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Developing indicators for the social benefits of university-industry collaborations

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Abstract
This paper focuses on the social benefits of university-industry collaborations (UICs) based on the cases of winners of the Industry-Academia Collaboration Prize presented by the UK Royal Society of Chemistry (RSC) (2010–2023). The research question, which concerns the social and environmental benefits of UICs, has received little attention in the literature, as it focuses mainly on their economic effects. Taking the framework approach to thematic analysis, a list of thematic indicators, which serve as benchmark criteria for evaluating the social impact of UICs in medical, pharmaceutical and chemical industries, is developed. The use of a case study to identify indicators via this approach is appropriate for generating in-depth insights into the characteristics of UICs that have considerable societal impacts. Knowledge creation and contribution to training and improved skills levels constitute the main social benefits of UICs in the three industries cited above. Our findings have practical and theoretical implications, as they emphasize the importance of UICs in fulfilling a specific function in society, namely, facilitating research and developing skills that make the world a better place.

Keywords University-industry collaboration, UIC, Social benefits, Indicators of social benefits

Introduction

Innovation today requires a diverse range of partners with varying technological expertise (Powell & Giannella, 2010; Ervits, 2023), which is why university-industry collaborations (UICs) have been reported as more than doubling between 2012 and 2016 (Elsevier, 2021). The economic benefits of UICs have been emphasized in multiple empirical and theoretical studies. For example, on the macro level, they are seen as a vehicle to boost economies' innovative output by facilitating the flow and utilization of technology-related knowledge and learning across sectors (Ankrah & Al-Tabbaa, 2015a, b). There is little discussion, however, about their social and environmental benefits (Lima et al., 2021; Cohen et al., 2023); hence, this paper focuses on this knowledge gap. Godin and Dore (2005) define the "social impact" of scientific research as an impact knowledge has on the welfare and behavior of people. There are also public health and environmental impacts such as illness prevention and the management of natural resources.

Our research question asks the following: What indicators can be used to identify the social benefits of UICs? We compile a list of social impact indicators from three sources: The European Commission (2010, p. 42), Lima et al. (2021, p. 13), and the UN 17 Sustainable Development Goals (UN, 2023). We then apply these indicators to the social benefits realized as a result of UICs, based on the cases of winners of the Industry-Academia Collaboration Prize presented by the UK Royal Society of Chemistry (RSC) (2010–2023) (Royal Society of Chemistry, 2023).[1]

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[1] No prize was awarded in 2013.

The use of a case study to identify indicators via the framework approach to thematical analysis is appropriate for generating in-depth insights into the characteristics of UICs that have considerable societal impacts. Due to the nature of this prize, which aims at honoring collaboration projects that contribute to the community and are socially impactful, this analysis will produce benchmark indicators for evaluating the social benefits of UICs in the medical, chemical, and pharmaceutical industries.

The co-innovation and technology transfer aspects of UICs have received a lot of attention among scholars from different disciplines (Fromhold-Eisebith & Werker, 2013; Awasthy et al., 2020). The evolution of UICs, their inner workings, and the mutual benefits they create have also been extensively discussed. For instance, O'Dwyer et al. (2023) elaborated on the four emergent evolutionary phases of UICs., while de Wit-de Vries et al. (2019) reviewed papers focusing on factors that determine the quality of interaction between a university and its industrial partners, especially in terms of intensity. Lee (2000), Motohashi (2008), Bruneel et al. (2010), and Barbosa et al. (2023) investigated the benefits of collaboration for both university and industrial partners. The social and environmental benefits of UICs, however, have received relatively little attention (Lima et al., 2021; Cohen et al., 2023), which is why this paper aims to identify indicators of their social and environmental benefits.

In the past three decades, businesses have become more aware of their environmental and social responsibilities. Environmental, Social and Governance (ESG) performance indicators have made their way into all functional areas, including finance and human resource management. Universities also have a public mission to carry out research and education, and they engage in community outreach and strive to develop their social profile (University of Konstanz, 2023). Like ESG rankings, various sustainability university rankings rate the social engagement of universities (Galleli et al., 2022). It is assumed that UICs create a triple bottom line bringing benefits to universities, their industrial partners, and the public. In the past, most studies looked at UIC benefits either from the university or the industry perspective, but herein, we apply a different lens from the perspective of society at large.

The concept of 'communities of practice'—a network in which knowledge generation is a result of social interaction at the individual level, both within and between organizations (Soekijad et al., 2004; Hardy et al., 2003)—emphasizes the innovative aspect of UICs. Their social and environmental benefits, however, are created within 'communities of shared values', i.e., inter-organizational collectives of researchers who pursue economic as well as social goals. Kramer and Pfitzer (2016) introduced the term "ecosystem of shared value," which implies different types of organizations, for example businesses, NGOs, government agencies, and universities, coming together to address social problems. The construct is inspired by "creating shared value" (Porter & Kramer, 2011) when businesses create economic value in a way that also creates value for society. UICs are the epitome of 'shared values' on different levels, in that these collaborations not only bring together basic and practice-oriented research goals, but they also represent the merging of public and private goals. The networking aspect of knowledge creation within UICs stems from the 'communities of practice' concept. Furthermore, the environmentally and socially oriented values that drive UICs are epitomized in the concept of 'communities of shared values'. These two interrelated terms focus on different aspects of UIC outcomes and processes and contribute to the theoretical framing of this paper.

Godin and Dore (2005) and Bornmann (2012) discuss the challenges of measuring the societal impact of research. The main challenge is to address the diverse range of research goals and forms, so is no standardized evaluation matrix that broadly applies to all university research and entrepreneurial initiatives. The lack of a social and environmental evaluation matrix is also relevant for UICs. Moreover, any evaluation of their social or environmental impacts is context-specific, and indicators should be developed based on the field of research (European Commission, 2010) and the nature and specifics of a UIC. Thus, this paper develops indicators for social benefits produced by UICs in specific industries: the medical, chemical, and pharmaceutical sectors.

The social impact of research has been mostly assumed rather than empirically demonstrated (Bornmann, 2012). Bornmann (2013) underscores the utility of case studies in collecting rich data on social benefits for academic research: "Case studies do not permit generalizations to be made but they do provide in-depth insight into processes which resulted in societal impact" (p. 226). The Industry-Academia Collaboration Prize recognizes outstanding industry-academia innovation-focused partnerships. It is administered by the prestigious UK Royal Society of Chemistry (Royal Society of Chemistry, 2023). More than 50 winners of the prize have gone on to become Nobel prize laureates, including John B. Goodenough in 2019 (University of Strathclyde, 2021). The award reflects government interest in specific medical, pharmaceutical, or chemical industry technologies. Based on a number of successful UICs, we typologize the important social benefits of prize-winning collaborations.

Since the winners of the Industry-Academia Collaboration Prize receive a stamp of approval regarding their social contribution, we summarize their characteristics and cross-reference them with established sustainability and social indicators set, for example, by the UN, and produce benchmarks of socially responsible UICs. This research has practical implications in terms of creating a framework for assessing the social benefits of UICs. We also address a more conceptual challenge of defining what UIC outcomes are considered 'socially-oriented' and how universities or businesses making social contributions can be distinguished from those made by UICs.

This paper proceeds with the literature review. First, we discuss the acknowledged gap in the literature concerning the social impact of UICs, following which we examine the extended literature on their mutual benefits, including innovative output and training/job creation. We also consider the underlying theoretical leitmotivs, i.e., the concepts of 'communities of shared values' and 'communities of practice'. Next, we move on to the methodology discussion, where the steps involved in the framework approach to thematic analysis are outlined. The results are presented in the form of a list of the social and environmental indicators of UICs, which are then reviewed through the joint 'communities of shared values' and "communities of practice" prism. Finally, conclusions are drawn.

As mentioned above, the empirical contribution of this paper is in providing clear and crystalized social benefit indicators of UICs in the medical, chemical, and pharmaceutical industries, based on best practice cases. Our conceptual contribution is in emphasizing the practical side of knowledge co-creation and training/job creation as important social benefits of UICs, but our findings have a broader impact by emphasizing the importance of UICs in fulfilling a specific function in society, namely, facilitating research and developing skills that can change the world for the better.

Literature review

Mutual benefits of UICs

In a UIC setting, universities can serve as a source of new knowledge by transferring their expertise in basic research to their industrial partners. Universities are better at basic research, while industry is better at generating and commercializing technology (Hall et al., 2003; Rothaermel et al., 2007; Tian et al., 2022). Furthermore, industrial partners offer financial support, the opportunity to apply and commercialize knowledge, and create employment prospects for students and alumni, while universities bring ideas and knowledge to the table (Lee, 2000). Lee (2000) argues that the most significant benefit realized by firms is increased access to new university research and discoveries. Faculty members benefit by securing funds for graduate students and lab equipment. Based on survey data, Lee (2000) contends that the contribution of a faculty to the development of new products and processes is especially appreciated by smaller firms that have fewer scientists and engineers on their staff. Motohashi (2008) also found that young, small-sized, and new technology-based firms benefited from their R&D collaborations with universities in Japan as their patent output increased. Ultimately, universities are primarily driven to create new knowledge, whereas firms are focused on appropriating valuable knowledge to gain competitive advantage (Bruneel et al., 2010).

It has been ascertained in multiple studies, particularly focusing on Europe, that UICs lead to improvements in innovation performance, proxied by the number of patent applications or the introduction of new products and processes (Arvanitis et al., 2005). Based on data from companies in several European regions, Kaufmann and Tödtling (2000) found that cooperation with universities leads to the introduction of "new to the market" products. UICs in environmental and sustainability-related research areas contribute to firm partners' economic performance (Di Maria et al., 2019). Similarly, based on evidence collected in Japan from biotechnology firms, Zucker and Darby (2001) conclude that UICs between university star scientists and firms have a large, positive impact on firms' research productivity, while Aschhoff and Schmidt (2008) reach a similar conclusion based on survey data from Germany. Caviggioli et al. (2022) acknowledge the contribution of large established European universities to the development of regional technological specializations. Mathisenand and Jørgensenalso (2021) also talk about the geographical proximity of partners in a UIC as a prerequisite of value co-creation.

In view of the global recognition of the United Nations 17 Sustainable Development Goals (SDGs) (UN, 2023), universities are perceived as "multipliers for sustainability," as they provide knowledge and guidance to policymakers and companies, as well as generate relevant research output (Di Maria et al., 2019). Their role is to "facilitate societal responses to the plethora of sustainability challenges" (Stephens et al., 2008). Hillerbrand and Werker (2019) argue that universities have intrinsically valuable goals that include the generation and dissemination of knowledge by doing research, contributing to applied research, and developing solutions to societal problems. Universities also instill society-oriented values among students (Bustamante et al., 2022). Business schools play a special role in fulfilling what society requires from academia in terms of social and environmental expectations, as they produce future business leaders, who in turn must be seen as role models of responsible leadership (Muff, 2013). Etzkowitz et al. (2017) argue that the entrepreneurial activities of universities must be evaluated in terms of not only financial returns, but also a wider range of social benefits, such as the diffusion of knowledge or job creation.

The in-depth focus on the nature and mechanisms of UICs, as well as their antecedents and output, has created a rich body of literature. The mutual benefits of such alliances have also been addressed, for example in Lee (2000) and Scandura and Iammarino (2021). However, we believe that there is room for more contextual discussion of their social benefits. For example, Hillerbrand and Werker (2019) argue that knowledge generation, diffusion, and contributing to education are intrinsically motivated, valuable goals of universities, while for business they are instrumental in generating profits. In the past, most studies looked at UIC benefits either from the university or the industry perspective, but we apply a different lens from the perspective of society at large.

Lack of research on the social benefits of UICs

There is a body of literature that focuses on measuring the social impact of research (Godin & Dore, 2005; Bornmann, 2012, 2013), university-based research (Etzkowitz et al., 2017, and scientific publications (Niederkrotenthaler et al., 2011). Molas-Gallart et al. (2002) developed an evaluation framework for the so-called "Third Stream" activities of universities, which go beyond teaching and research and involve different forms of interaction with society, including UICs. Kuruvilla et al. (2006) developed a conceptual framework to help health researchers think through and describe the outcomes of their work. With this practical goal in mind, and based on interviews with researchers, the authors identified broad themes that can be addressed when discussing the social impact of research: "Knowledge, attitudes and behavior; Health literacy; Health status; Equity and human rights; Macroeconomic/related to the economy; Social capital and empowerment; Culture and art; Sustainable development outcomes" (p. 4). These themes have been raised in the specific context of health research. Health improvement must be the main indicator of medical research quality, as per Smith (2001), albeit each discipline can develop its own indicators for social impact assessment purposes.

A European Commission Expert Group report on assessing the outcomes of university-based research (European Commission, 2010) lists a number of social benefits and environmental benefits, including improving people's health and quality of life, enhancing knowledge, reducing waste and pollution, and improving the management of natural resources (p. 42). These benefits can be measured quantitatively, for example, as publication counts or counts of citations to publications, or qualitative indicators can also be utilized to access the positive social spillovers listed above. These qualitative indicators can be applied to self-reports or peer- review evaluations.

The research above discusses various measurement schemes and conceptual approaches to measuring the social impact of—mostly university-based—research. Lima et al. (2021) state that there is "no consensus in the literature on a consolidated conceptual model for assessing" the socioeconomic impacts of UICs (p. 1). Indeed, the nature of research activity pursued by universities is different from UICs, in that the knowledge diffusion effect is multiplied, and there are other social spillovers related to the exchange of skills, know-how, and experience within UIC frameworks. Lima et al. (2021), based on an extensive literature review of publications on the economic, financial, and social outputs of UICs, identify the following positive social spillovers that have been acknowledged by prior research: more jobs and new jobs (especially in high tech), salary increases, higher-skilled labor, student and researcher training, postgraduate training, and internships (p.13). In this paper, we opt for the case study research approach to identify indicators via a thematical analysis of descriptions of research initiatives undertaken by highly appraised beneficiaries of the Industry-Academia Collaboration Prize of the UK Royal Society of Chemistry (RSC) (2010–2023).

Theoretical framing

The extant literature provides various theoretical explanations for why collaboration arrangements (both formal and informal) between industry and universities exist (Barringer & Harrison, 2000; Ankrah & Al-Tabbaa, 2015a, b). Indeed, knowledge generation is the most discussed benefit of UICs. However, as O'Dwyer et al. (2023) note, universities and industry have divergent time horizons. Universities, for their part, pursue a longer timeframe as they engage in basic research, while companies must react quickly to market demands. Additionally, there are possible conflicts between university researchers and industrial managers regarding research priorities and confidentiality requirements (de Wit-de Vries et al., 2019; Hillerbrand & Werker, 2019). Moreover, the extent to which universities and industry perceive knowledge as a 'public good' might differ—and this has practical implications.[2]

Some explanations in this regard draw from strategy theory. The learning aspect of UICs is important. An R&D partnership, for instance, is one way to compensate for a lack of internal competencies and skills (Hardy et al., 2003), and learning from a partner implies sustaining competitive advantage (Lei & Slocum, 1992; Tseng et al., 2020). Partners acquire a new competence in a collaborative setting because knowledge is frequently tacit and difficult to purchase as a 'product' on the market (Mowery et al., 1996). As Powell et al. (1996) put it, innovative activity "cannot be reduced to a simple process of information acquisition" (p. 120). Knowledge generation is

[2] Ndofirepi and Cross (2017) note that even though higher education is claimed to provide both private and public benefits, the extent to which higher education actually contributes to the 'public good' is debatable.

thus one of the most frequently quoted reasons for a UIC to exist.

Another theoretical explanation for why UICs create positive spillovers can be derived from sociology. Fromhold-Eisebith and Werker (2013) and Fromhold-Eisebith et al. (2014) discuss the communal aspect of UICs by applying social network theory to analyze the "spatial, social and cognitive proximity" implications of social interaction within innovation networks (Fromhold-Eisebith et al., 2014, p. 126). Fromhold-Eisebith et al. (2014) conceptualize the four social facets of knowledge networking, i.e., characteristics of a network structure, network history and dynamics, the quality of personalized relationships like trust, and shared culture. When Fromhold-Eisebith et al. (2014) refer to the role of "shared culture" in collaborative networks, they refer to "shared rationalities and narratives" as well as shared views and visions (p. 126). We believe that the discussion of 'shared culture' within a collaborative network is especially appropriate for understanding the environmental and social[3] implications of UICs. Grabher (2004) introduced the term "project ecology" to describe the network-based context of collaborating on a knowledge-producing project. Project ecology implies converging the ecology of "individual identities, values and loyalties" (p. 4). Why and how UICs produce social gains depends, in our opinion, on specific values that are community-oriented and ultimately benefit society at large.

Taking the value-oriented perspective, the assumption in this paper is that the social and sustainability values expressed by the European Commission (2010) and the UN 17 Sustainable Development Goals (UN, 2023), or summarized in Lima et al. (2021), will transpire in descriptions of winners of the Industry-Academia Collaboration Prize presented by the UK Royal Society of Chemistry (RSC). Following this logic, the social benefits created by the winners of the prize should be grounded in socially-oriented values and priorities.

'Communities of practice'—a network in which the generation of knowledge is a result of social interaction at the individual level, both within and between organizations (Soekijad et al., 2004; Hardy et al., 2003)—emphasizes the innovative aspect of UICs. Knowledge is developed through formal and informal networking and shared experience (Tallman & Chacar, 2011), and it can also be generated in an act of co-creation in a distributed network (Lee & Cole, 2003; Brown & Duguid, 1991; Cox, 2005; Soekijad et al., 2004; Jorgensen et al., 2019). 'Communities of practice' imply collective invention, which is "technological advance driven by knowledge sharing among a community of inventors who are often employed by organizations with competing intellectual property interests" (Powell & Giannella, 2010, p. 579), and a UIC serves as a perfect platform for building them.

We borrow from the notion of 'communities of practice' to emphasize the communal knowledge creation aspect. We also utilize the term 'communities of shared values' to understand the UIC context. The term implies that objectives and challenges are handled in a collaborative setting based on sharing society-oriented values, and it originated in Kramer and Pfitzer (2016), who introduced the label "ecosystem of shared value," i.e., different types of organizations (businesses, NGOs, government agencies, and universities) coming together to tackle social problems. The construct draws from "creating shared value," created by Porter and Kramer (2011), that advances the idea that businesses should collectively contribute to the bottom line and help solve social challenges.

To summarize, the networking aspect of knowledge creation within the UIC setting stems from the 'communities of practice' concept. The environmentally and socially oriented values that drive UICs are epitomized in the concept of 'communities of shared values'. These two interrelated terms focus on different aspects of UIC outcomes and processes and contribute the theoretical framing of this paper. We discuss the results—a list of the indicators of UIC social and environmental impacts—through the prism of the two concepts cited above.

Methods

Case study as a research design

Herein, we pursue a case study approach. Bornmann (2013) underscores a case study utility in terms of collecting rich data on the social benefits of academic research. The choice of the case study in this paper—winning UICs of the Industry-Academia Collaboration Prize of the UK Royal Society of Chemistry (RSC)—is dictated by how the winners are selected, i.e., based not only on the quality of scientific output, but also, and most importantly, on the contribution they make to the community (Royal Society of Chemistry, 2023a). In fact, the selection of prize winners is made by selection committees consisting of volunteers and representatives from the community (Royal Society of Chemistry, 2023b), so prize winners are screened based on social impact indicators and represent the best practices. The winning projects must manifest the important social benefit indicators of UICs.

Most of the awarded collaboration partnerships focused on finding solutions to fundamental social or environmental challenges, such as developing a medicine to cure acute pancreatitis, managing nuclear waste, or developing new household tools that conserve energy and water. In many instances, respective government agencies supported collaborative projects financially alongside industrial and university partners (Triple

[3] Here the term 'social' is used as relating to society, not in terms of networking or building relationships.

Helix). Collaborative partnerships produced patent output and scientific publications, and in some instances they prototyped and mass-produced products or new processes and services. Additionally, they were frequently driven by individuals from both universities and industry who tenaciously, sometimes over decades, pursued their research objectives.

After scrutinizing the winning projects based on their descriptions and discussions in news items, press releases, and relevant websites, we created a list of the most frequent themes associated with these projects. To recognize the important themes, we used the framework approach to carrying out a specific type of content analysis, namely, thematic analysis, which is described in the following subsection. We then benchmarked the selected themes against social impact indicators from three sources: The European Commission (2010, p. 42); Lima et al. (2021, p. 13), and the UN 17 Sustainable Development Goals (UN, 2023). As a result, a list of indicators relating to the societal and environmental benefits of UICs was generated. This list will help recognize socially meaningful UICs, as well as guide future prize-seekers. Table 1, below, contains short descriptions of the winning projects.

Framework approach to thematic analysis

In the UIC setting, mostly interviews and surveys have been utilized to understand the dynamic nature of interactions and their outcomes (Perkmann et al., 2013). Even when it comes to technology transfer as one aspect of a UIC, as Arvanitis et al. (2008) reason, the task of measuring the effects of transferred knowledge is a "methodological challenge for economists because the effects are usually numerous, and they are almost always difficult to separate from other parts of firms' activities" (p. 78). Hence, qualitative interviews are a fitting way of collecting data, as they can capture the nuances of interpersonal exchanges. For example, the SIAMPI approach, which focuses on the concept of productive interactions as a measure of the social impact of research, relies on collecting data via interviews (Molas-Gallart & Tang, 2011; de Jong et al., 2014).

In this paper, however, we utilized a different approach to qualitative data collection—thematic analysis. The goal was to generate benchmark indicators for evaluating the social benefits of UICs in the medical, chemical, and pharmaceutical industries. Like qualitative interviews, qualitative content analysis generates 'rich data' that goes through systematic examination and summation. Our research design is a case study involving looking for patterns across several cases, i.e., winners of the Industry-Academia Collaboration Prize awarded by the UK Royal Society of Chemistry (RSC) (2010–2023). More specifically, we utilize the framework approach to thematic analysis (Ritchie et al., 2003), which involves creating a matrix of themes and sub-themes substantiated by excerpts from diverse reports, newspaper articles, and websites covering the winning UICs. The objective of framework analysis is to "identify, describe, and interpret patterns within and across cases of and themes within the phenomenon of interest" (Goldsmith, 2021, p. 2061).

Table 2 presents a list of the initial indicators of the social and environmental benefits of UICs. It is a compilation of social impact indicators from three sources: The European Commission (2010, p. 42); Lima et al. (2021, p. 13), and the UN 17 Sustainable Development Goals (UN, 2023). These indicators originally guided the thematic analysis of news items, press releases, and other documents describing the activities, projects, and research outcomes of the UICs that won the prize between 2004 and 2022. The documents were included in the study based on their relevance. The framework analysis process is outlined in Fig. 1 below. It involved searching for, screening, and analyzing relevant websites, articles, and press releases containing information about the cases mentioned above. A matrix of themes was created in Excel specific to the prize-winning UICs and then benchmarked against and categorized based on the social indicators in Table 2. The themes were narrowed down to 'sub-themes'. Four leading themes were identified that resonated with at least four companies, following which 'sub-themes` for the four leading themes were narrowed down to thematic indicators, which represent our results and serve as 'best performance' indicators of the social benefits generated by UICs in the chemical, medical, and pharmaceutical industries. The emergent indicators are grounded more in the context of the industries and represent the social benefit benchmarks against which other UICs can be compared. Thus, our thematic analysis approach and a more specific technique—the framework approach—help narrow down from broad to more context-specific indicators of social benefits in our selected industries. Tables 3, 4, 5 and 6 provide lists of the broader 'sub-themes' and their thematic indicators. The contents of these tables illustrate the logic and the application of the framework approach to thematic analysis. The main steps of the thematic analysis are summarized in Fig. 1.

Results

Most frequent indicators of social benefits

We identified four leading themes that resonated with at least four companies on the list in Table 2: (1) "Improvements in people's health and quality of life"; (2) "Approaches to solving environmental problems"; (3) "Knowledge development that targets a social or an environmental problem;" and (4) "Job creation, contribution to training, and improved skills level." The indicators for the four leading themes are summarized in Table 7.

Table 1 Descriptions of the winning projects (Industry-Academia Collaboration Prize awarded by the UK Royal Society of Chemistry (RSC) (2010–2023))

No.	UIC	Area of collaboration	Short Description
1	University of St Andrews School of Chemistry & ZEM Fuel Systems Ltd (2023)	Decarbonization of the maritime industry	The result of technology collaboration between the University of St. Andrews School of Chemistry and ZEM Fuel Systems, a start-up Scottish company that offers an alternative to diesel engines in the shipping sector. The technology is based on direct ammonia fuel cells and makes a significant contribution to the decarbonisation of the maritime industry (Royal Society of Chemistry, 2023d). The ZEM Fuel Systems team has established itself as a leading provider of green technology solutions in the marine sector (Zem Fuel Systems, 2023).
2	The University of Edinburgh School of Chemistry & Sunamp Ltd (2022)	Sustainable heat battery technology	The School of Chemistry at the University of Edinburgh, in collaboration with SME Sunamp Ltd., developed the world's first commercially viable domestic heat battery. The battery provides an "energy-efficient, sustainable, low-cost alternative to the traditional gas boiler and water tank" (The University of Edinburgh, 2023).
3	University of Strathclyde and GSK (2021)	Furthering education in drug discovery	The University of Strathclyde and GlaxoSmithKline created a framework allowing GlaxoSmith-Kline employees to obtain M.Phil. and Ph.D. degrees. GlaxoSmithKline employees engage in drug discovery and development projects under both industry and academic supervision (Royal Society of Chemistry, 2023c).
4	The DISTINCTIVE Consortium (2020)	Nuclear de-commission-ing and waste management	The DISTINCTIVE Consortium is a collaboration of ten universities and three key industry part-ners from across the UK. The programme focuses on the area of nuclear decommissioning and waste management (Distinctie, 2023).
5	SCG-Oxford Centre of Excellence in Chem-istry (2019)	Nanomaterials and catalysis	The SCG-Oxford Centre of Excellence for Chemistry (CoE) is a collaboration between the Univer-sity of Oxford and SCG focusing on R&D in the area of nanomaterials and catalysis. SCG is a Thai conglomerate and a key industry leader in the Asia-Pacific region (University of Oxford, 2023).
6	Project Pelikan (2018)	Use of polymers in oil recovery	BP Project Pelican is a collaboration between BP Upstream Technology Subsurface Technology Centre, the University of Birmingham School of Chemistry and Kernow Analytical Technol-ogy Ltd. The results of collaboration are new polymers that help recover oil from oil reservoirs (University of Birmingham, 2018).
7	Gold VCM (2017)	Replacing cata-lysts containing toxic mercury compounds	"Johnson Matthey has been recognised for its innovative work with Cardiff University on an environmentally friendly catalyst for the manufacture of vinyl chloride monomer (VCM), which is used to make poly vinyl chloride (PVC)" (Johnson, 2015)
8	GlaxoSmithKline & University of Edin-burgh (2016)	Medicines to treat acute pancreatitis	The University of Edinburgh and GlaxoSmithKline (GSK) formed a collaborative partnership to discover and develop medicines to treat acute pancreatitis (Fierce Pharma, 2011).
9	Procter & Gamble and Durham University Partnership (2015)	Sustainable prod-uct technology	The collaboration between Procter & Gamble and Durham University was formed to accelerate the development of improved and sustainable products (P&G, 2021).
10	The Quill Research Centre (2014)	Ionic liquids and their analogues	The QUILL Research Centre (Queen's University Ionic Liquid Laboratories) is dedicated to study-ing ionic liquids and their analogues. The Centre conducts research in close collaboration with industry partners (Queen's University, 2023).
11	Biostatus Ltd & Univer-sity of Bradford (2012)	Cancer pharmacol-ogy research	The Institute of Cancer Therapeutics (ICT) at the University of Bradford partners with Biostatus Ltd. to focus on cancer pharmacology research (Biostatus, 2023).
12	The Institute of Cancer Research, Abiraterone Discovery and Clinical Development Team (2011)	Cancer research	The Institute of Cancer Research, London, is one of the world's most influential cancer research institutes, with an outstanding record of achievement dating back more than 100 years (The Institute of Cancer Research, 2023a).
13	Pfizer Global Research & Development (2010)	Discovery and development of medicines and vaccines	Pfizer has built an infrastructure, including through open innovation, to become a "leaner, more science-driven and patient-focused organization" leveraging "new ways of working and harness-ing novel digital, data, and technology solutions" to speed up the discovery and development of medicines and vaccines and enhance patient and customer experiences (Bio-ITWorld, 2021).

Source: This list of UICs is sourced from the Royal Society of Chemistry (2023)

Table 3 contains thematic indicators that correspond to "Improvements in people's health and quality of life." It is reasonable to expect that UICs in medical, chemical, and pharmaceutical science specialize in projects relevant to this theme. Many of the thematic indicators presented in the table, such as "developing drugs" or "developing diagnostics," are of a general nature and can apply separately to pharmaceutical companies or universities. Some indicators such as "making technology available to patients" and "using technology for optimizing drug development," however, allude to commercialization as one of the goals of a UIC. Additionally, they might

Table 2 Benchmark indicators for evaluating the social benefits of UICs.

Social benefits
1. Improvements in people's health and quality of life
2. Create new approaches to solving social problems
3. Create new approaches to solving environmental problems
4. Contribute to positive changes in behavior and attitudes
5. Contribute to informed public debate and improved policymaking
6. Contribute to safety and security
7. Enhance respect for human rights
8. Knowledge creation
9. Job creation, contributions to training, and improved skills levels
10. Infrustructure development

Sources: Own compilation from European Commission (2010, p. 42), Lima et al. (2021, p. 13), and UN (2023) sources

reflect more specific objectives associated with UICs, in that universities partner with industrial counterparts to seek practical realization and the diffusion of research outcomes.

Table 4 presents indicators for the theme "Approaches to solving environmental problems." The most frequent thematic indicators involve reductions in pollution, waste generation, and the consumption of fossil fuels. Thus, the indicators in this table are mostly general in nature and can apply to universities, companies, or UICs equally. One could argue that they are expected from any type of organization that must comply with national regulatory requirements and ESG evaluation standards.

The next theme, i.e., "Knowledge development (that targets a social or an environmental problem)" (Table 5), with thematic indicators such as "development of new products" and "commercialization," represents two worlds, namely, industry and academia, coming together to engage in a full circle of inventions for consumers and/or patients. In a UIC setting, there is always an element of transforming knowledge built on basic research, which is a recognized specialty of universities, into applied solutions pursued by industry. The combination of research papers and patents as outputs is another feature specific to UICs. Indeed, the thematic indicators below reflect the nexus of university and industry partners sharing knowledge, expertise, and know-how to create, patent, and disseminate innovation. The important features of recent technological developments are the fragmentation of knowledge and its increased complexity. Powell et al. (1996) and Powell and Giannella (2010) argue that especially in 'fermenting' radical innovation sectors involving high levels of technological uncertainty, innovation happens in networks of learning, rather than in individual firms. The communal dynamic of knowledge creation is captured by the concept of 'communities of practice'. Moreover, knowledge co-creation within a network of researchers from both university and industry is crucial in understanding the social benefits of UICs. The social role of UICs is to serve as a vehicle of knowledge exchange and facilitation, with the social impact of knowledge creation and commercialization being especially apparent in medical research.

The indicators address practical issues relating to knowledge creation and commercialization. In the grand scheme of things, however, it is believed that one way for UICs to contribute to society is to discover applications that societies can use (Elsevier, 2021). Thus, the social impact of cooperation in research, and the resultant knowledge creation, is implied. It has been empirically ascertained that UICs intensify patenting

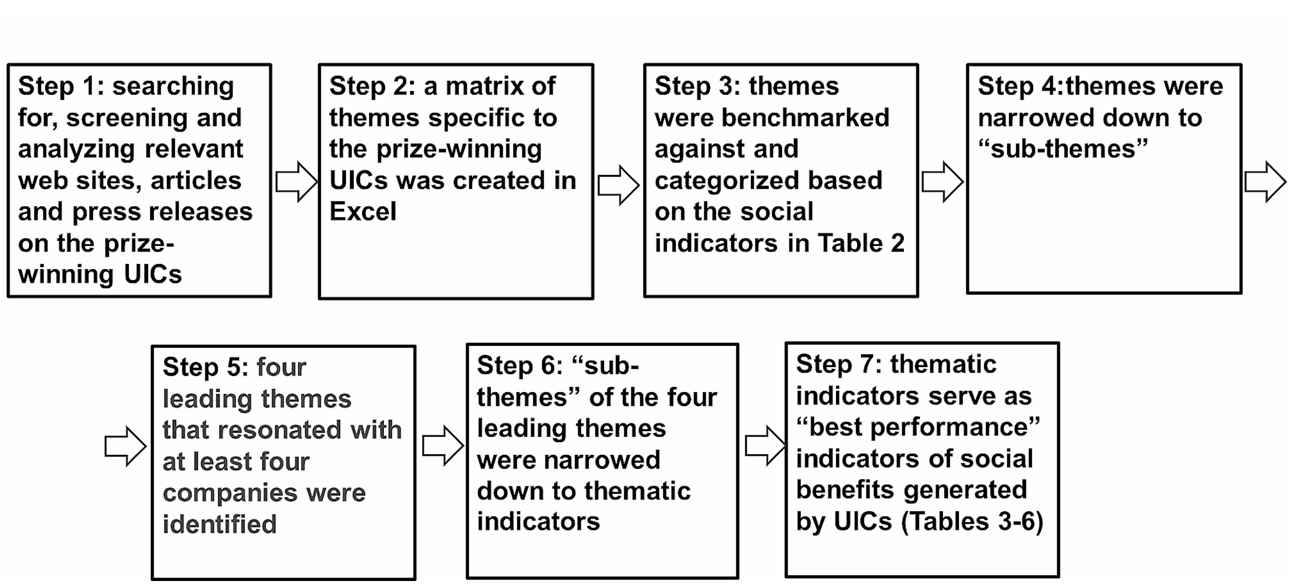

Fig. 1 Framework analysis applied to the Industry-Academia Collaboration Prize awarded by the UK Royal Society of Chemistry (RSC) (2010–2023). *Sources*: Own compilation

Table 3 Themes and thematic indicators of "Improvements in people's health and quality of life"

UIC	Themes: 1. Improvements in people's health and quality of life	Thematic indicators
The University of Edinburgh School of Chemistry & Sunamp Ltd (2022)	1. Increased comfort at home; 2. Monetary savings on bills, with "proven savings of up to 75 per cent on utility bills" (School of Chemistry, 2023); 3. Improvements in quality of life; 4. Housing associations meeting statutory obligations for energy efficiency and safety; and 5. "The Sunamp's battery lifespan is 50 years and they can be easily retrofitted to existing properties to enable households to move to all-electric and renewable energy solutions" (The University of Edinburgh (2023).	Quality of life: (1) Increased comfort at home; (2) Savings on bills; (3) Achieving energy efficiency and safety; 3. All-electric and renewable energy solutions.
GlaxoSmithKline & University of Edinburgh (2016)	(1) Treatment for severe acute pancreatitis (Fierce Pharma, 2011); (2) "Turning science into medicine"; and (3) Tackling "enormous unmet medical need" (Scottish Lifesciences Association, 2011).	Health: (1) Tackling medical needs; (2) Developing treatments.
Procter & Gamble and Durham University Partnership (2015)	(1) Reinventing the performance of household products like laundry detergents and household cleaners; (2) Making sustainable choices easier in households (P&G, 2021); and (3) "Washing clothes at low temperatures saves on running costs and stops clothes from shrinking and fading. P&G's laundry detergent needs to be able to remove soil and stains at lower temperatures, without compromising on performance" (Durham University, 2022).	Quality of life: (1) Sustainable performance of household products; (2) Improved quality.
The Quill Research Centre (2014)	1.Technology to remove mercury from natural gas (Queen's University, 2023).	Health: 1. Minimizing the use of health-threatening substances like mercury.
Biostatus Ltd & University of Bradford (2012)	(1) Cancer research and (2) "We fuse genetics, cell biology, medicinal chemistry and pharmacology to take medicines and diagnostics from concept to clinic" (The University of Bradford, 2023).	Health: (1) Developing drugs; (2) Developing diagnostics; (3) Making technology available to patients.
The Institute of Cancer Research, Abiraterone Discovery and Clinical Development Team (2011)	(1) Prostate cancer research; (2) "Developing drugs to try to shut down the production of the hormones that fuel prostate cancer's growth, rather than merely block their action" (Scowcroft, 2015); (3) "Diverse portfolio of over 20 therapeutic programs" (Business Wire, 2022); (4) Preclinical and clinical development of drugs and bringing them to patients globally (Business Wire, 2022); and (5) Developing effective oncology treatments (Business Wire, 2022; The Institute of Cancer Research (2023b).	Health: (1) Developing treatments; (2) Developing drugs; (3) Making technology available to patients.
Pfizer Global Research & Development (2010)	(1) Digital transformation to shared knowledge for vaccine and drug development (Pfizer, 2013); (2) Artificial intelligence and machine learning for drug development; (3) "Real-time predictive models of COVID-19 infection rates, helping the company to target and optimize trial-site selection"; and (4) "Pfizer used augmented-reality technology to diagnose, maintain and repair its laboratory and manufacturing equipment" (Moa, 2021).	Health: (1) Developing drugs; (2) Developing vaccines; (3) Using technology for optimizing drug development.

Source: List of UICs sourced from Royal Society of Chemistry (2023)

(Arvanitis et al., 2005), introduce new products to the market (Kaufmann and Tödtling, 2000), contribute to a firm's overall economic performance (Zucker & Darby, 2001; Aschhoff & Schmidt, 2008; Di Maria et al., 2019), and help develop regional technologies (Caviggioli et al., 2022; Mathisenand and Jørgensenalso, 2021). Knowledge creation and commercialization are referred to as the main objectives of UICs (Lee, 2000) and (based on our analysis and the nature of the relationship) their main social benefit.

Table 6 summarizes indicators for "Job creation, contribution to training, and improved skills levels." When respective company employees work toward Ph.D. and Master's degrees, this is a clear feature of a UIC. Another underlying thematic indicator in this regard is "combining industry and academia skills.". The social indicator categories in Table 6 are therefore more specific to the role of UICs in society.

UICs enhance the skills, knowledge, and social capital of students to improve the quality of human capital. This is one of UICs' objectives, at least from a university point of view (Lee, 2000). Working with a company offers valuable experience for students, as it allows them to expand their professional network and build relationships that can advance their careers. (Elsevier, 2021). Shah and Gillen (2023) document a plethora of studies on the learning benefits of UICs in engineering. The rich body of literature emphasizes application-based learning, collaborative learning, and experiential learning approaches. Case studies from various countries, for example the case of an industrial training program at the Universiti Teknologi Malaysia (Abd Manan and Wan Alwi, 2021), testify to the social benefits of training via UICs. Furthermore, UICs in engineering can also help students enhance their understanding and appreciation of socially responsible practices (Smith et al., 2018). Murphy and Dyrenfurth (2019) underscore that universities' strategic social role in job creation is enhanced by collaboration with industry.

Summarizing UIC social benefit indicators

Table 7 summarizes thematic indicators for the four most common social benefits of UICs: 1. Improvements in people's health and quality of life; 3. Creation

Table 4 Themes and theme indicators for "Creation of new approaches to solving environmental problems"

UIC	Themes: 3. Creation of new approaches to solving social or environmental problems	Thematic indicators
University of St Andrews School of Chemistry & ZEM Fuel Systems Ltd (2023)	1. "Change from fossil fuel-driven marine transport to a renewable one" and 2. "Green fuel replacing marine diesel oil" (Royal Society of Chemistry, 2023c).	1. Reduced consumption of fossil fuels.
The University of Edinburgh School of Chemistry & Sunamp Ltd (2022)	(1) "Sunamp heat batteries offer multiple environmental benefits as a domestic heating system in comparison to traditional hot water boilers, cylinders and radiators"; (2) Batteries reduce heat loss, can be charged with off-peak electricity, and deliver a steadier supply of heat; (3) Significant reductions in carbon emissions and energy usage; (4) Sunamp batteries provide "a cheap, renewable source of hot water" (The University of Edinburgh, 2023); and (5) "Heat-battery technology that can store energy from any source as heat and release it on demand to provide space heating and hot water, thereby reducing use of fossil-fuel energy sources, and reducing carbon emissions" (School of Chemistry, 2023).	(1) Reductions in carbon emissions; (2) Reductions in energy usage; (3) Reduced consumption of fossil fuels.
The DISTINCTIVE Consortium (2020)	1. Innovative approaches to waste management and decommissioning (Fairweather et al., 2018, p. 2).	1. Reduced waste and pollution.
SCG-Oxford Centre of Excellence in Chemistry (2019)	1. Solutions addressing long-term carbon-neutral targets; solutions helping mitigate the effects of global warming (University of Oxford, 2023a).	1. Reductions in carbon emissions.
Project Pelikan (2018)	(1) New polymers that help recover oil from oil reservoirs; (2) Solving a complex environmental problem (University of Birmingham, 2018).	1. Reduced waste and pollution.
Gold VCM (2017)	(1) Controlling and reducing emissions of toxic mercury compounds (Johnson, 2015); (2) "Cleaning up the global environment"; and (3) Developing a mercury-free catalyst (Cardiff University, 2023).	1. Reduced waste and pollution.
Procter & Gamble and Durham University Partnership (2015)	(1) Addressing complex environmental challenges; (2) Sustainable alternatives to current household products and tasks, making sustainable choices easier; (3) Using "expert understanding of the science and engineering behind household cleaning products to create experimental and theoretical tools that can unlock new formulations to help consumers use less water and energy whilst still achieving excellent results – enabling them to be both clean and green"; (4) Reducing greenhouse gas emissions; a five degree drop in average wash temperatures (P&G, 2021); (5) "Improving the performance and environmental footprint of everyday cleaning tasks"; (6) Generating "new sustainably-sourced polymers for formulation within consumer goods products" (Durham University, 2023); and (7) Meeting the complex global challenges of water scarcity, energy consumption and decarbonization (N8 Research Partnership (2021).	(1) Reductions in energy usage; (2) Reductions in water use; (3) Reductions in carbon emissions.

Source: List of UICs sourced from Royal Society of Chemistry (2023)

of new approaches to solving environmental problems; 8. Knowledge creation (that targets a social or an environmental problem); and 9. Job creation, contribution to training, and improved skills levels. The rest of the themes from Table 2 did not resonate substantively with the case studies.

The indicators "8. Knowledge creation (that targets a social or an environmental problem)" and "9. Job creation, contribution to training, and improved skills levels" in Table 7 are more specific to UICs. There is also a leitmotif of mutuality, knowledge exchange, and the complementarity of skills that make a UIC worthwhile pursuing. Our results indicate that knowledge co-creation is a recurring theme among winners of the Industry-Academia Collaboration Prize. Indeed, these results support prior empirical evidence regarding larger-scale, national-level positive effects of UICs in the pharmaceutical, biotechnology, and medical technology sectors (Petruzzelli & Murgia, 2020). Scholars show, based on a sample of joint patents generated by Italian and German universities, the diversification of national technological specialization because of innovative UIC efforts. O'Dwyer et al. (2023), for instance, argue that UICs have increases the competitiveness of the national pharmaceutical industry, whilst in China, they have had a significant positive impact on the patent output of high-tech industries (Sun et al., 2020).

Knowledge co-creation is the output of 'communities of practice'—a network in which the generation of knowledge is a result of social interaction at the individual level, both within and between organizations (Soekijad et al., 2004; Hardy et al., 2003). Alongside the concept of 'communities of practice', 'communities of shared values' emphasize beliefs, values, and priorities shared by members of the UIC partnership. Most importantly, 'shared values' suggest that both economic and societal goals are being pursued by a collaborative venture. Based on our analysis of the commentaries on and discussions of projects awarded the UK Royal Society of Chemistry prize, we can conclude that emergent indicators reflect the practical benefits of UICs and combine society- and profit-oriented goals. Figure 2 below summarizes our main outcomes. These are the best performance indicators of social and environmental benefits created by UICs based on the case of national UK prize winners in the pharmaceutical, medical, and chemical industries.

Table 5 Themes and theme indicators of "Knowledge creation" (that targets a social or an environmental problem)

UIC	Themes: 8. Knowledge creation (that targets a social or an environmental problem)	Thematic indicators
University of Strathclyde and GSK (2021)	1. Research papers as outputs; 2. Patents as outputs (Royal Society of Chemistry, 2023c); 3. "Enhanced levels of project-relevant scientific knowledge, advanced thinking, and overall scientific rigor" (Royal Society of Chemistry, 2023d; University of Strathclyde, 2023); 4. Participating research students; 5. Skills to develop even greater scientific excellence" (University of Strathclyde, 2023); and 6. "Exceptional levels of productivity, rigor, and creativity from the participating research students" (Schwartz, 2022).	(1) Research papers as outputs; (2) Patents as outputs; (3) Scientific knowledge development; (4) Participating research students.
SCG-Oxford Centre of Excellence in Chemistry (2019)	1. Research papers as outputs; 2. Patents as outputs (University of Oxford, 2023); 3. New product development; and 4. "Commercialization of a new polymer composite that would make a huge impact on the composite sector" (The Nation, 2015).	(1) Research papers as outputs; (2) Patents as outputs; (3) New product development; (4) Commercialization.
Project Pelikan (2018)	(1) Polymers help in an oil recovery technique known as 'waterflooding' (University of Birmingham, 2018) and (2) Commercially viable manufacturing routes (Loughborough University, 2018).	(1) New product development; (2) Commercialization.
Gold VCM (2017)	(1) "This novel catalyst is a further example of Johnson Matthey's capabilities in and commitment to sustainable technologies, and most importantly, it enables our customers to meet forthcoming legislation in an economically viable way" (Johnson, 2015); (2) Product and new production process development (Cardiff University, 2023); and (3) Commercial validation, including full pilot plant trials in China (Research Excellence Framework, 2014).	(1) New product development; (2) Commercialization.
GlaxoSmithKline & University of Edinburgh (2016)	(1) Bringing together the "complementary skills from academia and GSK into partnerships that could translate innovative academic research into medicines for patients" and (2) Marrying "the drug discovery expertise and infrastructure of big Pharma with the deep biological insight and patient availability of clinical academia" (The University of Edinburgh, 2016).	(1) New product development; (2) Commercialization
Procter & Gamble and Durham University Partnership (2015)	(1) New product development and commercialization and (2) "This work contributed to the introduction of new patented polymer technologies into single unit dose formulations – otherwise known as 'Ariel pods'." (Durham University, 2022)	(1) Patents as output; (2) New product development; (3) Commercialization
The Quill Research Centre (2014)	(1) Bringing together researchers from the fields of applied chemistry and chemical engineering; (2) Patents as outputs; (3) New product development and commercialization; and (4) "Redox flow batteries can store large amounts of energy in their electrolytes and have a lifespan of more than 25 years, offering clear advantages over lithium-ion batteries" (Times Higher Education, 2023).	(1) Patents as output; (2) New product development
Biostatus Ltd & University of Bradford (2012)	(1) New product development; (2) Diagnostics development (The University of Bradford, 2023; Biostatus, 2023).	(1) New product development; (2) Diagnostics development.
The Institute of Cancer Research, Abiraterone Discovery and Clinical Development Team (2011)	1. Patents as outputs; 2. New product development; 3. "The ICR is also one of the world's most successful academic institutions in industry collaboration and is especially well-known for its excellence in drug discovery" (Business Wire, 2022); 4. "Protecting our intellectual property for licensing is one of the most important roles of the Enterprise Unit and we encourage researchers doing work with commercial implications to get in touch at an early stage" (The Institute of Cancer Research, 2023b).	(1) Patents as outputs; (2) New product development.
Pfizer Global Research & Development (2010)	(1) Digital transformation; (2) "Pfizer embarked on a digital transformation—leveraging new ways of working and harnessing novel digital, data, and technology solutions to enhance every aspect of our business from speeding up the discovery and development of medicines and vaccines to how we enhance patient and customer experiences to improve health outcomes, and how we make our work faster and easier through automation"; and (3) Knowledge sharing ecosystem (Pfizer EU Policy, 2023). "Digital technologies as a growth drivers and value creators for the business" enabling "chemists to easily and quickly search and analyze both internal and external compound collections that exceed a billion molecules in just hours rather than weeks" (Bio-ITWorld, 2021).	(1) Digital transformation; (2) Knowledge sharing.

Source: List of UICs sourced from Royal Society of Chemistry (2023)

As emphasized in the prior literature, universities specialize in basic research, while industry is better at generating and commercializing technology (Hall et al., 2003; Rothaermel et al., 2007; Tian et al., 2022). The role of universities is in training post-doctoral research assistants, as well as facilitating Ph.D. and Master's degrees for industry partners. This social role—training and job creation—is exercised more effectively through UICs

Table 6 Themes and theme indicators relating to "Job creation, contribution to training, and improved skills levels"

UIC	Themes: 9. Job creation, contribution to training, and improved skills levels	Thematic indicators
The University of Edinburgh School of Chemistry & Sunamp Ltd (2022)	Job creation: 1. As a result of the partnerships, direct job creation at Sunamp and jobs at distributors, resellers and installers across the UK (The University of Edinburgh, 2023).	Job creation: 1. Job creation in the industry.
University of Strathclyde and GSK (2021)	Training and skills: 1. Facilitating Ph.D. and Master's degrees; 2.GSK employees work towards an MPhil/PhD degree: 105 students have graduated to this stage with higher degree awards (97 PhD and 8 MPhil) (Royal Society of Chemistry, 2023d); 3. Continuous professional development "to better equip them with the skills to develop even greater scientific excellence" (University of Strathclyde, 2023); 4. The partnership "created a flow of skilled personnel to enhance capabilities within the sector" (University of Strathclyde, 2021); and 5. Combining industry and academia skills (University of Strathclyde, 2023)	Training and skills: (1) Facilitating Ph.D. and Master's degrees; (2) Continuous professional development; (3) Combining industry and academia skills.
The DISTINCTIVE Consortium (2020)	Training and skills: (1) Training the next generation of UK researchers and potential employees in the sector (Distinctive, 2023); and (2) "Training of a significant number of PDRA (post-doctoral research assistants) and PhD student researchers with high level skills of direct relevance to issues in nuclear waste and decommissioning, directly addressing the skills agenda" (Fairweather et al., 2018).	Training and skills: (1) Facilitating Ph.D. and Master's degrees; (2) Training post-doctoral research assistants.
GlaxoSmithKline & University of Edinburgh (2016)	Training and skills: 1. The aim of collaboration is "to bring together the skills from academia and GSK into partnerships that could translate academic research into novel medicines" (GEN, 2014).	Training and skills: 1. Combining industry and academia skills.

Source: List of UICs sourced from Royal Society of Chemistry (2023)

Table 7 Summary of thematic indicators

Social benefits	Thematic indicators
1. Improvements in people's health and quality of life	Quality of life: (1) Increased comfort at home; (2) Savings on bills; (3) Achieving energy efficiency and safety; 3. All-electric and renewable energy solutions; (4) Sustainable performance of household products.
	Health: (1) Tackling medical needs; (2) Developing treatments; (3) Minimizing the use of health-threatening substances like mercury; (4) Developing drugs; (5) Developing diagnostics; (6) Making technology available to patients; (7) Developing vaccines; (8) Using technology for optimizing drug development
3. Creation of new approaches to solving environmental problems	(1) Reduced consumption of fossil fuels; (2) Reductions in carbon emissions; (3) Reductions in energy usage; (4) Reduced waste and pollution; (5) Reductions in water use
8. Knowledge creation (that targets a social or an environmental problem)	(1) Research papers as outputs; (2) Patents as outputs; (3) Scientific knowledge development; (4) Participating research students; (5) New product development; (6) Commercialization; (7) Diagnostics development; (8) Digital transformation; (9) Knowledge sharing
9. Job creation, contribution to training and improved skills levels	Job creation: 1. Job creation in industry.
	Training and skills: (1) Facilitating Ph.D. and Master's degrees; (2) Continuous professional development; (3) Training post-doctoral research assistants; (4) Combining industry and academia skills

Sources: Own compilation from European Commission (2010, p. 42), Lima et al. (2021, p. 13) and UN (2023) sources

(Murphy and Dyrenfurth, 2019). As ascertained in this paper, the second most significant and relevant social benefit of UICs is knowledge creation or co-creation. The nature of UICs, their goals, and how they are managed determine the contribution made to society in two specific aspects: knowledge generation and job creation/training. Both human resource enhancement and knowledge creation benefits have positive implications for social as well as economic development. Essentially, it is a case of shared values.

Conclusions

Analyzing successful UICs in the medical, chemical, and pharmaceutical industries that have been awarded the Industry-Academia Collaboration Prize by the UK Royal Society of Chemistry (RSC) (2010–2023) produced four categories of social benefits: (1) improvements in people's health and quality of life; (2) creation of new approaches to solving environmental problems; (3) knowledge creation (that targets a social or an environmental problem) and job creation, and (4) contribution to training and improved skills levels. The last two are specific to UICs, and thus they constitute the most important thematic indicators of social benefits generated as a result of a collaborative effort. Knowledge creation and training/job creation are the benefits at the nexus of universities' educational mission and industry's innovative drive. UICs create communities of practice that combine different skills, experiences, and expertise to create, shares and utilize knowledge. The thematic indicators of their social benefits reflect more practical, innovation, co-creation, and commercialization aspects. Furthermore, the values of UIC partners might be shared, but they are pursued via very concrete and practically oriented goals, and they combine both commercial and social goals.

We borrow from the literature on 'communities of practice', stemming from sociology focusing on knowledge co-creation. In addition, the concept of 'communities of shared values' is introduced, suggesting value-oriented communal effort to create solutions to environmental and social problems. We emphasize the

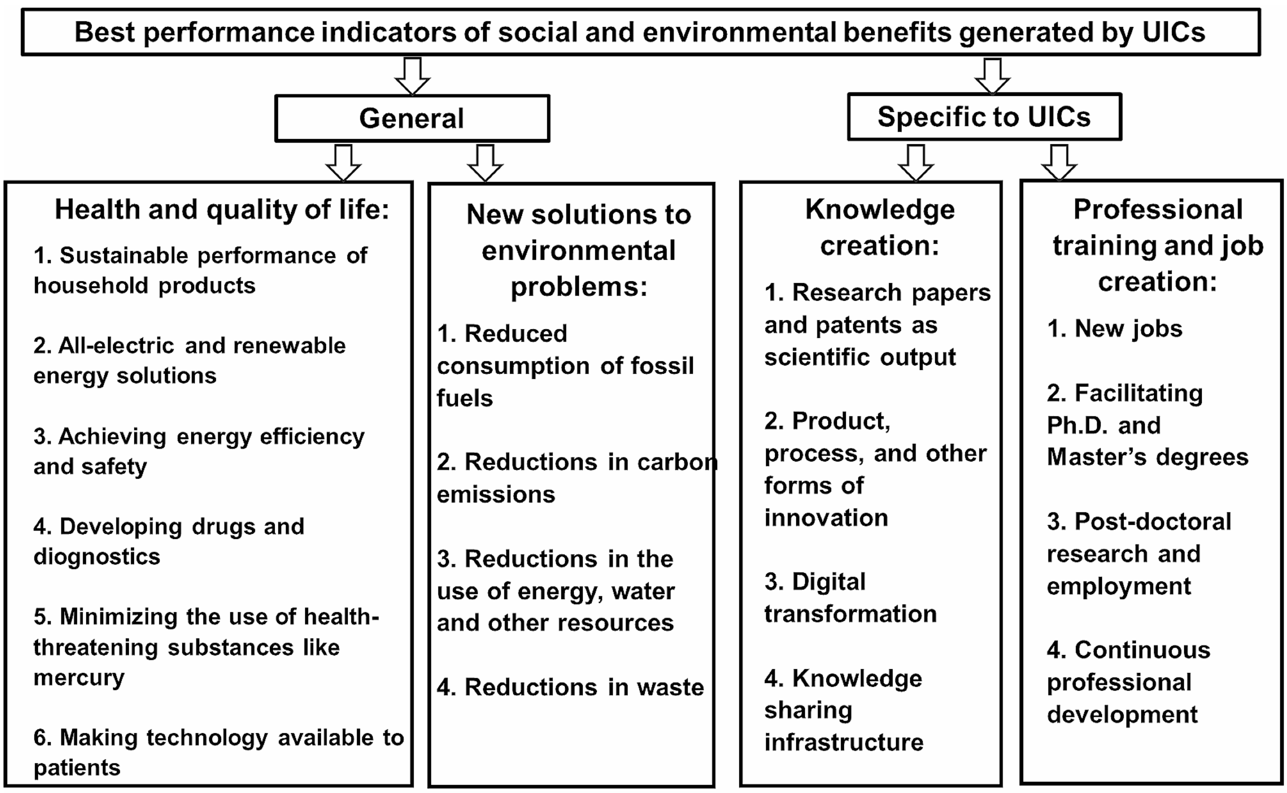

Fig. 2 Best performance indicators of the social benefits generated by UICs. *Source*: Own compilation

utility of both terms, as they cover different dimensions of UIC outputs. The term 'communities of practice' is a useful tool applied specifically to the collaborative effort of researchers with complementary skills and expertise who come together to generate some form of innovative output. Knowledge generation is the key feature of 'communities of practice'. The broader term 'communities of shared values' is applied to indicate both the social and the environmental goals of UICs. The application of this concept is highly relevant in the context of successful UICs in the medical and chemical industries and is observable in our sample of the prize-winning UICs.

The empirical contribution of this paper is in providing clear and crystallized social benefit indicators based on best practice cases. The thematic indicators presented in Fig. 2 can serve as criteria for identifying the social impact of UICs in the medical, chemical, and pharmaceutical industries. Our conceptual contribution is in emphasizing the practical side of knowledge co-creation and training as important social benefits of UICs, but our findings have a broader impact, in that we emphasize the importance of UICs in fulfilling a specific function in society, namely facilitating research and developing skills that can change the world for the better. How these are executed within the confines of UICs is a potential avenue for future research, but we can state confidently that UICs offer a 'shared values' platform where various vestured interests meet, compromise, and adjust to produce practical solutions to social problems.

The resulting list of thematic indicators of a UIC's social benefits has wide practical implications—it is a starting point for discussing the value of UICs for society at large and what traits are conducive for creating this social value. Our research alludes to the necessity of creating a conducive policy environment for UICs in the medical, chemical, and pharmaceutical industries. Tax incentives, government funding of university-based technology incubators, or other forms of support will improve the national system of innovation and quality of human capital.

The results of case studies, however, are not generalizable, and the choice of a research design is a limitation of this paper. We cannot assume that UICs have the same social and environmental benefits in other contexts or sectors. We argue, however, that the insights gained from our specific case of the best, prize-winning UIC practices in the pharmaceutical, medical, and chemical industries in the UK provide a benchmark, i.e., a point of reference, for other contexts. It is especially relevant considering our conclusion that the two identified social benefits, namely knowledge creation and new jobs, training, and improved skills levels, are specific to UICs. They constitute the most important thematic indicators of social benefits generated because of a collaborative effort. Of course, cross-country and cross-industry comparisons would be a desirable avenue for future research.

Abbreviations

AI	Artificial intelligence
BP	British Petroleum
CoE	Centre of Excellence for Chemistry
EU	European Union
GEN	Genetic Engineering and Biotechnology News
GSK	GlaxoSmithKline
The ICR	The Institute of Cancer Research
Ltd	Limited
M.Phil.	Master of Philosophy
P&G	Procter & Gamble
PVC	Poly vinyl chloride
QUILL	Queen's University Ionic Liquid Laboratories
R&D	Research and Development
Ph.D.	Doctor of Philosophy
RSC	Royal Society of Chemistry
SCG	Siam Cement Group
SDG	Sustainable Development Goals
SIAMPI	Social Impact Assessment Methods of Productive Interactions
UK	United Kingdom
UICs	University-industry collaborations
UN	United Nations
VCM	Vinyl chloride monomer

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Data availability
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Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Publisher's Note

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