-quality human resources, including researchers and students [4], [5], [6]. Driven by these mutual goals, University-Industry Collaboration (UIC) manifests in various forms, such as joint research, academic entrepreneurship, and collaborative teaching.

Significant resources and attention have been dedicated to the support and pursuit of UIC, and researchers have devoted considerable effort to finding the determinants of their success [7], [8], [9]. However, achieving seamless collaboration between industry and academia is particularly challenging in the context of teaching-focused UIC. This type of collaboration aims to enhance students' learning experiences and improve the quality of higher education[10], [11], [12]. It often involves activities such as delivering guest lectures, adapting university curricula based on feedback from industry partners, and engaging students in collaborative research projects [13]. Such collaborations are especially prevalent in the field of engineering education. However, student training is a long-term endeavor, whereas enterprises often prioritize short-term benefits [14], making teaching-focused UIC challenging to sustain. Furthermore, universities frequently find themselves in a relatively vulnerable position within such partnerships due to less power and control over resources [15], which can lead to a unilateral dependence on the industry and, ultimately, the collapse of the collaboration. Therefore, beyond achieving successful implementation, enhancing the sustainability of teaching-focused UIC remains a complex and pressing issue.

Hence, the key question we seek to address is: **How to effectively promote the sustainability of Teaching-focused UIC?** To answer this, we conduct a case study of an integrated circuit engineering doctoral training program at a leading university in China. Utilizing an integrative framework for analyzing UIC implementation, we examine the strategies employed in this case to ensure sustainable operations across four dimensions: institutional, relationship, framework, and output. Our findings indicate that government support serves as a critical driver for establishing UIC, while training outcomes are vital for sustaining such collaborations. To sustain teaching-focused UIC, universities must take proactive measures to enhance industry motivation and foster long-term partnerships. Specifically, universities can achieve this by bridging boundary organizations, corporatizing large-scale infrastructure, and developing student evaluation criteria aligned with industry needs.

The findings have broader implications for both the theoretical study and practical implementation of UIC. First, while much existing research focuses on industry-education integration aimed at knowledge and technology transfer or academic commercialization [9], [16], [17], teaching-focused UIC has received comparatively little attention. By situating our study in the context of such collaborations, this study provides valuable empirical evidence to the field. Second, we propose an analytical framework for the sustainable implementation of UIC based on existing research, extending the research focus beyond successful implementation to the sustainability of collaboration—a perspective that remains underexplored. Third, we offer practical strategies for enhancing the sustainability of UIC programs at multiple levels, providing actionable insights to improve students' learning experiences and teaching quality, particularly for engineering students.

The remainder of this paper is organized as follows. First, we review the existing literature on the objectives, forms, and implementation of UIC and present the analytical framework underpinning this study. Next, we outline the research design, detailing the methodology, case selection, and data collection process. We then provide an in-depth case study analysis. Finally, we summarize the findings and discuss their theoretical and practical implications for UIC research and practice.

2 Literature Review

2.1 Objectives and Forms of UIC

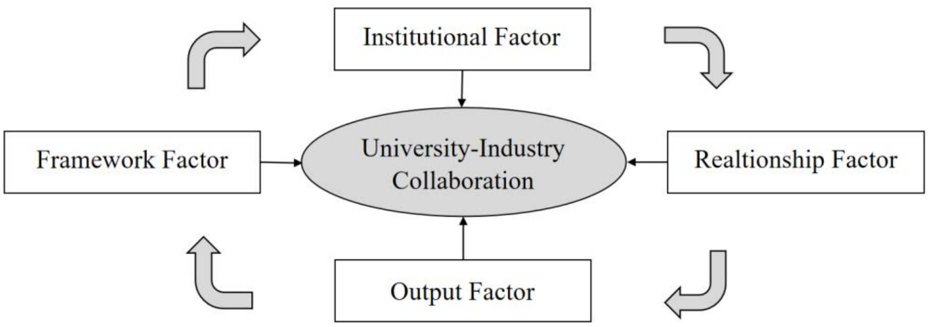
University-industry collaboration refers to the interaction between any part of the higher educational system and industry [5], which is a multifaceted process driven by diverse objectives. For the industry sector, such collaboration allows them to profit from highly qualified human resources such as researchers and students [6], the use of expensive research infrastructure [5], advanced technology and knowledge [4], and graduates with skills tailored to specific work environments [18]. For universities, UIC supports the enhancement of teaching activities [13], while fulfilling the dual expectations of contributing to traditional knowledge generation and engaging with industry, as often encouraged by government policies [20]. Motivated by these varied objectives, UIC has manifested in multiple forms, including technology transfer, consulting, joint research, and student placements [19], [20], [21].

Among these forms, teaching-focused UIC—sometimes referred to as education-focused UIC [22], has been largely overlooked in existing research, a shortcoming that recent studies have begun to address [9], [13]. This form of collaboration often involves activities such as the joint creation and delivery of academic courses, the development of tailored student projects and internships, and the integration of industrial equipment on university campuses for student use [23]. These initiatives are believed to enrich the student learning experience by providing a deeper understanding of professional practice, including the dispositions, skills, and identities of professionals, as well as exposure to cutting-edge technologies and equipment used in industry. However, education is inherently a long-term endeavor, while enterprises tend to prioritize short-term goals, creating a dilemma in which these activities often struggle to achieve sustainability. This challenge underscores the importance of addressing the implementation and sustainability of teaching-focused UIC.

2.2 Implementation of UIC

Researchers have devoted considerable effort to finding the determinants of the successful implementation of UIC. Based on a systematic literature review, Rybnicek (2019) proposed a conceptual model to organize success factors within the collaboration process in four dimensions [24]. The first dimension is institutional factors. Resources play a critical role in the successful implementation of UIC, encompassing elements such as good timing [25] and research infrastructure [26]. Additionally, structural characteristics are crucial. The structural complexity and inflexibility often inherent in universities can act as barriers to the success of UIC initiatives [27]. Second, relationship factor. Effective collaboration is facilitated by reciprocal communication [28], mutual commitment [29], trust [30], and the ability to overcome cultural barriers [4]. Third, output factors. One output factor that has garnered significant scholarly attention is goals. Both sides must reach a shared understanding of the objectives of UIC and develop achievable goals accompanied by precise action plans to ensure successful implementation [31]. Additionally, effective knowledge and technology transfer is widely recognized as a critical component [32]. Finally, framework factor, including environment and geographical distance. Specifically, environment factors include government support [33], [34], [35], market condition [36] and so on. Research on geographical features primarily focuses on distance, suggesting that a suitable geographic distance may facilitate collaboration[37]. However, there is no definitive consensus on whether proximity or distance is more advantageous for successful UIC [38], [39].

Figure 1 Analytical framework for the sustainable implementation of UIC



Rybnicek's (2019) findings offer a clear and valuable analytical framework for deconstructing UIC by examining its development and successful implementation through four dimensions: institutional, relationship, output, and framework. As a form of UIC, teaching-focused UIC certainly applies to this framework, which at the same time fits well with our research question on how to promote the implementation of teaching-focused UIC. Furthermore, we emphasize the sustainability of collaboration as a crucial dimension of successful implementation—an emphasis driven in part by the long cycle inherent in teaching-focused UIC. Moreover, as suggested by Rybnicek (2019), the importance of these factors varies over the course of the collaboration process, warranting further investigation into the relationships among different factors across various phases of a collaboration project. Therefore, we extend Rybnicek's conceptual framework to analyze the interactions among these factor dimensions and their impact on the sustainability of collaboration.

In this study, we propose that these dimensions are interrelated and interact synergistically to facilitate the sustainable implementation of UIC. Specifically, framework and institutional factors serve as the motivating and contextual conditions for initiating collaboration. Once support and resources are secured from these dimensions, the collaboration shifts to the relationship dimension, which focuses on effectively linking the two sides to operationalize the partnership. The output dimension then measures UIC outcomes and serves as a key indicator in the evolution of collaboration. Both the university and industry evaluate the partnership based on these outcomes—if both parties are dissatisfied, the collaboration may terminate; if willingness to collaborate persists, the partnership is maintained by preserving or adjusting the institutional, framework, and relationship factors to further improve outcomes. Therefore, we propose a cyclic analytical framework for the sustainable implementation of UIC (Figure 1), which not only focuses on achieving successful implementation but also ensures long-term viability. This framework is particularly significant for teaching-focused UIC, an area where limited research has provided evidence or insights. We aim to use this framework to explain how these key factors contribute to the sustained operation of UIC.

3 Research Design

3.1 Method

This study aims to address the question of "how" to effectively enhance the sustainability of UIC. Given that case studies are particularly well-suited for answering process-oriented questions such as "how" and "why," [40], this study adopts a case study approach [41].

3.2 Case Selection

Following the selection criteria of the case study design, which include problem alignment, revelatory potential, and access to rich data [42], we selected an Integrated Circuit engineering doctoral training program at a leading university in China as the subject of our study for the following reasons.

First, as the world's largest higher education system, China has implemented a series of policies to promote collaboration between universities and industries, particularly in engineering education. For instance, under the Ministry of Education's initiative, China introduced the Emerging Engineering Education proposal in 2017, which calls on universities to collaborate with industries in cultivating engineering talent to align with national strategies and enterprise needs. This supportive environment and the long-standing exploration of UIC within China's higher education system provide a strong research context for this study.

Second, integrated circuits, as core components of modern electronic technology, form the foundation of the information technology industry. Both China and the global integrated circuit (IC) market continue to expand, driven by significant market demand. To address this demand, talent training in the IC field increasingly emphasizes market orientation, necessitating the training of engineering graduates through teaching-focused UIC to align their skills with industry needs.

Third, we selected the integrated circuit engineering doctoral training program offered by the College of Integrated Circuits at Zhejiang University as our case study. This academic unit, one of China’s first national microelectronics schools, has implemented numerous innovative UIC initiatives and received multiple awards from the Chinese government for its contributions to IC talent training. Furthermore, the Doctor of Engineering degree, introduced in China in 2011, was specifically designed to address national innovation needs and enhance the training of engineering and technical professionals. Focused on addressing the practical demands of enterprises, Zhejiang University’s Doctor of Engineering in Integrated Circuits program aims to cultivate exceptional engineering and technical talent through UIC, making it a representative example of a teaching-focused UIC program. Thus, this case aligns well with the criteria for case study design.

3.3 Data Collection

Table 1 Data Summary

Type of Data	Type of Data	Amount of Data	Code[1]
Interviews	associate dean of the IC academic unit （01/16/2023）	50 mins; 8k words	P1
	assistant director of the IC academic unit （01/14/2023）	50 mins; 5k words	P2
	associate dean of the boundary organization （02/18/2023）	90 mins; 14k words	P3
Archival	policy documents published on government websites	5 documents, 14k words	D1
	documents published on the university and the academic unit websites	11 documents, 22k words	D2
	literature published in the CNKI database	3 documents, 23k words	D3
	news and reports published on Baidu and Bing	10 documents, 27k words	D4
	public lecture of the director of the IC academic unit (03/03/2024)	44 pages	D5

To ensure the reliability and validity of the study, we employed multiple models of data collection [43], including archival research and interviews. Archival documents: We conducted extensive searches on government websites, university and college websites, the CNKI database, Baidu, Bing, and other platforms to gather secondary materials related to the case. Additionally, we accessed internal archival materials through institutional channels to systematically compile key practices of the college in cultivating IC engineering talent. This effort resulted in the collection of 29 documents and materials, including policy documents,

[1] Coding rules: P for person; D for document.

literature, news reports, internal archives, and other sources, totaling approximately 86,000 words. Furthermore, we attended a seminar where the college director presented on IC talent development goals and programs. After the seminar, we compiled the 44-page slide deck used in the presentation to supplement our data. Interviews: We conducted three semi-structured interviews with the associate dean and assistant director of the IC academic unit, as well as an administrator from a relevant boundary organization. These interviews explored the history and practices of the college in advancing teaching-focused UIC. The interviews were audio-recorded and transcribed, producing 190 minutes of recordings and 27,000 words of transcribed text. Table 1 provides a detailed summary of the data collected.

4 Case Analysis

The data analysis involved three phases. In the first phase, all data were converted into textual form and classified according to their sources. In the second phase, we systematically organized the history and initiatives of Zhejiang University's College of Integrated Circuits in collaborating with industry to cultivate IC engineering doctoral students. In the third phase, using the analytical framework for the sustainable implementation of UIC, we identified and generalized the effective strategies for enhancing UIC sustainability observed in this case across four dimensions: institutional, framework, relationship, and output.

4.1 Framework factor: Securing incentives for collaboration through sustained government support

Framework factors encompass external environmental influences on UIC, including government support, market conditions, and geographic distance. In its initial phase, Zhejiang University began exploring teaching-focused UIC largely in response to regulatory pressures from the government. Zhejiang University's College of Integrated Circuits[2], one of China's first microelectronics schools, was established in 2015. At that time, China's IC market had surpassed one trillion RMB in size, accounting for 50% of the global market share. This vast market scale created a significant demand for IC talent. However, systematic IC education was lacking in China at the time, with related teaching and research scattered across various university research centers. To address the needs of the IC industry, the Chinese government supported nine universities, including Zhejiang University, in establishing microelectronics schools and provided extensive guidance for their development. Among the explicit requirements for these schools was collaboration with industry to cultivate talent. Accordingly, in its early stages, the College of Integrated Circuits sought to strengthen cooperation and engagement with enterprises, including creating a joint university-enterprise council and incorporating industry feedback into the design of student training programs.

For example, in 2015, the Ministry of Education issued the "Notice on Supporting the

[2] Over the nearly 10 years since its establishment, the College of Integrated Circuits at Zhejiang University has undergone two name changes: from the initial School of Microelectronics to the School of Micro-Nano Electronics, and finally to the College of Integrated Circuits. To maintain coherence and consistency throughout this narrative, we uniformly refer to this academic unit as the College of Integrated Circuits.

Construction of Microelectronics Schools in Relevant Colleges and Universities," which emphasized that microelectronics schools should strengthen collaboration with leading regional enterprises, industrialization bases, and local governments to jointly establish student internship and practice bases. (D1)

Government support is often essential for establishing UIC [45], and maintaining such partnerships may also require sustained governmental backing. With the advancement of next-generation information technologies such as AI, big data, and cloud computing, the global IC market continues to expand, driving a persistent demand for IC talent. Since 2015, the Chinese government has introduced a series of policies and initiatives encouraging universities to cultivate IC talent, with nearly all emphasizing the importance of achieving this through UIC. In 2020, the State Council designated integrated circuit science and engineering as China's first interdisciplinary discipline to address the long-term demand for interdisciplinary engineering talent required for the IC industry's growth. Under continuous governmental attention and support, the College of Integrated Circuits has prioritized industry collaboration as a core principle of talent training and has actively explored innovative approaches to deepen these partnerships.

The college's profile on its official website provides supporting evidence: "The college has carried out in-depth cooperation with leading enterprises and established more than 10 joint research centers...We are committed to creating high-quality university-industry collaboration and interdisciplinarity as the college's defining characteristics." (D2)

4.2 Institutional factor: Establishing flexible structures by bridging boundary organizations

Institutional factors are related to the participating institutions, with structure being a key influence. Universities' rigid structures are often criticized for hindering collaboration [26], [27].

For example, when asked about the college's operational status within the university, the assistant director admitted: "Although the Ministry of Education required the microelectronics school to operate independently, we were unable to achieve this at the time due to limited office space, insufficient funds, and inadequate teacher positions." (P2)

To address this, the College of Integrated Circuits stepped beyond the traditional university framework by engaging with boundary organizations. In 2020, the college relocated from Zhejiang University's main campus to the Hangzhou International Science and Technology Innovation Center (hereinafter referred to as the Innovation Center), located 20 km away. The Innovation Center is a specialized innovation district jointly established by Zhejiang University and the local government, dedicated to industrial incubation, aggregation, and promoting technological innovation and achievement transformation. By joining the Innovation Center, the College of Integrated Circuits gained greater access to industrial partners and expanded its collaboration network.

> *The assistant director explained the relocation during the interview: "The main goal of the Innovation Center is technology research and transformation. The IC field aligns closely with this mission, as it also emphasizes industrialization. Therefore, moving to the Innovation Center makes sense in terms of cultural identity and collaboration."(P2)*

The relocation also established a more flexible operational structure for the college to advance UIC. On one hand, the college retains its affiliation with the university, ensuring access to high-quality students, faculty, and other institutional resources. Simultaneously, support from the Innovation Center, including space, funding, and additional resources. On the other hand, stepping beyond the university framework allows the college to bypass rigid structural constraints, such as standardized student evaluation and limited enterprise engagement, and to integrate into a more open and inclusive industrial innovation atmosphere.

> *When asked about the relationship between the Innovation Center and the college, the associate dean of the Innovation Center explained: "The College of Integrated Circuits does not belong to the Innovation Center but remains part of the university. It is simply located here, so the Innovation Center fulfills some campus functions... However, we are relatively independent from the college. We don't interfere with their teaching and research activities; we simply ensure they have the necessary resources." (P3)*

4.3 Relationship factor: Sustaining long-term collaboration through engineering infrastructure

The relationship factor refers to the links between the partners. Because universities and enterprises have differing objectives and benefits from UIC, especially in teaching-focused UIC, these collaborations often face the challenge of low enterprise motivation.

> *A news report on the director of the College of Integrated Circuits noted his frustration when discussing the UIC: "We want to send students to leading chip manufacturing enterprises, but the enterprises worry about disrupting their production lines. The actual effectiveness of UIC is not ideal!" (D4)*

To prevent the collapse of collaboration due to unilateral dependence on enterprises, this case established an effective and stable cooperation mechanism by creating large-scale engineering infrastructure. Around 2021, the college built a large-scale IC infrastructure called CMOS, which not only realizes the complete chip production process but also serves as a teaching and research platform for integrated circuit engineering doctoral students. As part of the program, each doctoral student is required to rotate through various stages of the production line for at least two months, providing them with a comprehensive understanding of the real IC production process before engaging in actual research projects. This approach offers students real learning scenarios while reducing the university's reliance on the industrial environments of external companies. In addition, the infrastructure represents the most advanced production line in China for teaching and research, making it an attractive platform for leading Chinese enterprises in the IC field, such as SMIC and NAURA, to collaborate through joint research and talent training. This infrastructure thus serves as a channel of communication and interaction between the university and industry. Moreover, to enhance the sustainability of the collaboration, the College has ensured the infrastructure's self-sufficiency through entrepreneurial operations.

> *In the interview, the associate dean explained that the purpose of corporatization is to ensure the continuous operation of the infrastructure. He stated, "For example, by producing some products, we can ensure that the infrastructure at least breaks even or generates a small surplus annually. This approach allows us to sustain our IC talent training platform." (P1)*

4.4 Output factor: Reforming the evaluation system to meet the needs of both sides

The output factor plays a crucial role in the sustainability of UIC. If either party is dissatisfied with the results of the collaboration, it can diminish their enthusiasm and potentially lead to the termination of the partnership. In teaching-focused UIC, a key output is whether graduates meet the needs of enterprises.

> *This importance was highlighted in one of the interviews: "The lack of motivation among enterprises stems from the fact that the talent trained by universities or their research outcomes often fail to meet industry needs. To address this issue at its root,we need to reflect on whether there is any misalignment in the objectives of talent training in universities, especially for engineering degrees. If we train students well and ensure their research is valuable to enterprises, based on my experience, companies are quite motivated and very willing to collaborate with us." (P1)*

Guided by this belief, the college has reformed its training process and evaluation mechanisms to ensure graduates meet the expectations and needs of enterprises. The IC engineering doctoral program implements a dual-supervisor system, assigning each student both a faculty supervisor and a corporate supervisor. All key aspects of the program, including individual study schedules, practice reports, thesis proposals, and dissertations, are jointly guided and approved by both supervisors. This approach not only ensures that students receive formal scientific research training but also aligns their research projects with the real needs of enterprises, thereby establishing a positive feedback mechanism between the university and industry. In terms of evaluation criteria, the mainstream academic assessment in universities remains constrained by disciplinary specialization, with a primary focus on the number of publications and patents. This has contributed to low motivation among some faculty and students to engage in UIC. To address these concerns, the college has incorporated IC engineering innovation as one of its evaluation criteria, encouraging greater participation in UIC activities.

The associate dean shared details about a new evaluation criterion during an interview: "Inside the university, the traditional evaluation system focuses on how many projects you've undertaken and how many papers you've published. But we now place greater emphasis on whether you have solved a specific engineering problem. If you've truly addressed an engineering issue, you can write a report and have industry experts evaluate whether it is a critical problem in engineering. We created this new criterion to ensure that teachers and students engaged in engineering innovation can also achieve favorable evaluation results." (P1)

5 Discussion and Conclusion

By analyzing this IC engineering doctoral program across four dimensions—framework, institutional, relationship, and output—we identified key factors that drive successful UIC, including government support, flexible structures, engineering infrastructure, and evaluation criteria. In particular, universities must enhance their efforts to sustain collaboration by bridging with boundary organizations, corporatizing large-scale infrastructure operations, and developing student evaluation criteria aligned with industry needs. Moreover, sustainable teaching-focused UIC requires the interaction of factors between different dimensions. Collaboration is driven by framework factors, such as urgent industry timing and government support. The institutional dimension creates a supportive environment for the establishment of collaboration, such as more flexible structures. Relationship factors relate to specific aspects of collaboration implementation. Universities and industry need to think about what measures they can take to effectively build mutual communication mechanisms to achieve collaboration. Finally, the output factor needs to be set very carefully, which can greatly affect the expectations of both sides in terms of sustaining collaboration. Setting student evaluation criteria based on industry needs may be an effective strategy. In the following sections, we will explore the broader implications of these findings.

First, government support serves as a key driver for the establishment of UIC, while sustained government backing enhances the long-term sustainability of such collaborations. Existing research has indicated that UIC does not occur automatically [12], and our findings similarly highlight that government support is a critical factor influencing the initiation of UIC [33], [34], [35] and can even be an essential motivation for the initiation of the collaboration, particularly for universities. Given the rigidity and inflexibility of university structures [27], they are often reluctant to modify their existing teaching approaches. Government policy directives can provide regulatory pressure that encourages universities to explore UIC, serving as a catalyst for collaboration. While this phenomenon is shaped by the higher education environment in China, similar patterns may exist in other countries, particularly where public universities operate under significant government influence. Additionally, beyond short-term measures such as tax incentives and public funding, stable and continuous policy support is essential for sustaining UIC. Such support offers universities stronger incentives to pursue partnerships and helps enterprises remain engaged in collaborative efforts.

Second, in teaching-focused UIC, universities have to invest greater effort in establishing long-term collaboration mechanisms and mobilizing enterprises' motivation to sustain partnerships. In such partnerships, universities are more likely to be in a vulnerable position due to less power and control over resources [15]. Our findings reveal that the case sustains collaboration through two key strategies. First, universities can expand their collaboration networks by engaging with boundary organizations outside the university, such as industrial zones. This approach allows them to integrate into a more industry-oriented, open, and dynamic environment while accessing a broader range of enterprise contacts. Additionally, this strategy helps maintain a loosely coupled structure, avoiding the limitations imposed by rigid university frameworks [26]. On the other hand, universities can attract enterprises and facilitate collaborative teaching and joint research by providing access to large-scale, expensive research infrastructure. According to Rybnicek (2019)'s work, infrastructure was included in the institutional factors as an important resource. In this case, because of the leading edge and uniqueness of this IC infrastructure, it does reinforce the university's resource advantage in the partnership. Furthermore, we find that the infrastructure also plays an important role in the relationship dimension, functioning as a connecting link for partnerships by providing a channel for communication and interaction between the university and the industry. Besides, this case ensures the long-term operation of the infrastructure by corporatizing it, a strategy that may also be viable for sustaining collaboration in industry-oriented disciplines.

Third, output is a critical factor influencing the sustainability of UIC, and developing student evaluation criteria that align with industry needs can enhance collaboration outcomes. The effectiveness of UIC depends on the active participation of both industry and universities, and the results serve as a key reference for both parties to assess their level of engagement. For enterprises, the primary expectation is access to high-quality human capital. However, students' limited ability to apply theoretical knowledge in practical contexts often acts as a barrier to successful UIC [45]. In turn, students' perceptions of industry involvement in higher education influence their level of engagement in such collaborations [11]. To address the concerns of both the industrial sector and students, universities can develop assessment criteria that align with enterprise needs. For example, evaluating engineering innovation and the ability to solve practical industry problems can serve as assessment criteria, rather than relying solely on publications and examination results. Additionally, universities can involve industry professionals in the student training process to ensure that the quality of training aligns with the expectations and demands of enterprises.

In conclusion, this study provides theoretical and practical insights for improving the sustainability of teaching-focused UIC from four dimensions of institutional, relationship, frameworks, and output through a case study of an IC engineering doctoral training program in the field of integrated circuits. However, we acknowledge several limitations in this study. First, while we propose an analytical framework for the sustainable implementation of UIC based on existing research, the interactions and transformations between the different dimensions are not fully depicted. Future research could focus on refining and optimizing this framework. Second, this study employs a single-case study approach, concentrating solely on the IC field to explore effective strategies for sustaining teaching-focused UIC. The external validity of these findings requires further verification. Future research could incorporate multiple case studies across diverse disciplinary contexts or enterprise types to validate and extend the applicability of the findings.

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