A Framework for Evaluating and Improving University-Industry Collaboration

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Except where otherwise indicated, this thesis is my own original work.

Richa Awasthy
1 February 2021

To my parents, and
my daughters Jiya and Jini,
who make me feel blessed.
To the memories of my loving bua.
To the lotus feet of my Lord.
To the nothingness,
where I want to belong...

"And once the storm is over,
you won’t remember how you made it through, how you managed to survive.
You won’t even be sure, whether the storm is really over.
But one thing is certain.
When you come out of the storm, you won’t be the same person who walked in.
That’s what this storm’s all about."
-Haruki Murakami

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This accomplishment wouldn't have been possible without the support of many people during this research journey.

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Abstract

University-Industry Collaboration (UIC) has been a topic of interest for decades and has gained additional attention in recent times as the educational, research, industry, economic, and social benefits of such collaboration are increasingly recognized. While there are continuing efforts both globally and locally within Australia to encourage such collaboration, establishing successful UIC remains a challenge. The poor ranking of Australia against Organisation for Economic Co-operation and Development (OECD) comparators in most business-to-research collaboration indicators confirms that collaboration is an ongoing concern and that there is a lot more work to be done to improve collaborations, particularly in Australia.

The research presented in this thesis addresses this problem by developing a framework for evaluation and improvement of UIC. This was achieved using a Design Science Research (DSR) approach.

The proposed UIC Framework comprises a set of newly developed tools based on a literature review and initial qualitative research. These tools can be used in conjunction with the Cynefin sense-making framework to understand, evaluate and improve UIC of various types and complexity. The first tool is a UIC Systems Model, which will help users to analyse and gain a better understanding of a UIC. The second tool is a comprehensive UIC Practices Framework that can be used to improve the effectiveness of a UIC. The final tool is a UIC Maturity Model (UICMM), which can be used to assess the UIC maturity of an organisation, and guide improvements.

By using this Systems Model, Practices Framework, and Maturity Model in conjunction with the Cynefin sense-making framework, stakeholders will be able to better understand their UIC activities, make improvements through informed decision-making, and evaluate the impact of such improvements.

The developed UIC Framework has been evaluated using descriptive and expert evaluations. These evaluations demonstrate the utility and applicability of the framework. A strategy for continuous real-world evaluation and improvement of the framework has also been developed and documented in this thesis. This strategy is being piloted with two industry partners and will be used for future improvement of the UIC Framework.

List of Publications

The following publications resulted from the research presented in this thesis.

- **A Framework to improve University-Industry Collaboration**, *Richa Awasthy*, Shayne Flint, Ramesh Sankarnarayana and Richard L. Jones. Journal of Industry-University Collaboration, 2020, publisher - Emerald Publishing Limited.

  This paper was based on the content of Chapter 7 of this thesis.

- **UICMM: A Maturity Model for University-Industry Collaboration** *Richa Awasthy*, Shayne Flint, Richard L. Jones and Ramesh Sankarnarayana. Proceedings of the 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), Stuttgart, Germany.

  This paper was based on the content of Chapter 8 of this thesis.

- **Bridging the Gap - A Workshop of Industry Practitioners and University Researchers** *Richa Awasthy*, Shayne Flint, Ramesh Sankarnarayana and Richard L. Jones. Proceedings of the 2017 IEEE TENCON - IEEE Region Ten Conference.

  This paper was based on the content of Chapter 4 of this thesis.

- **Lifting the Constraints - Closing the Skills Gap with Authentic Student Projects** *Richa Awasthy*, Shayne Flint and Ramesh Sankarnarayana. Proceedings of the EDUCON 2017 the IEEE Global Engineering Education Conference.

  This paper is reproduced in Appendix C.

- **Towards improved Adoption: Effectiveness of Research Tools in the Real World:** *Richa Awasthy*, Shayne Flint and Ramesh Sankarnarayana. Proceedings of the 4th International Workshop on Quantitative Approaches to Software Quality (QuASoQ 2016).

  This paper is reproduced in Appendix A.

- **Multi-dimensional approach to bridging the gap between Software Engineering Research and Industry Practice** *Richa Awasthy*, Shayne Flint and Ramesh Sankarnarayana. ASWEC ' 15 Vol. II Proceedings of the ASWEC 2015 24th Australasian Software Engineering Conference.

  This paper is reproduced in Appendix E.

Contents

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List of Abbreviations

ACT Australian Capital Territory

AR Action Research

ARC Australian Research Council

ATSE Australian Academy of Technology and Engineering

BPMM Business Process Maturity Model

CEMM Collaboration Engineering Maturity Model

CIMAM Crowdsourcing Ideation Maturity Assessment Model

CLD Causal Loop Diagram

CMG Collaboration Maturity Grid

CMI Cambridge-MIT Institute

CMM Capability Maturity Model

CMMI Capability Maturity Model Integration

CollabMM Collaboration Maturity Model

Col-MM Collaboration Maturity Model

CPR Collaborative Practice Research

DPMM Distributed Process Maturity Model

DS Design Science

DSR Design Science Research

DSRM Design Science Research Methodology

ECMM Enterprise Collaboration Maturity Model

ICT Information and Communication Technology

IP Intellectual Property

IPIRA Intellectual Property and Industry Research Alliances

IS Information Systems

KIC Knowledge Integration Community

KMMM Knowledge Management Maturity Model

KPA Key Process Area

LISI Levels of Information System Interoperability

MIT Massachusetts Institute of Technology

NIS National Innovation System

OECD Organization for Economic Cooperation and Development

QMMG Quality Management Maturity Grid

R&D Research and Development

RMIT Royal Melbourne Institute of Technology

SEI Software Engineering Institute

SRIP Sponsored Research Interaction Process

SSM Soft Systems Methodology

ST Systems Thinking

TRL Technology Readiness Level

TTO Technology Transfer Office

UIC University-Industry Collaboration

UICMM University-Industry Collaboration Maturity Model

UML Unified Modelling Language

Glossary of Terms

Terms may be interpreted differently by different people. I present here the definition of the terms used within this thesis.

Barrier
A factor that restricts UIC, acts as an impediment to UIC, or poses a challenge to establishing effective UIC.

Effectiveness
'Extent to which planned activities are realized and planned results achieved' [ISO, 2015].

Focus group
Engagement of a small group of people in an informal discussion focused around a particular research topic (UIC within the context of this thesis) [Wilkinson and Silverman, 2004, pg.177].

Practice
A practice is a well-articulated specific action, or measure taken within an organization to overcome barriers and/or enable UIC success factors.

System
'A group of interacting, interrelated, or interdependent parts that form a unified whole having a specific purpose.' [Kim, 1999]

Systems thinking
A discipline that emphasises a holistic view of a system, with a focus on interrelationships within and outside the system, and emerging patterns based on dynamic cause and effect, in order to understand the behaviour of complex systems and identify measures to improve their performance.

Technology transfer

Transfer of 'know-how, technical knowledge, or technology from one organisation to another', including the creation of licensing and IP agreements.

University-Industry Collaboration (UIC)

A joint effort and relationship between a university and industry involving people, sharing of resources, and coordination of activities to achieve a common purposeful objective.

Part I
Introduction

Chapter 1

Overview

This chapter outlines the purpose of this thesis starting with the background context of the research. It provides information regarding the motivation behind conducting this research, the aim of this research, associated research objectives, and describes the scope of this thesis. The structure of this thesis is presented in Section 1.6. Finally, the contributions this thesis makes to evaluation and improvement of University-Industry Collaboration (UIC) are summarised.

1.1 Introduction

Today's highly competitive global environment requires businesses to innovate at a rapid pace. It has become imperative for businesses to collaborate with universities in order to satisfy such market demands and maintain a competitive edge [Ankrah and Omar, 2015; Perkmann et al., 2013]. This has led to growing interest in UIC research, which, in part, has identified barriers and challenges to improving collaboration between university and industry [Galán-Muros and Plewa, 2016; Bruneel et al., 2010; Agrawal, 2001; Meyer-Krahmer and Schmoch, 1998]. Around the world there is an increasing emphasis on the need to improve UIC [Mowery et al., 2015; Trencher et al., 2014; Acworth, 2008]. Within our region, there is a growing concern about the fact that Australia lags behind many OECD countries in terms of UIC [Dang et al., 2019; OECD Paris, 2017] and levels of research commercialisation [Chartered Accountants Australia and New Zealand, 2017; Davis, 2017].

This indicates that there is a strong need to develop approaches to overcome the challenges and improve UIC.

This thesis describes research undertaken to gain a deeper understanding of UIC and how it can be improved. The initial research showed that UICs operate in diverse ways, and, in many cases, improving UIC is a complex problem. In order to deal with this complexity a Design Science Research (DSR) approach [Peffers et al., 2007; Hevner et al., 2004] was used to develop a UIC Framework comprising a UIC

Systems Model, a UIC Practices Framework and a UIC Maturity Model (UICMM) that are used with the Cynefin sense-making framework [Snowden and Boone, 2007] to facilitate better understanding, evaluation and improvement of UICs.

1.2 Motivation

The initial motivation for this research draws from my own experience in industry as a software engineer. The perceived gap between software engineering education and industry practice during my short tenure in industry motivated me to dig deeper into the area of UIC and gain a better understanding of its current state. I started by investigating the gap between best practices prescribed through education and their application in industry. This was followed by exploring the UIC ecosystem and its current state.

UICs are widely recognized as important due to the scientific, education, social, innovation, economic and other benefits they offer to universities, industry and society more broadly. While efforts have accelerated to encourage such collaborations, there are barriers to establishing successful collaborations. This has led to an increasing need to find ways to overcome these barriers and improve the effectiveness of collaborations, including establishing practices and principles to guide their initiation, implementation and success.

I have been further motivated by recent increased interest in this area world-wide, and many governments' emphasis on encouraging UIC, particularly within Australia [Australian Government, 2020, 2018, 2017b,a, 2016, 2014].

1.3 Research aim

The research presented in this thesis aims to develop a framework that can be used to evaluate and improve the effectiveness of University-Industry collaboration (UIC).

1.4 Research objectives

The following objectives support the aim of this research:

- Investigate the current state of UIC to understand how collaboration is currently pursued.

- Investigate existing barriers to establishing successful UICs.

- Investigate the factors that enable the success of UICs.
- Integrate the results of the above investigations to develop a general framework for evaluating and improving the effectiveness of UICs.

1.5 Thesis scope

The research presented in this thesis encompasses the process of exploring university-industry relationships including investigating the different types of engagements between universities and industry, various barriers to UIC, and measures adopted to improve UIC. Further, it proposes a novel framework for dealing with UIC effectively. The research focuses on proposal of the framework at a conceptual level and not its implementation. However, application of the framework is demonstrated using example scenarios. In addition, a strategy for evaluation and improvement of the framework in real-world UICs is documented in this thesis.

While the thesis covers UIC in general, rather than any specific type of UIC, its focus is confined to various aspects of UIC at an organizational level with university and industry as the main stakeholders.

1.6 Thesis structure

This thesis comprises 11 chapters and 9 appendices. I have presented the structure of this thesis using the Unified Modelling Language (UML) [OMG, 2007] activity diagram depicted in Figure 1.1. Each chapter of this thesis is represented as an activity (rounded box) with directed arrows representing the flow of ideas and results of the research. The rectangular boxes in the diagram denote the contributions made by this research.

The vertical lanes in the activity diagram depict the three parts of this thesis: Introduction, Contribution, and Conclusions. I provide an outline of the contents of these parts and comprising chapters below.

1.6.1 Part I - Introduction

There are three chapters in Part I of this thesis. Chapter 1 is the current chapter in which an overview of the research presented in this thesis is provided.

In Chapter 2, the context and relevance of the research is set. I examine UIC in general and present a comprehensive literature review related to the benefits of collaboration from both universities and industry perspectives, different ways of collaboration, and models proposed for effective collaboration. The review of existing models for UIC led to establishing a need for new approaches to UIC. This knowledge forms the foundation of the proposed approach to improving UIC presented in Part II of the thesis.

In Chapter 3, the research design adopted for the research presented in this thesis is detailed. The research design is based on the Design Science Research (DSR) approach, which facilitates the research aim of developing a framework for evaluation and improvement of UIC (a design artefact).

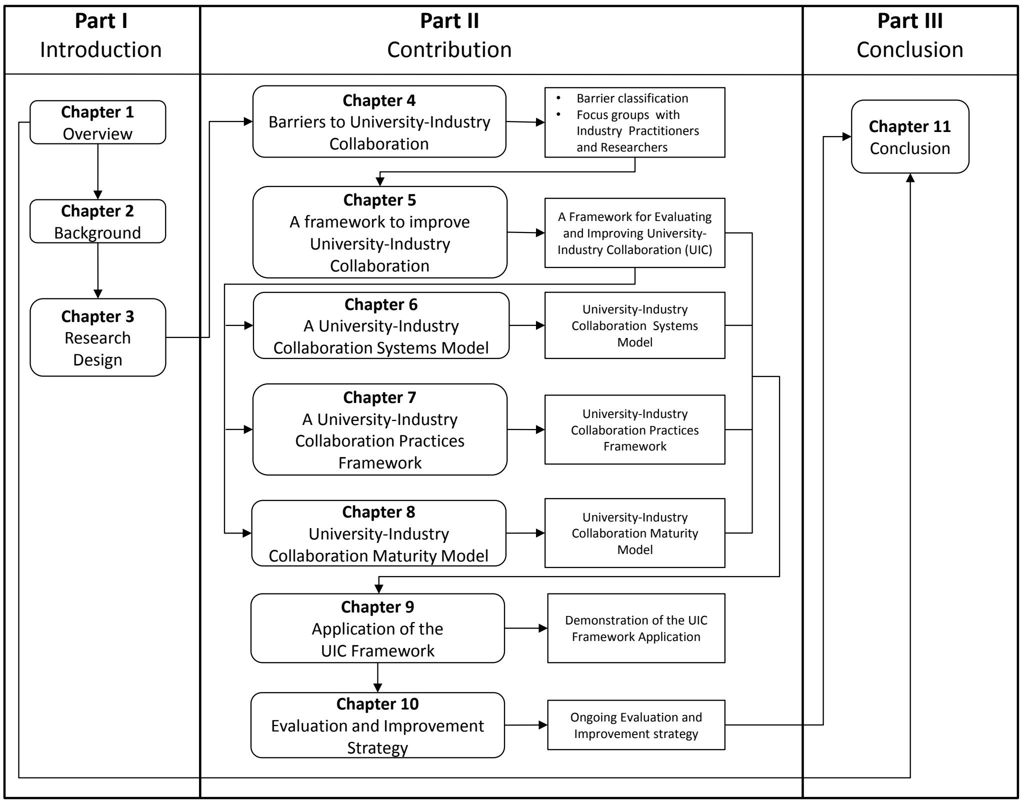

Figure 1.1: Research flow and thesis structure

1.6.2 Part II - Contribution

Part II of this thesis consists of seven chapters. Chapter 4 makes a theoretical contribution to the UIC literature with findings about barriers to UIC from a review of existing literature and a qualitative study involving researchers and industry practitioners. The findings of the qualitative study confirm the barriers described in the reviewed literature and identify a few additional barriers. They also confirm the scope for universities to play a greater role in increasing their level of engagement with industry.

Chapter 5 makes a theoretical contribution in terms of a novel framework proposed to deal with UIC. The basis of the claim that UIC is often a complex problem is established. It is proposed that an appropriate approach to deal with this complexity is to utilise the Cynefin sense-making framework with three newly developed tools: A UIC Systems Model, a UIC Practices Framework, and a UIC Maturity Model.

Chapter 6 makes a practical contribution to the field of study by proposing a UIC Systems Model, which views UIC as a system and defines the various components of UIC and their interrelationships.

Chapter 7 makes a practical contribution in terms of a UIC Practices Framework for overcoming barriers to UIC and enabling UIC success factors. The framework is based on a review of best practices for collaboration and findings of the qualitative study described in Chapter 4. The framework offers a practical tool that has managerial and research implications for UIC.

Chapter 8 makes a practical contribution in terms of a University-Industry Collaboration Maturity Model (UICMM), which can be used by organizations to assess and improve the maturity of their collaborative efforts. The UICMM can be used for self-assessment or third-party assessment of organizations.

Chapter 9 uses a set of scenarios to demonstrate the application of the UIC Framework presented in this thesis.

Chapter 10 elaborates a strategy for real-world evaluation and improvement of the UIC Framework.

1.6.3 Part III - Conclusion

Part III of the thesis comprises Chapter 11, which presents the conclusion of this work along with limitations and directions for future work.

1.7 Use of terminology

A ‘Glossary’ of terms provided at the beginning of this thesis ensures a consistent understanding of key concepts and terms. For terminology additional to the glossary, a coherent approach has been adopted to ensure clear understanding as intended by the researcher. Throughout this thesis, the terminology used in cited papers is generally used as defined in the papers. In case it is necessary to use different terminology to that used in cited papers, the terminology used is clearly defined. This may be required when different authors have used different terminology for the same concept or to convey the same meaning. When specific terminology is used for the purpose of this thesis, that terminology is defined or explained.

1.8 Summary of contribution

The work presented in this thesis facilitates a better understanding of the UIC ecosystem, and develops a framework for evaluating and improving the effectiveness of UIC. Specifically, this thesis contributes the following:

- **Comprehensive review related to UICs.** This thesis presents a comprehensive literature review of the UIC ecosystem, including benefits, different types of UICs, and existing models for effective collaborations (Chapter 2). The review has led to creation of novel classification schemes for UIC barriers (Chapter 4), success factors (Chapter 7), and practices (Chapter 7).

  From the perspective of contribution to knowledge, this thesis has brought together several aspects of UIC that were fragmented in the existing literature. The novel classification scheme provides a structure that connects these aspects and improves our understanding of the relationships between them.

- **Qualitative Research to understand the state of UICs.** Qualitative research (Chapter 4) involving multiple focus group meetings was conducted to identify barriers to UIC, and measures that can be adopted to improve the effectiveness of UICs (Publication [Awasthy et al., 2017b]).

- **A holistic approach to UIC.** A novel UIC Framework has been proposed for dealing with UICs of varying complexity (Chapter 5). The framework makes use of the Cynefin sense-making framework along with three newly developed tools (described below) to evaluate and improve UICs of varying complexity. A description of how the proposed framework can be applied in practice, along with example scenarios, is presented (Chapter 9). A strategy for evaluating and improving the UIC Framework in real-world settings is developed and documented (Chapter 10).

- **A UIC Systems Model.** A UIC Systems Model was developed by applying a systems approach to UIC (Chapter 6). The model can be used to describe UICs as a system of interacting components.

- **A UIC Practices Framework.** A UIC Practices Framework was developed based on evidence from a literature review and qualitative research. This framework comprises a categorised set of practices that can be used to improve the effectiveness of UIC (Publication [Awasthy et al., 2020]).

- **A UIC Maturity Model (UICMM).** A UIC Maturity Model was developed for use in assessing and improving the level of UIC maturity in collaborating organisations. Improvements in UIC maturity can lead to more effective UICs (Publication [Awasthy et al., 2018]).

- **Contribution to DSR literature.** This thesis makes a contribution to the DSR literature by demonstrating the use of DSR methodology for developing artefacts for improving and evaluating UIC.
- **Proof of Concept of application of DSR and Systems Thinking to UIC.** This thesis presented a case for the value of applying systems thinking and DSR methodologies to the domain of UIC.

Chapter 2

Background

'In the long history of humankind (and animal kind, too) those who learned to collaborate and improvise more effectively have prevailed.' - Charles Darwin

This chapter establishes the need for new approaches to evaluating and improving UIC.

The context of this research is set by establishing the importance and relevance of University-Industry Collaboration (UIC). It describes the multi-faceted benefits of UIC from the perspective of universities and industry. It also presents a study of various ways in which universities and industry can collaborate, and several existing models proposed to establish effective collaborations. This study was conducted to gain a deeper understanding of the current state of collaboration and how it is pursued.

Analysing the various types of collaboration between university and industry provides a more comprehensive picture of the collaborative activities beyond the usual focus on licensing and patenting activities. Gaining information of various types of UIC and paying attention to how they are structured is expected to improve the effectiveness of collaborations as it will allow better informed decision-making regarding the selection of appropriate approaches to collaboration.

2.1 Setting the context

The context for this research comprises the key aspects listed below and discussed in the remainder of this section, namely.

- The knowledge economy
- The need for collaboration
- The role of Government

- The role of universities
- The National Innovation System
- The Australian perspective
- The impact of information and communication technology

These aspects may not cover the entire context of UIC. However, they do cover the key relevant aspects discussed in the reviewed literature and provide an adequate basis for setting the context of this research.

2.1.1 The knowledge economy

UIC has gained widespread interest in recent years due to a transition in global economic conditions involving rapid growth, innovation and competition [Perkmann et al., 2013].

The current economic environment is characterised by:

- fast paced technological changes including rapid advancement and increased complexity of technology, which has been termed as a 'new competitive landscape' [Giannopoulou et al., 2019; Dealtry et al., 2005; Bettis and Hitt, 1995].
- globalization leading to more open and vast markets [Metcalfe, 2010] along with more intense international competition [Giannopoulou et al., 2019; Burnside and Witkin, 2008], and internationalisation of R&D activity [Metcalfe, 2010].
- more rapid innovation, disrupting markets, tightening deadlines and making product development life cycles shorter [Giannopoulou et al., 2019; Santoro, 2000].
- rising complexity in the world [Sheffield et al., 2012], and in particular, scientific research which is dealing with more complex problems [Hara et al., 2003].
- 'entrepreneurial enterprises and associated approaches to venture capitalization' [Etzkowitz, 2017; Mascarenhas et al., 2017; Tornatzky et al., 2002] are gaining importance.
- increasing requirements and strong competition for highly skilled workforces [Lutte and Mills, 2019; Andrews and Higson, 2008; Tornatzky et al., 2002].

Such trends have radically transformed the competitive landscape for businesses. They now operate in a knowledge-based economy, where overall economic performance is dependent on knowledge and capability to learn and adapt. Increasingly, businesses understand that their future lies in innovation. They anticipate that most of their earnings and revenue generation will depend on rapidly responding to market requirements by creating and adopting new products and technologies [Dealtry et al., 2005]. Increased global competition places demands on businesses to rapidly innovate, achieve high performance, and meet customer needs [Ireland and Webb, 2007]. UIC provides a means to fulfill these demands.

2.1.2 The need for collaboration

The diversity of skills and multidisciplinary approaches required to tackle problems in the knowledge economy means that a 'go-it-alone' attitude is no longer viable [Burnside and Witkin, 2008]. This seems increasingly true in today's world. Relationships are the key to connecting knowledge, capability, expertise, and innovation [Chartered Accountants Australia and New Zealand, 2017].

Collaborating and partnering among organizations and institutions opens up new possibilities and enables the development of an innovation ecosystem [Rajalo and Vadi, 2017] and creation of new industries [Johnson, 2006]. Therefore, collaboration is becoming more important than ever for facilitating knowledge-sharing, interactions, and ideas generation. It appears that 'collaborate or die is the modern imperative' [Burnside and Witkin, 2008].

2.1.3 The role of government

Realizing the challenges posed by global economic competitiveness, many countries are adopting measures for building a 'knowledge economy' capability in order to strengthen their position [Nolan, 2011, pp. 14-15], [Australian Government, 2017a]. A popular approach to building such capability is to encourage and facilitate UIC [Acworth, 2008; D'Este and Patel, 2007; Barnes et al., 2006]. There are government programs to provide funding to firms that are engaging with universities for various collaboration purposes. For example, the Australian Research Council (ARC) Linkage Grant Scheme [Australian Research Council, 2018] encourages long-term strategic UICs for improved utilisation of research output for innovation.

2.1.4 The role of universities

Universities are widely considered to be key knowledge creators and providers [Uyarra, 2010]. They are an important stakeholder in the process of innovation, and have been recognized as a key contributor to economic development for decades [Demircioglu and Audretsch, 2019; Uyarra, 2010; Mansfield and Lee, 1996].

More recently, there are proponents that encourage universities to exercise a third mission of playing a greater role in economic development by working closely with businesses [Baglieri et al., 2018; Veilleux and Queenton, 2015; Sánchez-Barrioluengo, 2014; Breznitz and Feldman, 2012; Uyarra, 2010; Youtie and Shapira, 2008; Etzkowitz and Leydesdorff, 2000]. Universities are also realizing the importance of participating and contributing to the regional and national innovation systems by producing new knowledge and novel technologies, and transferring them to industry [Sánchez-Barrioluengo, 2014; Breznitz and Feldman, 2012; Kaymaz and Eryiğit, 2011; Uyarra, 2010; Wright et al., 2008; Tether and Tajar, 2008; Bekkers and Freitas, 2008; Shane, 2004a].

Universities also have a role to play in addressing the critical requirement for a highly skilled workforce [Lutte and Mills, 2019; Sánchez-Barrioluengo, 2014; Andrews and Higson, 2008]. In addition to meeting ongoing national work-force needs, universities are also expected to produce suitably skilled employees and entrepreneurs for faster innovation and fostering entrepreneurship. Collaboration between universities and industry is critical to producing this workforce.

2.1.5 The national innovation system

UIC forms an important element of the concept of a National Innovation System (NIS). According to Nelson, a National Innovation System 'is a set of institutions whose interactions determine the innovative performance of national firms' [Nelson, 1993, pg. 4]. This definition emphasises the institutional dimension in NIS. Lundvall [Lundvall, 2010, pg. 2] emphasises the relational dimension and defines it as a system 'constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful knowledge [either located or rooted inside the borders of a nation state]'. Thus, the NIS is one of the most comprehensive systems of relationships among various elements encouraging collaboration among different organisations for innovation, which includes UIC.

2.1.6 The Australian perspective

Given the emerging significance of UIC, the Organization for Economic Cooperation and Development (OECD) reports a significant rise in the number of government funded collaborative R&D projects [OECD Publishing, 2011]. However, analysis within the Australian context provides us with another picture regarding collaborative projects.

According to the OECD [OECD Paris, 2017], Australia lags behind other OECD countries in terms of the level of collaboration between academia and industry. Other studies have observed Australia's low levels of research commercialisation and industry engagement [Chartered Accountants Australia and New Zealand, 2017; Davis, 2017]. A Commonwealth of Australia report also notes that only 4.8 percent of innovation-active businesses in Australia collaborate with a university or publicly funded research institution while 22.8 percent of such businesses collaborate with competitors or other businesses [Australian Government, 2017a]. Data regarding translation of research into business through UIC is also concerning as it indicates low collaboration in Australia [Australian Parliament and O'Dowd, 2016].

In response to the above, the Australian Federal Government has implemented measures to encourage collaborations. The following list, adapted from [Australian Government, 2017a], shows some of the strategic initiatives introduced by the government in recent times:

1. '*The National Innovation and Science Agenda is delivering initiatives to support innovation and science, across the full spectrum of science education and engagement, research and research infrastructure, translation and commercialisation.*

2. *Innovation and Science Australia's Performance Review of the Australian Innovation, Science and Research System has provided a performance baseline ahead of the 2030 Strategic Plan for innovation, science and research.*

3. *The 2016 National Research Infrastructure Roadmap identifies national priority research infrastructure needs over the next 10 years.*

4. *The Australian Medical Research and Innovation Strategy 2016-2021 and the Australian Medical Research and Innovation Priorities 2016-2018 will guide decision making for disbursements under the $20 billion Medical Research Future Fund, [that commenced] in 2017.*

5. *In partnership with states and territories, the National STEM School Education Strategy 2016-2026 is taking action to lift foundational skills in STEM learning areas, develop mathematical, scientific and technological literacy, and promote the development*

> *of the 21st century skills of problem solving, critical analysis and creative thinking.'* [Australian Government, 2017a].

Apart from the initiatives listed above, several other efforts such as industrial transformation research hubs [Australian Government, 2020], studies, conferences, resource creation, and measures have been reported [Australian Government, 2018, 2017b, 2016, 2014; Chartered Accountants Australia and New Zealand and RMIT, 2017; ACOLA, 2016; Criterion Conferences Pty Ltd., 2016].

2.1.7 The impact of Information and Communication Technology

The development of information and communication technologies has led to broader production, increased availability and wider dissemination of knowledge. Baur and Wee [Baur and Wee, 2015, pp. 1] summarised the development in ICT as: 'the astonishing rise in data volumes, computational power, and connectivity, especially new low-power wide-area networks; the emergence of analytics and business intelligence capabilities; new forms of human-machine interaction such as touch interfaces and augmented-reality systems; and improvements in transferring digital instructions to the physical world, such as advanced robotics and 3-D printing'. Such developments in ICT have facilitated and improved rapid communication and knowledge sharing at lower costs [Luo and Bu, 2016], which opens up a lot of challenges and opportunities for UIC.

2.2 Why University-Industry Collaboration is important

> '*Joint technology development simply yields results neither group could have achieved alone*' - Randolph Guschl, DuPont [Hasselmo and McKinnell, 2003]

To further understand the importance of UIC, this section explores the benefits that universities, industry, and society can gain from collaboration. These benefits are multi-faceted, manifold, and vary depending on the duration and type of collaboration as described in the literature discussed below.

The various benefits of collaboration identified through analysis of the reviewed literature are described in detail in the following subsections.

2.2.1 Benefits to universities

The following key benefits of collaboration for universities (adapted from various studies, primarily from [Dooley and Kirk, 2007]) are discussed in this section.

- Access to sources of research funding
- Increased access to proprietary technology held by industry
- Enhanced status
- Scientific productivity of academics
- Faster feedback loops
- Increased relevance
- Application and Commercialization
- Learning impact
- Influence on Education

2.2.1.1 Access to sources of research funding

The literature indicates that the benefits for universities are largely finance based [Garcia et al., 2018; Rahm et al., 2013; Edmondson et al., 2012; Arvanitis et al., 2008; Baldini et al., 2007; Dooley and Kirk, 2007; Prigge, 2005; Hall et al., 2003; Howells et al., 1998]. Universities usually depend on support from government for funds and grants. Many government and industrial grants, and contracts increase the propensity of academic researchers to work with industry [Bozeman and Gaughan, 2007].

Collaboration with industry opens up an additional source of research funding for universities, which can increase their research capacity and competence [Hughes et al., 2016; Ramos-Vielba et al., 2016; Australian Industry Group, 2015; D'Este and Perkmann, 2011; Lee, 2000; Autio et al., 1996]. They also gain access to funds to support their research staff during the gaps between research funding applications and approvals, which can help to retain staff [Schubert and Bjørn-Andersen, 2012]. Collaborations may also become an additional source of personal income for a researcher [Hughes et al., 2016].

University administration and Technology Transfer Offices (TTOs) try to market the university's intellectual property to firms for commercial usage while protecting the interest and rights of the university. Royalties and licensing fees from such arrangements provide additional research funding [Siegel et al., 2003a].

2.2.1.2 Increased access to proprietary technology held by industry

University and industry may have an overlap of research interests and might be investing their efforts and time in similar work with access to their progress and results shielded from each other. Collaboration can provide access to such proprietary technology including specialist industry equipment [Hughes et al., 2016] and materials, which can speed up and reduce the costs of research for both partners [D'Este and Perkmann, 2011; Dooley and Kirk, 2007; Dealtry et al., 2005; Arvanitis et al., 2008]. It also helps academics to keep up to date with research in industry [Hughes et al., 2016].

2.2.1.3 Enhanced status

Another benefit for academics by engaging in industry collaborations is the professional recognition and status potentially gained by the university through working on collaborative projects [Ramos-Vielba et al., 2016; Schubert and Bjørn-Andersen, 2012; Dooley and Kirk, 2007]. A strong record of collaboration with industry can enhance the status of universities when competing for research grants offered through public funding agencies as, in many countries, academics need to provide evidence of societal impact [Perkmann et al., 2013]. For example, the demonstration of such collaboration is an important criterion contributing to the success of public funding applications in the United Kingdom [Etzkowitz et al., 2000]. Such collaborations provide some assurance that the output generated through publicly funded research will be utilized for economic development of the country. Finally, through extensive collaboration, universities can build recognition as world-class research institutions that engage with business to create greater socio-economic and environmental impact [Prigge, 2005; Australian Industry Group, 2015].

2.2.1.4 Scientific productivity of academics

Benefits to individuals will also drive UIC. University researchers usually pursue recognition within the scientific community through publications in highly recognized journals, presentations at prestigious conferences and by procuring research grants. Collaborative projects can provide an opportunity to gain insight into a researcher's area of research [Hughes et al., 2016], enhancing a researcher's ability to generate knowledge [Salter and Martin, 2001] that can be published in academic journals [Perkmann and Walsh, 2009] leading to increased visibility and recognition of their work.

The scientific productivity and success of an individual is also determined by their ability to mobilise resources [Perkmann et al., 2013]. Hence individual researchers can benefit from the additional funding generated by collaborations [Arvanitis et al., 2008; Baldini et al., 2007; Siegel et al., 2003a].

2.2.1.5 Faster feedback loops

UIC provides a means to seek faster feedback on the results of university research [Dooley and Kirk, 2007] by adopting an incremental approach involving frequent interactions between researchers and practitioners [Potts, 1993]. This is referred as the 'Industry-as-Laboratory' approach. In this approach, closer involvement of researchers with practitioners at an early stage can lead to identification of problems relevant to industry based on an understanding of the application context, emergence of potential solutions, and continuous evaluation of those solutions during the research [Potts, 1993]. Universities can frequently verify and validate their research findings more quickly in an industrial context, and industry can provide useful feedback to universities on possible directions to take [D'Este and Perkmann, 2011; Perkmann and Walsh, 2009; Lee, 2000; Autio et al., 1996].

2.2.1.6 Increased relevance

UIC provides a mechanism for better alignment of research output with industry needs as well as improved knowledge transfer between stakeholders [Schubert and Fisher, 2009; Mathiassen, 2000]. Academics gain an opportunity to work on a wide range of interesting and challenging problems [Schubert and Bjørn-Andersen, 2012; Australian Industry Group, 2015; Perkmann and Walsh, 2009], which are important to industry. They also gain exposure to an array of research avenues through interaction with practitioners [Schubert and Fisher, 2009] as well as access to company data [Hughes et al., 2016; Schubert and Bjørn-Andersen, 2012], industry trends and current practices. These interactions enhance the relevance of their research while increasing their understanding of the application side and user perspective [Australian Industry Group, 2015; D'Este and Patel, 2007; Siegel et al., 2003b; Lee, 2000; Howells et al., 1998].

Such interactions have the potential to produce more significant results in science compared with the traditional approach of working independently in a silo [Schubert and Fisher, 2009; Van de Ven, 2007].

2.2.1.7 Application and commercialization

UIC can increase the application and commercialization of research in industry [Ramos-Vielba et al., 2016; D'Este and Perkmann, 2011; Schubert and Fisher, 2009; Rothaermel et al., 2007; Dooley and Kirk, 2007; Poyago-Theotoky et al., 2002]. It provides an outlet for research results to be tested for practical application [Hughes et al., 2016], exploited in authentic settings and the potential to be translated into a commercial outcome [Schubert and Bjørn-Andersen, 2012; Howells et al., 1998]. Collaboration can help by validating research results in a 'real world' setting. Industry commercialisation expertise, and skills such as development, engineering, manufacturing and marketing can then be exploited to realize the full potential of research outcomes [Australian Industry Group, 2015]. Through such UIC, business opportunities linked to a research can be explored [Hughes et al., 2016].

2.2.1.8 Learning impact

UIC provides employment and work integrated learning opportunities which can improve the work-readiness [Salter and Martin, 2001] and hence employability of post-doctoral staff and students. By engaging with industry, academics also have an opportunity to learn how their work can be applied and adopted in real-world situations. This can lead to better quality and increased relevance of their teaching. Academics create new connections and can become part of well developed international networks of experts across industry and academia. Overall, there are benefits ranging from improved education and know-how to better employment outcomes for students [Wang et al., 2016; Hughes et al., 2016; Rahm et al., 2013; Edmondson et al., 2012; Australian Industry Group, 2015; Lee, 2000].

2.2.1.9 Influence on education

UIC can provide academics with an opportunity to understand the work-force needs of high-technology firms. They can 'gain knowledge about practical problems useful for teaching' [Hughes et al., 2016]. They can draw on this experience and accordingly provide feedback and assist in the development of curriculum that delivers courses that are relevant and closely aligned with business needs [Wang et al., 2016; Australian Industry Group, 2015; Edmondson et al., 2012; Schubert and Bjørn-Andersen, 2012; Poyago-Theotoky et al., 2002; Stephan, 2001; Lee, 2000].

2.2.2 Benefits to industry

The following key benefits of collaboration for industry (adapted from various studies, primarily from [Dooley and Kirk, 2007]) are discussed in this section.

- Access to base scientific competence
- Access to knowledge
- Access to world-class academics
- Enhanced capability to build competitive advantage

- Lower Research & Development expenditure
- Access to skilled human resources

2.2.2.1 Access to base scientific competence

It is unlikely that an organization will have all of the diverse expertise and competencies required to succeed in today's dynamic, highly-competitive and innovation-centric market. Universities build up expertise by conducting basic research across multiple disciplines. Collaboration with universities can provide industry with access to such expertise [Dooley and Kirk, 2007; Dealtry et al., 2005; Lee, 2000]. Such access raises industrial competence [Ahrweiler et al., 2011].

2.2.2.2 Access to knowledge

Universities have always worked with a primary mission of knowledge creation and dissemination. A huge body of knowledge has been created over many decades within universities through education and research. By engaging with academics, industry gains access to the knowledge created within universities thereby increasing their own varieties of knowledge [Ahrweiler et al., 2011; Dooley and Kirk, 2007]. This knowledge, when applied for commercial purpose, helps businesses to succeed in a competitive market [Lee, 2000; Hagedoorn et al., 2000].

2.2.2.3 Access to world-class academics

Many universities have some of the world's best experts in areas relevant to industry. These experts are considered scientifically and industrially aware of the state of the art in certain fields. Engagement with universities provides access to this intellectual capital [Dooley and Kirk, 2007; Dealtry et al., 2005]. Such engagement is the best medium to transfer tacit and implicit knowledge. Tacit knowledge, residing in mind, is rooted in individual experience [Polanyi, 1966]. It is often difficult to articulate, and requires cognition of information, observation, and personal interaction to develop and utilise competence [Santoro and Bierly, 2006]. '...the unexpressed (tacit) components of knowledge matter critically in translating a generic scientific discovery or technological result into a specific, commercially viable application' [Metcalfe, 2010]. Through access to the world-class experts during engagement with universities, tacit knowledge is exchanged.

2.2.2.4 Enhanced capability to build competitive advantage

As discussed in Section 2.1.1, businesses operate in a rapidly changing knowledge economy. The speed of technological change, increasingly shorter product lifecycles, and global competitive markets with increasing consumer demands has transformed the competitive environment for most businesses [Bettis and Hitt, 1995]. This new competitive environment has placed ever-increasing demands on corporations to continually create or exploit new technologies [Dealtry et al., 2005] leading to a greater need for external collaboration [Rothwell, 1994]. Engaging with universities is an enabler for technological innovation [Autio et al., 1996] providing businesses with a channel to gain faster access to capabilities in terms of new technology and processes, which can help them build a competitive advantage in the market [Broström, 2012; Philbin, 2008; Dooley and Kirk, 2007; Lee, 2000].

2.2.2.5 Lower research & development expenditure

Collaborative research with university can provide access to resources including knowledge, tools and advanced scientific equipment that has been developed for publicly funded research projects. By sharing access to these resources industries can reduce the cost of research and development (R&D) [Australian Industry Group, 2015; Dooley and Kirk, 2007; Hagedoorn et al., 2000]. Studies confirm that companies collaborating with universities have lower R&D expenses per employee and a higher level of innovation compared with the firms that are not engaged in any collaboration [Dealtry et al., 2005; George et al., 2002]. These lower R&D expenses are attributed to the access industry gains to complementary equipment and facilities in a university.

2.2.2.6 Access to skilled human resources

Collaboration with universities provides industry access to highly skilled researchers in various areas [Dooley and Kirk, 2007]. In addition, practitioners may also gain early access to the brightest students who can help solve new and complex business and technical problems [Australian Industry Group, 2015; Schubert and Fisher, 2009; Lee, 2000].

2.2.3 Benefits to Society

In addition to universities and industry, society more broadly can gain direct or indirect benefits from UIC such as:

- **Innovative products.** UIC may result in the creation of new technologies and innovative products to solve societal challenges or for improving lives

[Bercovitz and Feldman, 2006].

- **Establishment of new industries.** UIC may also lead to establishing new industries, which can create employment opportunities, and improve productivity [Alexander et al., 2018; Davey et al., 2011].

- **Improvement of skilled workforce.** UIC can lead to improved educational outcomes [Van der Sijde, 2012] by providing students with opportunities to develop industrially relevant knowledge, skills, and competency. This can result in a better trained workforce for society [Davey et al., 2011; Gibb and Hannon, 2006].

- **Fostering economic development.** Entrepreneurship and new industries established as a result of UIC contribute to the economic development of a region leading to increased local GDP and disposable income [Davey et al., 2011].

- **Recreational benefits.** UIC may enhance the quality of life in a specific area by creating a range of recreational benefits such as improved physical infrastructure [Davey et al., 2011].

2.3 Approaches to University-Industry Collaboration

The benefits listed in the reviewed literature demonstrate the importance of UIC. These benefits cannot necessarily be derived through one means of interaction, which means that UIC will operate in many different ways. In this section, the diversity of approaches used for UIC are explored.

The aim behind this study is to improve understanding of the various types of collaborations. It provides a comprehensive view of the various dimensions that can be utilised to classify the diverse types of collaborations. This knowledge supports effective decision-making about the types of collaboration applicable in a given context.

The diversity of UIC is an important factor to be considered within the contextual practices of the UIC Practices Framework presented in Chapter 7.

2.3.1 Types of collaborations

Academic literature and policies have heavily focused on activities related to commercialisation of academic knowledge [O'Shea et al., 2008; Rothaermel et al., 2007; Phan and Siegel, 2006; Shane, 2004b; Friedman and Silberman, 2003; Jensen et al., 2003; Link et al., 2003]. However, studies have also found that UIC frequently occurs

Table 2.1: Types of UIC (Adopted from [Ankrah and Omar, 2015])

Personal Informal Relationships	- Academic spin-offs - Individual consultancy (paid for or free) - Information exchange forums - Collegial interchange, conference, and publications - Joint or individual lectures - Personal contact with university academic staff or industrial staff - Co-locational arrangement
Personal Formal Relationships	- Student internships and sandwich courses - Students' involvement in industrial projects - Scholarships, Studentships, Fellowships and postgraduate linkages - Joint supervision of PhDs and Masters theses - Exchange programmes (e.g. secondment) - Sabbaticals periods for professors - Hiring of graduate students - Employment of relevant scientists by industry - Use of university or industrial facility (e.g., lab, database, etc.)
Formal Targeted Agreements	- Contract research (including technical services contract) - Patenting and Licensing Agreements (licensing of IP rights) - Cooperative research projects - Equity holding in companies by universities or faculty members - Exchange of research materials or Joint curriculum development - Joint research programmes (including Joint venture research project with a university as a research partner or Joint venture research project with a university as a subcontractor) - Training Programmes for employees
Formal Non-Targeted Agreements	- Broad agreements for U-I collaborations - Endowed Chairs and Advisory Boards - Funding of university posts - Industrially sponsored R&D in university departments - Research grant, gifts, endowment, trusts donations (financial or equipment), general or directed to specific departments or academics
Focused Structures	- Association contracts - Innovation/incubation centers - Research, science and technology parks - University-Industry Consortia - University-Industry research cooperative research centers - Subsidiary ownerships - Mergers

through joint research, contract research and consultancy, or training [D'Este and Patel, 2007; Perkmann and Walsh, 2007; Mowery and Sampat, 2005; Agrawal, 2001; Fritsch and Schwirten, 1999].

In addition to research, there are arrangements for collaboration in education including student internships or fellowships, involvement of students in industrial projects, joint curriculum development, and joint supervision of academic researchers [Ankrah and Omar, 2015; Mathieu et al., 2011; Beckman, 1999]. Collaboration for education has potential to impact education through influence on teaching and learning [Edmondson et al., 2012]. Through such collaboration, academics gain knowledge about industry requirements, and practitioners bring current real-world experience to education.

The diversity of UIC types has led to development of several taxonomies in the reviewed literature. Examples of such taxonomies can be found in Davey and Muros [Galan-Muros and Davey, 2017], Ankrah and Omar [Ankrah and Omar, 2015], and D'este and Patel [D'Este and Patel, 2007]. The classification of UICs has been based on the sector involved [Geisler, 2001], the 'relational involvement' (focusing on collaborations involving face-to-face-contacts and personal relations) [Schartinger et al., 2002], the type of knowledge networks involved [Starkey and Madan, 2001], people, problem-solving, and community [Hughes and Kitson, 2012], the time horizon of collaboration [Perkmann and Salter, 2012; Onida and Malerba, 1989], the focus of collaboration (such as short-term problem solving or applied reasearch) [Onida and Malerba, 1989], and the members of the collaboration or the organizational structure of the collaboration [Hagedoorn et al., 2000].

Table 2.1 provides a list of various types of UICs. This table is adopted (slightly modified) from the work of Ankrah and Omar [Ankrah and Omar, 2015] as it presents one of the most comprehensive lists of UIC types in the reviewed literature. It addresses the requirement of understanding the diverse types of UIC for the purpose of this research. The types of UIC are categorised as follows:

- **Personal informal relationships.** This group comprises the types of UICs where the university is not involved in any formal agreement for collaboration between a firm and an academic. For example, Individual consultancies or Academic spin-offs, though involving formal agreement, do not involve the university itself in the agreement.

- **Personal formal relationships.** This group comprises the types of UICs where an agreement is formalised between a university and a firm for collaboration between a firm and an academic.

- **Formal targeted agreements.** The UIC types in this group involve a formal agreement between collaborating university and industry, and have specific objectives defined at the beginning of the UIC.

- **Formal non-targeted agreements.** The UIC types in this group involve a formalised agreement between collaborating organizations. However, they focus on broader, long-term, and strategic objectives rather than a specific objective defined at the beginning of a UIC.
- **Focused structures.** This group comprises UICs carried out by the collaborators together in specific permanent structures created for various purposes in addition to research collaborations.

2.3.2 Diversity of approaches to UIC

UIC is a diverse activity. Key dimensions of this diversity are described below. While these dimensions may not be exhaustive, they do illustrate the diversity discussed in the reviewed literature.

- **Purpose.** The purpose of UIC includes sharing of knowledge, resources, and equipment, generation of intellectual property and associated patents, setting of standards, as well as sharing and exchange of highly educated, knowledgeable and skilled students and staff between universities and industry [Hughes and Kitson, 2012].
- **Time.** Engagement between universities and industry operates over a wide variety of time frames from short-term (perhaps 6 months or less) to long-term (over many years) [Perkmann and Salter, 2012; Onida and Malerba, 1989].
- **Dissemination of Results.** The sharing of knowledge can occur through a variety of venues including scientific publishing, consulting, conferences, provision of training, and data sharing [Bell et al., 2015].
- **Types of Research.** There are various types of research [Van de Ven, 2007, p. 27-28] with each having specific characteristics such as: basic and fundamental, targeted applied (directed towards solving a specific problem of commercial value), pre-competitive applied (early stage collaboration for creation of results that are not ready for commercialization but form a basis for products to be commercialized), design and evaluation research, and action/intervention research. In practice, a UIC may well involve some combination of these types of research [Onida and Malerba, 1989].
- **Competence.** The actors involved in UIC, such as universities and firms may have different levels and areas of competence [Onida and Malerba, 1989].

2.4 Existing models for effective UIC

In addition to the variety of UIC types discussed in Section 2.3.1, the reviewed literature also shows that researchers have proposed several models to improve the effectiveness of collaborations. These models are summarised in sub-sections below.

These models have been selected as they primarily aim to encourage UIC and offer guidance for establishing effective UICs, which aligns with the aim of this research. These models can be considered representative of the relevant models for UIC described in the existing literature.

2.4.1 The Process Model

Philbin [Philbin, 2008] proposed a process model that can be utilised by academic and industry practitioners to develop and effectively manage research collaborations. The model is based on the findings of a literature review and an empirical study involving 32 stakeholder interviews.

The main components of the model are a central linear process, and enabling features such as social capital, knowledge factors, and collaboration agent. The linear process includes sequential five stages: terrain mapping; proposition; initiation; delivery; and evaluation.

The strength of the model is the systematic opportunity identification through industry and market analysis during the terrain mapping, definition of project scope and contract negotiations during the initiation stage, recognition of effective communication, and progress monitoring as important factors during the delivery stage, and a valuable evaluation stage for post-delivery review. The model focuses equally on university and business requirements. In addition, the model defines a clear application process that offers flexibility in practice as it recognizes that some contexts may not require application of all the stages of the process.

While the model was developed with a focus on contract research and may not be applicable to other types of UIC, some factors within the model such as social capital, knowledge factors, and effective communication are relevant to all types of UIC. Since social capital plays a major role in the model, it has more potential to be successful when partners are already familiar with each other as they are likely to have formed trust and increased commitment. This can also be inferred from the demonstration of the model in the scenario described in the paper, where the author of the model is engaged, and played the role of a collaboration agent.

The utility of the model is demonstrated in an initial collaborative research programme with a company in the engineering sector. As mentioned by the author of the model, the model needs additional evaluation to determine its value and limitations.

2.4.2 The Generic Collaboration Model

Schubert and Fisher [Schubert and Fisher, 2009] proposed the Generic Collaboration Model (CBR Model) for collaborative empirical research with the primary aim of increasing the relevance and rigour of research. The model is based on real-world experience derived from a case study of a specific collaboration over a period of eight years in Switzerland.

The model considers four basic aspects of funding, topic, cooperation, and interpretation. The definition of these four aspects varies for three different intervals - 1 year, 3 years, and long term. This indicates the flexibility of the model in organising these aspects based on the duration for which the stakeholders want to engage.

This model selects research questions through iterative joint meetings involving various stakeholders. Such an iterative and collaborative process is a strength of the model, which ensures rigour and increases the relevance of research.

Because it specifically addresses short and long term collaboration, the Generic Collaboration Model may be suitable in a context where the partners have the goal of long-term collaboration but begin with a short-term collaboration to test and later strengthen the partnership. The model may also be useful when the purpose is to study specific trends over a period of time as it is well-suited for understanding emerging sectors.

2.4.3 The Idea Lab

Perkmann and Salter presented four models of collaboration based on findings from action research projects in which the author of the model engaged, surveys of collaborating industries and academics, interviews with company executives, entrepreneurs and academic scientists, and secondary material identified through a literature review [Perkmann and Salter, 2012].

The first of these models is the Idea Lab in which managers from industry work with academics and university researchers to innovate by creating options or emerging solutions to a relevant problem, and establish contacts leading to long-term relationships. It is considered suitable when a business wants an idea to be tested.

The success factors identified for the model are clear articulation of the problem, simple working contracts, emphasis on results, and flexibility to academics in setting objectives and methods to be adopted in order to achieve the results. However, the model's emphasis on results rather than time seems to be conflicting with its short-term collaboration aspect, as desired results may not be always achieved within short time-span. The short-term collaboration may not always align with the academic researcher's time requirement.

The Idea Lab appears to be similar to contract research. However, in contrast to contract research, the open nature of the Idea Lab usually allows publications, which helps to overcome the conflicts related to publications. Contract research may not always allow publications.

It has been successfully deployed in various companies, such as HP and IBM.

2.4.4 The Grand Challenge

The Grand Challenge is the second model presented by Perkmann and Salter [Perkmann and Salter, 2012], in which industry professionals and academics work together on open, long-term research projects of significance resulting in a new knowledge base leading to wider benefits for society. For example, the rising production costs and declining research productivity in pharmaceuticals has led to competitors exploring the option of collective investment in the creation of an industry commons to accelerate creation of new knowledge. Merck, Novartis and Pfizer, though fierce competitors, have adopted this option and invested together in open science initiatives.

The success factors identified for this model of collaboration are clearly defined objectives balancing industry relevance and academic's research interest, commitment to, and management of the collaboration. This model is 'open', which can help overcome barriers associated with legal aspects, including lengthy negotiations with universities. However, it must be ensured that proprietary information is protected.

The Grand Challenge is applicable in dealing with problems having a wider economic, technological, and social impact. This collaborative arrangement contributes to the shaping of an innovation ecosystem, developing a research agenda, meeting societal challenges, and hiring talented graduates by industry [Perkmann and Salter, 2012]. It has been applied in real-world settings by companies such as GlaxoSmithKline, and Intel.

2.4.5 The Extended Workbench

The Extended Workbench is the third model presented by Perkmann and Salter [Perkmann and Salter, 2012], in which managers work with university researchers to rapidly develop solutions to proprietary problems.

In contrast to the Idea Lab and the Grand Challenge, this model places constraints on information sharing as industry wants to maintain confidentiality.

The success factors for this model are identified as trust, maintaining a database of expertise and contacts by companies, creation of outreach entities by universities, and contractual agreements to work under.

While other models provide a way to organize a particular type of UIC, the Extended Workbench provides flexibility for organizing UIC in the form of consulting agreements with university researchers, contract research with universities, or student projects.

Industry can set objectives at the beginning of the project and expect rapid delivery of results as they would from any commercial organisation. However, these short-term projects are believed to be more successful if they are part of a long-term relationship. The reason for this is that constraints on publication does not offer much for academics so they may not be interested in short-term project. In addition, overhead costs associated with small projects may act as a barrier. However, the possibility of long-term relationships could help overcome these barriers and keep the researchers engaged.

The model has been applied in real-world settings by companies such as Intel.

2.4.6 Deep exploration

Deep exploration is the fourth model presented by Perkmann and Salter [Perkmann and Salter, 2012], in which a company creates long-term relationships with universities in order to tackle fundamental business challenges, gain access to new areas of expertise, gain access to an array of discoveries by university researchers, and hire talented graduates.

The strength of this model is strong alignment of research with the company's strategy, and IP provisions to protect information. The success factors for this model are funding, management of collaboration, and clearly defined IP rights.

Deep explorations can be organised as university center sponsorship or framework agreements that provide 'the business rights of first refusal to license collaboration results'. A typical mechanism is to set up a medium-term agreement (often more than three years) with an academic partner to establish a new center, or to invest in an existing center. For example, Rolls-Royce Holdings PLC has established Rolls-Royce University Technology Centres with various universities globally, where each centre specializes in a particular technological area of expertise such as aerodynamics or manufacturing technology.

2.4.7 A Knowledge Integration Community model

The Cambridge-MIT Institute (CMI) formulated a Knowledge Integration Community (KIC) model [Acworth, 2008] for the UK as a more effective approach to knowledge sharing and enhancing the effectiveness of university-industry linkages. Its objective is to increase competitiveness, enhance productivity, and encourage entrepreneurship.

The model is based on a review of background literature and relevant government policy, benchmarking of relevant grant-making organisations, a study of the Massachusetts Institute of Technology (MIT) and Cambridge University institutions, and consultation through a strategic planning process that includes 27 stakeholder groups.

KIC has six components that include four human groups from key institutional sectors: Research universities, industry, government and education are involved in planning and delivery of the KIC objectives, and two concept-based components: knowledge exchange and the study of innovations in knowledge exchange (SIKE). The SIKE component allows for evaluation and continuous improvement of the model.

The success factors identified for the model include development of an application-driven solution, communication, KIC manager and overall management of a KIC.

Similar to the Grand Challenge, the KIC model is applicable in dealing with problems having a wider economic, technological, and social impact. The KIC appears to provide a model for implementation of the Grand Challenge approach to UIC. It provides a platform for collaboration between people from diverse disciplinary backgrounds, who may not otherwise interact. This provides researchers with access to contributions from a broad range of disciplinary perspectives.

Unlike other models discussed so far in this section, the KIC model is unique in terms of problem identification, because it typically looks for multiple solutions for several related problems around a common theme. In contrast to uni-directional knowledge transfer common in the other models, KIC has multi-directional approach towards knowledge sharing. While most of the models have university and industry as the main stakeholders, the KIC also involves government as one of the main stakeholders. The model also values virtual partnerships, which increases geographical reach.

The model has been applied in seven experimental KICs.

2.4.8 The Model for Collaborative Practice Research

Sandberg et al. proposed a collaboration model [Sandberg et al., 2011] for setting up collaborative practice research projects that bring together practitioners and reflecting researchers. Reflecting researchers (re)construct the reality in which practitioners operate, interpret it critically and reflect on them to create solutions for the problems that practitioners want to solve. The model identifies five success factors related to research results (need orientation, industry goal alignment, deployment impact, industry benefit, and innovativeness), five success factors related to research activities (management engagement, network access, collaborator match, communication ability, and continuity), and 10 action principles for UIC management. The action principles are based on the success factors.

The model is based on experience with an eight-year-long CPR effort between an academic research institute and a telecommunications company [Sandberg et al., 2011].

The model has an emphasis on industry need and an agile approach, which may increase commitment from industry partners. However, they may not always align with the interest and time-requirements of academic researchers.

2.4.9 The Sponsored Research Interaction Process model

The Sponsored Research Interaction Process (SRIP) model [Burnside and Witkin, 2008] is designed to help universities and businesses handle the complexity of negotiations related to IP contracts. The model is based on collaborative efforts between UC Berkeley and industry.

The strength of the model is that it describes a dynamic process to overcome negotiation and cultural barriers, and establishing a joint shared process in order to successfully conclude negotiations associated with sponsored research.

The main focus of the SRIP model is limited to negotiation of IP contracts. It is useful when IP conflicts are a major concern. However, the model is expected to be successful when the collaborative relationship is valued more than any single collaboration opportunity, or IP conflict [Burnside and Witkin, 2008].

2.4.10 Conceptual frameworks for UIC

In addition to the various models for specific types of UIC described so far, there are some proposed conceptual frameworks that aim to improve understanding of UICs in general [Alexander et al., 2018; Galan-Muros and Davey, 2017; Ankrah and Omar, 2015]. These works are closest to the work presented in this thesis in terms of the aspects of collaboration studied.

Ankrah and Omar proposed a conceptual framework for university-industry collaboration [Ankrah and Omar, 2015]. The framework is based on a systematic review of UIC, which identifies various aspects relevant to collaboration. The five key aspects identified in the framework are the forms of UIC, motivations, formation and activities, enabler and inhibitors, and outcomes. The framework has broadly captured aspects within the UIC formation stage. It identifies communication and mobility factors as main factors for achieving collaboration results.

Muros and Davey [Galan-Muros and Davey, 2017] describe the University-Business Cooperation (UBC) Ecosystem based on a systematic review of UIC literature. Both the studies identify various aspects of UIC with several aspects being common such as activities, enablers and inhibitors, and outcomes. However, the two studies organise these common aspects in different ways. While Ankrah and Omar's framework appears more like a linear process, the UBC Ecosystem framework includes a cyclical process. In contrast to Ankrah and Omar's framework, the UBC Ecosystem includes 'impact' in addition to 'outcomes', which indicates that UBC Ecosystem considers a wider perspective on UIC results.

In terms of the aim to improve understanding of UIC system, the UBC Ecosystem has comprehensively considered various aspects of UIC. In addition to comprehensiveness, the UBC Ecosystem is based on a large study spanning several years.

Alexander et al. [Alexander et al., 2018] present an approach to managing UIC based on the application of meta-rules. These mete-rules are, in effect, high-level guiding principles or questions that should be considered when designing and managing a specific, and potentially complex, UIC. The study identifies three factors influencing the management of UIC: contextual factors, organisational factors, and stakeholder factors. It identifies three organizational levels to frame UIC and defines meta-rules for management at each level: the corporate level, the departmental level, and the project level. The application of the meta-rules is expected to improve understanding of UIC and help overcome challenges to its management. The meta-rules have focused on the UIC context from initiation to formation stage. The effectiveness of the approach needs validation in a practical setting. Though the proposed approach is interesting, compared to the other two studies [Ankrah and Omar, 2015; Galan-Muros and Davey, 2017], this study is less comprehensive in terms of the aspects of UIC considered.

2.5 The need for a new approach

Section 2.4 presented a review of existing models and frameworks for UIC. The review led to the following inferences.

- **Clear process of application.** Having organised a UIC based on one of the reviewed models, a question remains regarding how to conduct successful operation of the UIC types organised as per a particular model. This means a clear process of application is required for the model. The strength of the Process model [Philbin, 2008] is the clear process of its application. However, not all the models provide a clear process of application.

- **Identification of success factors.** All the models consider various factors that play a major role in the success of UIC. These factors are valuable within the context of this research as they are identified as success factors and play an important role in enabling UICs. Hence, it is important to identify all the relevant factors. However, it is to be noted that the models may have limitations regarding the relevant success factors considered. For example, the SRIP model focuses mainly on IP conflict management, which is not duly considered in the KIC model.

- **Consideration of different stages of UIC.** A UIC will pass through various stages [Philbin, 2008]. So, it is important to consider these stages and identify ways to conduct them effectively. However, most of the models and frameworks have mainly focused on the initiation or formation stages of UIC.

- **Evaluation and improvement.** It is important to evaluate a UIC and identify future improvements. While the KIC model has a component for evaluation and continuous improvement, and the Process model has an evaluation stage, not all the models include a systematic approach for evaluation.

Table 2.2: Analysis of existing Models for UIC

	Clear process of application	Identification of success factors	Consideration of different stages of UIC.	Evaluation and improvement	Types of UIC	Support for selecting UIC types	Integrated approach to UIC
The Process Model [Philbin, 2008]	X	X	X	X		X	
The Generic Collaboration Model [Schubert and Fisher, 2009]		X				X	
The Idea Lab [Perkmann and Salter, 2012]		X				X	
The Grand Challenge [Perkmann and Salter, 2012]		X				X	
The Extended Workbench [Perkmann and Salter, 2012]		X				X	
Deep Exploration [Perkmann and Salter, 2012]		X				X	
A Knowledge Integration Community (KIC) model [Acworth, 2008]		X	X	X		X	
A Model for Collaborative Practice Research [Sandberg et al., 2011]		X		X	X	X	
Sponsored Research Interaction Process Model [Burnside and Witkin, 2008]		X				X	
Conceptual Frameworks for UIC							
- Ankrah and Omar's Framework [Ankrah and Omar, 2015]		X			X		
- UBC Ecosystem [Galan-Muros and Davey, 2017]		X			X		
- Meta-rules based model [Alexander et al., 2018]	X	X			X	X	

- **Types of UIC.** While collaboration is the focus of all the models, the existing models have primarily focused on organising specific types of UIC and not UIC in general, which is the focus of this research. The focus on UIC, in general, is important as organisations often engage in diverse types of UICs. Considering the diversity in which UICs can be organised, the reviewed models are valuable when stakeholders are making decision regarding selection and organisation of a suitable UIC type.

  The 'Conceptual Frameworks for UIC' discussed in Section 2.4.10 aim to improve understanding of UIC by considering UIC as a whole system. While this thesis also considers an improved understanding of UIC by adopting a systems view, its aim is to develop a framework that can be used to evaluate and improve UICs.

- **Support for selecting UIC types.** Because of the diversity of possible UIC types, it is important that models guide users in selecting an appropriate UIC type for a given situation. The models provide such guidance to some extent as they identify a context for which the models are suitable. For example, Perkmann and Salter [Perkmann and Salter, 2012] suggest identification of a suitable model for a UIC based on the duration of UIC and degree of openness of its outcomes. However, in general, a systematic approach for decision-making is lacking.

- **Integrated approach to UIC.** An integrated approach that provides support for all aspects involved in a UIC will be useful for establishing successful UICs. Such an approach should provide systematic support and appropriate tools for effective decision-making. For example, the Process Model [Philbin, 2008] makes use of the Soft Systems Methodology [Checkland, 1981] for creating an overall picture of a collaboration. This picture can help stakeholders make better decisions regarding the design and operation of a UIC. While there is a need for an integrated approach to UIC, there is a lack of such approaches reported in reviewed literature.

The models described in Section 2.4 were analysed in terms of the above features. The results of this analysis are summarized in Table 2.2. Cells containing 'X' indicate the features of each model. Empty cells indicate features not supported by models.

By reading across each row of the table, it can be seen that none of listed models have all of the listed features, and because these models were chosen as representative of UIC methods discussed in the literature, this analysis confirms the limited availability of frameworks to manage UIC acknowledged in the UIC literature

[Alexander et al., 2018; Noble et al., 2017; Philbin, 2008]. Hence, it can be inferred that there is a need for an integrated approach for dealing with UIC.

This thesis addresses this need by developing a framework to not only improve the understanding and management of UIC but also for practical evaluation and improvement of UIC.

2.6 Conclusion

In this chapter, a background study to understand University-Industry Collaboration (UIC) has been presented. The study addresses two aspects of UIC. First, the benefits that are derived from UIC, are established. While this shows that there is no longer a need to argue the importance of improving UICs, it is necessary to examine ways through which they may be improved and strengthened.

Secondly, the various types of collaborations that operate between universities and industry are briefly reviewed in order to understand the diverse ways through which collaboration occurs. This knowledge is important to making informed decisions when selecting a type of collaboration applicable within a particular context. Decisions informed by UIC outcomes are expected to improve the efficiency of resource usage, eliminate wrong decisions [Landry et al., 2003], and lead to more effective collaborations.

Overall conclusions to be drawn thus far are that there are substantial benefits of UICs and that they operate in a variety of forms. Several models have been proposed to organise these forms of UIC and manage their operation.

However, despite the acknowledged benefits of UIC, the variety of collaboration types, and models to organize them, the need for a new approach to evaluating and improving UIC was established in this chapter.

In the next chapter, I describe the research approach adopted in this thesis to develop a new approach.

Chapter 3

Research Design

The research reported in this thesis aims to 'develop a framework that can be used to evaluate and improve the effectiveness of University-Industry Collaboration (UIC)' (Section 1.3). This aim informed the adoption of a Design Science approach to the research.

This chapter presents the research design adopted for this research in detail. It explains the Design Science Research (DSR) methodology that guided the conduct of research presented in this thesis. It provides an overview of the research methods used while conducting this research. Further details of the research methods are provided in subsequent chapters.

3.1 Research methodology

This section presents the rationale for the selection of the Design Science Research (DSR) approach, details of the guidelines for DSR, and the methodology selected to conduct the research in accordance with those guidelines.

3.1.1 Research approach

There are various relevant approaches available to a researcher, for example, Action Research [Baskerville and Wood-Harper, 1996], Grounded Theory [Strauss and Corbin, 1994], and Design Science Research [Simon, 2019]. There is no single approach that can be claimed as the best approach. When selecting a research approach, a researcher should ensure that it can be used to achieve the specific research aim.

Action research (AR), elaborated in Section 3.3.3, involves close collaboration between a researcher and research context with an intention to solve practical problems. It may involve creation of an artefact through close cooperation with the users of the artefact during its development. AR is often used in applied settings, and may require extensive fieldwork. As stated in Section 3.3.3, this approach was deemed suitable for future real-world evaluation and improvement of the artefact developed as a result of this research.

Grounded theory is a qualitative research approach that aims to develop hypothesis and theories based on the gathering and analysis of data. It wasn't considered suitable for this research as the aim of this research is artefact development rather than theory development.

Design science research is a problem-solving paradigm with its roots in the scientific study of the artificial [Simon, 2019]. According to Simon, design is a process with a focus on 'changing existing situations into preferred ones'. The purpose of DSR is the creation of knowledge to improve a situation [Baskerville, 2008]. Such creation of useful knowledge about 'how' to accomplish goals is the main distinguishing feature of DSR. This knowledge can be used for building artefacts to solve problems identified in various organizational settings [Hevner et al., 2004]. Artefacts can be defined as something created by humans, usually for a practical purpose. They encompass a wide variety of 'things', which can be broadly classified as concepts (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems) in DSR [March and Smith, 1995]. An artefact enables the researcher to learn about the real-world situation for which it is created, the effects of the application of the artefact in that situation, and required improvements to the artefact [Hevner et al., 2004].

After carefully considering the mentioned relevant approaches, DSR was selected. The choice of DSR as a suitable approach for this research is based on the following considerations:

- The aim of this research is to develop a framework that can be used to evaluate and improve UIC. In other words, the research intends to create an artefact for improving UIC. The selected research methodology should facilitate the creation of such a purposeful artefact. DSR [Peffers et al., 2007; Hevner et al., 2004] appeared relevant and applicable as 'artifact creation to address a problem' is the most important characteristic of DSR.

- DSR is a dominant and successful approach to research in Information Systems (IS). The DSR paradigm has been explicitly recognized as an appropriate research paradigm in problem situations involving socio-technical contexts composed of people, (business) organizations, and their existing or planned technologies. For example, DSR has been used to develop the Software-mediated Process Assessment (SMPA) approach [Shrestha et al., 2016], a framework for process improvement [Barafort et al., 2014], a cross-enterprise service infrastructure [Skorna et al., 2010], and maturity models [Becker et al., 2009; Mettler and Rohner, 2009]. Because the socio-technical context of UIC research is similar to the context of IS research, the researcher is optimistic that use of DSR will also be successful within the context of UIC research.

- An important property of DSR is its iterative character involving repetition of development and evaluation of an artefact multiple times [Peffers et al., 2007; Hevner et al., 2004]. The proposed iterative and ongoing approach to evaluation and improvement in this research aligns with this property.

- DSR was considered appropriate for this research because it is flexible regarding evaluation. DSR accepts various evaluation methods, including observational, experimental, action research, expert evaluation, and descriptive evaluation [Venable et al., 2016; Peffers et al., 2012; Pries-Heje et al., 2008; Hevner et al., 2004]. Because the time, costs, and resource constraints associated with a typical Ph.D. project posed a challenge in conducting evaluation of the developed framework in a real-world setting, descriptive evaluation seemed appropriate.

  Within the Information Systems (IS) domain, the most commonly used descriptive evaluation methods include informed arguments and illustrative scenarios [Peffers et al., 2012]. Illustrative scenarios are used to illustrate the suitability or utility of an artifact by applying it to a synthetic or real-world situation.

  This research uses illustrative scenarios, and expert evaluation.

3.1.2 Guidelines for Design Science Research

Research activities in design science are twofold: build and evaluate [March and Smith, 1995]. Hevner et al. [Hevner et al., 2004] have provided the following guidelines for conducting DSR within the discipline of Information Systems (IS). While these guidelines were developed within the context of IS, they are also applicable to UIC due to similarities in the research contexts of IS and UIC. These guidelines describe the characteristics of a well-conducted DSR.

- **Design as an Artifact.** DSR must create a purposeful design artifact [Offermann et al., 2010; March and Smith, 1995] to address an important organizational problem [Hevner et al., 2004].

- **Problem Relevance.** DSR should develop solutions to important and relevant business problems [Hevner et al., 2004].

- **Design Evaluation.** The utility, quality, and efficacy of the design artifact must be rigorously demonstrated via well-executed evaluation methods [Hevner et al., 2004].

- **Research contributions.** Effective DSR must provide clear and verifiable contributions in the areas of the design artifact, design foundations (constructs, models, methods, and instantiations), and/or design methodologies [Hevner et al., 2004].
- **Research Rigour.** DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artifact [Hevner et al., 2004].
- **Design as a Search Process.** The search for an effective artifact should utilize existing knowledge, and approach research as a cyclical process of problem-solving in which various solutions are tested against each other for their ability to solve the subject organizational problem [Hevner et al., 2004].
- **Communication of the Research.** DSR must be presented effectively to relevant audiences such as academic researchers and industry practitioners, including technology-oriented and management-oriented audiences. Technology-oriented audiences can enable the implementation of the designed artefact. Management-oriented audiences can enable the usage of the artefact within their organizations [Hevner et al., 2004].

3.1.3 Design Science Research Methodology

The previous section described the characteristics of DSR, the approach selected for this research. This section details the Design Science Research Methodology (DSRM) [Peffers et al., 2007] utilized for conducting the research presented in this thesis. The DSRM is consistent with the established guidelines for DSR [Hevner et al., 2004] described in the previous section. It is based on a review of prior literature about DS in IS and comprises the sequence of activities depicted in Figure 3.1 and summarized below:

1. **Problem identification and motivation.** 'Define the specific research problem and justify the value of a solution' [Peffers et al., 2007].
2. **Definition of the objectives for a solution.** 'Infer the objectives of a solution from the problem definition and knowledge of what is possible and feasible' [Peffers et al., 2007].
3. **Design and development.** 'Create the artifact. Such artifacts are potentially constructs, models, methods, or instantiations (implemented and prototype systems) or new properties of technical, social, and/or informational resources' [Peffers et al., 2007].

4. **Demonstration.** 'Demonstrate the use of the artifact to solve one or more instances of the problem. This could involve its use in experimentation, simulation, case study, proof, or other appropriate activity. Resources required for the demonstration include effective knowledge of how to use the artifact to solve the problem' [Peffers et al., 2007].

5. **Evaluation.** 'Observe and measure how well the artifact supports a solution to the problem. This activity involves comparing the objectives of a solution to actual observed results from the use of the artifact in the demonstration' [Peffers et al., 2007].

6. **Communication.** 'Communicate the problem and its importance, the artifact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences such as practising professionals, when appropriate' [Peffers et al., 2007].

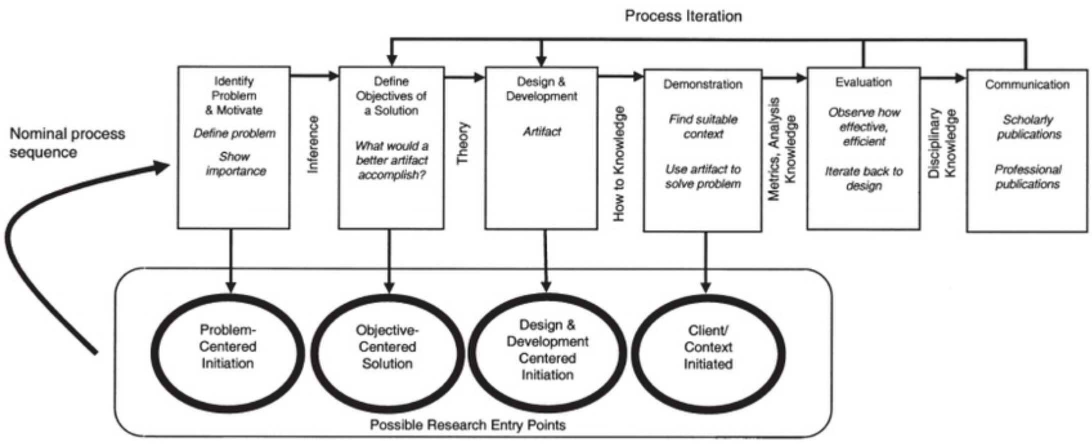

Figure 3.1: The DSRM Process Model adopted from [Peffers et al., 2007]

The DSRM was selected as it is one of the most widely accepted and used models for DSR. The model is easy to understand due to its clear and simple description. It provides a template for structuring the research process. All projects, that are the subject of DSR, are expected to follow the nominal sequence of activities listed above. However, the DSRM does not require all of these activities to have been completed as part of a DSR project. That is, some activities may be completed using other approaches or even reconstructed from available information when no formal approaches have been used. This means that DSR can enter a project at different stages along its life-cycle from activity 1 to 4 so long as all previous activities have been completed or can be re-constructed. A problem-centered approach will start with activity

1, an objective-centered solution will begin with activity 2, design-and-development centered approach would start with activity 3, and client-/context-initiated solution starts with activity 4 [Peffers et al., 2007]. The process can proceed with iteration, as depicted in Figure 3.1. For example, after evaluation in activity 5, the researcher can go back to solution design in activity 2.

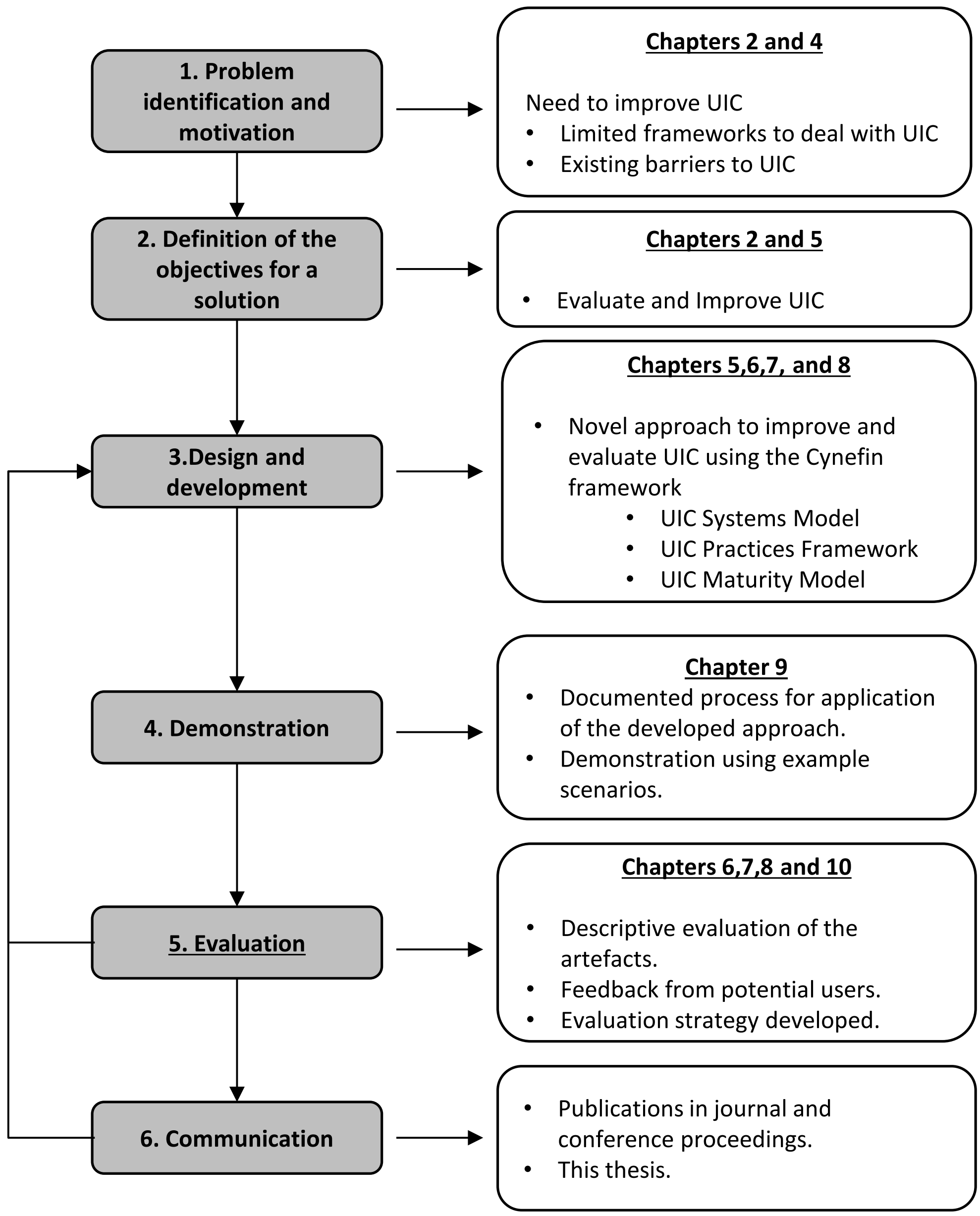

Figure 3.2: Thesis research methodology using DSRM [Peffers et al., 2007]

3.2 Adoption of the Design Science Research Methodology

In this section, I describe how DSRM has been adapted to conduct the research presented in this thesis. A problem-centered approach to research entry in the DSRM is followed, which means the researcher started with activity 1 of the DSRM as described below. Figure 3.2 depicts the mapping of these activities to thesis content.

1. **Problem identification and motivation.** The purpose of this activity is to articulate the research problem, establish its relevance, and justify the value of a solution. This involved a broad study of relevant literature to investigate the current state of University-Industry collaboration (UIC) and various models adopted to facilitate it as detailed in Chapter 2. This helped in gaining clarity about the domain of study and a need to improve UIC. There is growing interest in UIC research, which, in part has identified barriers and challenges to improving UIC (Section 1.1). In order to overcome those challenges and improve UICs, the need to develop approaches is established in Chapter 2 (Section 2.5). A study of barriers to UIC, presented in Chapter 4, further establishes the need for new approaches. The relevance of the research problem is established in Chapter 2 (Sections 2.1 and 2.2). The solution to the research problem will help stakeholders establish effective UICs.

2. **Definition of the objectives for a solution.** This activity in DSRM involves defining the objectives that will lead to the design of a solution for the identified problem. The primary aim of this research is to develop a framework to evaluate and improve UIC. The objectives of the solution are identified as evaluating and improving the effectiveness of UIC as described in Chapters 2 (Section 2.5) and 5 (Section 5.5).

3. **Design and development.** This activity involves the design and development of artefacts. A novel UIC framework has been developed for evaluating and improving UIC effectiveness. It is based on an analysis of the existing UIC literature and data gathered through a qualitative study involving industry practitioners and university researchers (Chapter 4), and then synthesis of the findings into a new holistic approach. It consists of the following three tools, which can be used independently or together in conjunction with the Cynefin Framework as described in Chapter 5:

   (a) **UIC Systems Model.** The Systems Model, presented in Chapter 6 provides a well-defined language for describing and discussing UICs. It is useful during the formation phase of UICs to improve understanding of the UIC context leading to informed decision-making about dealing with various factors influencing UIC.

(b) **UIC Practices Framework.** The comprehensive UIC Practices Framework, described in Chapter 7, is expected to improve the operation of UICs by facilitating the identification and application of appropriate practices.

(c) **UIC Maturity Model (UICMM).** The UICMM, described in Chapter 8, is a useful tool for evaluation of the maturity of an organisation's UIC efforts. Higher levels of maturity indicate that an organisation is likely to be engaging in more effective UICs.

4. **Demonstration.** In this activity, the applicability of the designed artefacts needs to be demonstrated. A process for applying the proposed UIC Framework is described and demonstrated using example scenarios in Chapter 9.

5. **Evaluation.** This activity involves evaluation of the developed artefacts. An evaluation involving an ongoing 'iterative' process of research and practice aimed at learning how to use the proposed approach in different contexts (eg. where it works and doesn't work), and how the approach might be improved over time is considered appropriate.

   In order to complete this activity, a two-phase approach to evaluation is adopted.

   Phase one has been completed and documented within this thesis. It comprises a descriptive evaluation, including illustrative scenarios, detailed in Chapter 9. In addition, two industry stakeholders are engaged in pilot projects using the UIC Practices Framework and the UICMM. Their testimonies (Appendix F) provide evidence of the applicability and utility of the tools, and serve as 'expert evaluation'. In addition, publications related to this research, which have been reviewed by experts in the field, also serve as 'expert evaluation' [Peffers et al., 2012] of the research results.

   Phase two involves real-world evaluation and is part of future work. It is acknowledged that this is a limitation of the research reported in this thesis. However, a detailed strategy for future real-world evaluation is documented in Chapter 10.

6. **Communication.** This thesis is currently the primary means of communication of research outcomes. Specific aspects of this research, including data analysis and proposed tools, have been communicated via publications in relevant conference proceedings and journals (refer to List of Publications on page xiii, and Appendices A, C, and E). In addition, there is an ongoing communication of

ideas with potential stakeholders regarding the practical application of research results in future work, as described in Chapter 10.

3.3 Research methods

In this section, I provide an overview of the research methods used during the research presented in this thesis. Table 3.1 summarizes the use of these research methods throughout this thesis.

3.3.1 Literature review

A literature review is an important research activity. In this thesis, an examination and extensive review of the available literature regarding UIC is presented. This review was conducted in multiple streams covering scientific publications, government reports, media reports, and white papers on the following topics:

- benefits of UIC,
- types of UIC,
- barriers to UIC,
- success factors for UIC, and
- existing approaches to evaluating and improving UIC.

The literature search was carried out using tools such as Google Scholar and university library resources. The researcher tried to identify and cover relevant literature to a large extent by applying techniques such as snowballing (finding relevant literature from the reference lists in, or citations to, papers being reviewed) [Webster and Watson, 2002] and expert recommendations from research supervisors. However, there is a possibility that some of the relevant studies did not feature in the search, which is acknowledged as a limitation of this research.

In order to become familiar with the literature, the researcher used the following steps (also referred to as 'immersion' [Cruzes and Dyba, 2011]) after the search:

- make an initial selection of papers that satisfy the following inclusion criteria based on reading the title, abstract, and conclusion of each paper.
  - The paper addresses at least one of the topics identified for the review.
  - The paper provides enough details of the topic, which means the topic is part of the main discussion in the paper.

- make a final selection of papers from the initial list of papers based on reading each entire paper.

The researcher then conducted an analysis of information presented in these selected papers.

3.3.2 Qualitative study

During the initial stages of research to understand the current state of UIC, how it is currently pursued, and related barriers and success factors, it was imperative that efforts were made to understand academic researcher and industry practitioner points of view.

The researcher selected a qualitative study as a suitable research method for the early phase of the research. It included a series of meetings with industry practitioners and university researchers organised to understand the current state of collaboration within the Australian Capital Territory (ACT). These meetings, along with the literature review, helped the researcher formulate the research problem, articulate the aim of the research, and design a framework for improving UIC.

The qualitative study confirmed the results of the literature review regarding various barriers to UIC and the scope for universities to play a greater role in increasing their level of engagement with industry. It also provided inputs for approaches that can be adopted to overcome those barriers.

Chapter 4 (Section 4.3) provides the details of this study including sampling, data collection and analysis.

3.3.3 Action Research

Action Research (AR) traces its origin to Lewin's [Lewin, 1951] work. It is an interventionist approach that is expected to produce highly relevant research findings for the subject research settings [Baskerville and Wood-Harper, 1996]. The essence of AR can be explained in two stages:

- the 'diagnostic stage' involving collaboration among researchers and the subjects of the research for analysis of the context and formulation of hypotheses, and

- the 'therapeutic stage' involving experiments to change the situation and observation of the effects [Blum, 1955].

Table 3.1: Use of Research Methods in the Thesis

Research method	Chapter	Research Methodology Step
Literature review	2. Background,	Step 1 and 2
	4. Barriers to University-Industry Collaboration,	Step 1
	6. A University-Industry Collaboration Systems Model,	Step 3 and 5
	7. A University-Industry Collaboration Practices Framework,	Step 3 and 5
	8. University-Industry Collaboration Maturity Model	Step 3 and 5
Qualitative study	4. Barriers to University-Industry Collaboration	Step 1
Action research	10. Evaluation and Improvement Strategy	Step 5

Thus, AR focuses on generating solutions to practical problems through a collaborative approach to inquiry between researchers and practitioners.

Adopting additional structure for the two stages can help achieve scientific rigour in AR. A five-phase structure proposed by Susman [Susman, 1983, pp. 101-102] involves a cycle of diagnosing, action planning, action taking, evaluation, and critical reflection leading to the implementation of required changes in the generated solution. This sequence of phases can be repeated until the problem is resolved. Thus, AR is characterized by an iterative approach to problem-solving.

The observation and reflection on the effects of actions during AR lead to a better understanding of the organizational context and development of scientific knowledge through practice.

Action research is part of the evaluation strategy described in Chapter 10.

3.4 Data analysis

Data has been collected during this research by the adoption of various research methods such as literature review, and a qualitative study. In order to identify and communicate the core of the gathered data, a researcher needs to conduct proper analysis and interpretation of the data. There are various data analysis approaches available [Creswell, 2007; Langley, 1999]. At a broader level, thematic analysis was applied to identify themes for various aspects discussed in the selected literature, which are included in various parts of this thesis. 'Thematic analysis is a method for identifying, analyzing, and reporting patterns (themes) within data. It minimally organizes and describes the data set in rich detail and frequently interprets various aspects of the research topic' [Cruzes and Dyba, 2011].

The thematic analysis included data familiarisation, and coding. Data familiarisation refers to studying the data in its entirety to gain a better understanding [Cruzes and Dyba, 2011]. The researcher may identify the basic themes, concepts or categories within the data during the process.

Coding refers to the 'operations by which data are broken down, conceptualized, and put back together in new ways [Straus and Corbin, 1990, pg. 57]'. The following two approaches to coding have been used during this research:

- **Deductive approach.** This is a theory-driven approach [Langley, 1999]. In this approach, a provisional 'start list' of themes, categories or codes is determined before the analysis of the data [Huberman et al., 2014]. This list is created on the basis of research questions, problem areas, relevant theories, hypotheses, and/or key concepts based on the understanding of the researcher. The predetermined list helps researchers in a logical grouping of the concepts to the categories established or well-known in the extant literature. The value of such an approach is that a researcher can build on existing insights in the field from previous researchers' work. However, the researcher must take care to avoid forcing the reviewed data into these predetermined categories. This approach does not allow the researcher to identify the existence of other unanticipated categories.

- **Inductive approach.** This approach is data-driven, where themes or categories emerge from the data being analysed [Langley, 1999]. A researcher reviews the data line by line in detail, and assigns a code as a concept becomes apparent. The researcher continues to assign codes based on emerging concepts upon further review of data. Throughout this process, the researcher compares the raw data with the data already having assigned codes for similarities. Using such comparison, the researcher refines the dimensions of existing codes and identifies new categories [Creswell, 2007]. The advantage of this approach is the flexibility and freedom the researcher has for the interpretation of data. Moreover, there is no risk of the researcher forcing data into predetermined categories.

Details of the specific data analysis are described in respective sections in subsequent chapters.

3.5 Conclusion

In this chapter, I have presented the research methodology used to conduct the research reported in this thesis. The research is classified as Design Science Research. The Design Science Research Methodology (DSRM) proposed by Peffers et al. [Peffers et al., 2007] guided the conduct of the research. This chapter also provided an overview of the various research methods used, and the data analysis methods adopted during the research.

Part II
Contribution

Chapter 4

Barriers to University-Industry Collaboration

University-Industry Collaboration (UIC) offers numerous benefits to various stakeholders as explored and elaborated in Section 2.2 of Chapter 2. However, there are barriers to effective UIC, which can limit the realization of these benefits.

In this chapter, I investigate, categorize and describe various barriers to UIC identified in the literature. The results of a qualitative research activity involving industry practitioners and researchers conducted to further explore the state of UIC within the Australian Capital Territory (ACT) are also presented. The main purpose of this study was to substantiate the barriers to UIC identified in the reviewed literature, identify any additional barriers, rule out any barriers arising from the geographical context and to identify measures that can be adopted by universities in order to overcome these barriers.

4.1 Introduction

Interest in UIC has led to several studies that investigate challenges to successful collaboration between university and industry. According to a study of European UIC, most academics are either not engaged in collaboration at all or offer little cooperation in such efforts leading to possible under-utilization of their potential [Edmondson et al., 2012]. The situation is not much different in Australia with industry and research organizations undertaking less collaborative research in comparison to the United States, Europe, and Asia [NSW and Sydney Business Chamber, 2014]. Though Australian universities are undertaking quality world-class research, barriers exist between the academic and industry communities [Tim Mazzarol, 2014]. This implies that despite the perceived benefits of university-industry engagement, such collaboration is neither easy nor natural. As stated in the Lambert Review of University-Business Collaboration in the UK: 'companies and universities are not natural partners: their cultures and their missions are different' [Lambert, 2003, pg.14].

I agree with Gregory [Gregory, 1997] that both universities and industry should recognise the impediments to establishment of strategic partnerships, and make efforts to overcome them in order to derive mutual benefits [Bjursell and Engström, 2019; John et al., 2015; Greitzer et al., 2010].

While barriers or impediments are the factors that pose challenges to establishing successful collaboration, there are other factors that positively influence UICs. These factors, known as drivers, are benefits that motivate collaboration and success factors that improve the effectiveness of UICs. Though it may be claimed that drivers play a more important role in UICs than barriers, the effects of barriers are more diverse [Galán-Muros and Plewa, 2016]. Agazarian [Agazarian and Gantt, 2005], inspired by Lewin's field theory [Lewin, 1997], argues that overcoming or reducing the barriers can increase the energy of driving forces. Hence, it is likely that overcoming the barriers may in turn increase the impact of drivers. Nevertheless, a holistic approach to studying UIC has been adopted so the drivers have also been considered during this research (as 'benefits' in Chapter 2, and as 'success factors' in Chapter 7).

Recognition of potential barriers at an early stage is of paramount importance as it can enable informed decision-making and effective negotiations before entering into collaborations [Gregory, 1997]. However, one of the major challenges is the identification of barriers during early stages of collaboration.

In order to recognize and deal with potential barriers, it is important to gain awareness of the barriers to collaboration and approaches that can be used to overcome them. For this purpose, I investigate the various barriers to collaboration through a review of the existing literature and findings of qualitative research involving industry practitioners and researchers within the Australian Capital Territory (ACT). This study also confirms any region specific barrier as geographical context has an influence on UIC [Sjöö and Hellström, 2019; Davey et al., 2016]. In addition, it contributes to bridging the gap regarding lack of studies from the regions other than US and Europe.

4.2 Existing literature

A number of studies have been conducted to investigate the various challenges, or barriers, to successful collaboration between university and industry [Davey et al., 2016; Tartari et al., 2012; Schubert and Bjørn-Andersen, 2012; Bruneel et al., 2010; Baldini et al., 2007]. In order to discuss barriers to UIC, it is useful to group related barriers into categories. While the literature presents various categorisations, such as from the perspective of industry [Bruneel et al., 2010] and universities [Tartari et al., 2012], they don't generally cover the breadth of possible UICs. For example, 'transaction-related barriers' [Bruneel et al., 2010] or 'Williamson barriers' [Tartari et al., 2012] focus on TTOs and IP. For these reasons, existing categorisations are not suitable for use in this thesis.

In order to develop an appropriate categorisation for use in this thesis, the researcher collected data on barriers reported in the literature and then followed an iterative process of data analysis using the inductive approach (Section 3.4). Table 4.1 shows the proposed categorization along with the barriers in each category and the perspective from which each category is perceived. The following sections discuss each of these categories.

4.2.1 Cultural barriers

Analysis of some UICs indicates that there is a cultural divide between universities and industry, which acts as a deterrent to effective collaboration [de Wit-de Vries et al., 2019; Frølund et al., 2018; Galán-Muros and Plewa, 2016; Garousi et al., 2016; Ghauri and Rosendo-Rios, 2016; Davey et al., 2016; Ivascu et al., 2016; Goduscheit and Knudsen, 2015; Wallin et al., 2014; Edmondson et al., 2012; Hughes and Kitson, 2012; Gilsing et al., 2011; Philbin, 2008; Dooley and Kirk, 2007; ; Siegel et al., 2003a; Schartinger et al., 2001]. They differ in their motivations, beliefs, values, objectives, expectations, and processes based on the distinct organizational cultures in which they operate [de Wit-de Vries et al., 2019; Ehrismann and Patel, 2015; Muscio and Vallanti, 2014; NSW and Sydney Business Chamber, 2014; Baldini et al., 2007; Dealtry et al., 2005; Lambert, 2003]. Firms complain of lack of understanding or appreciation of industry goals/culture/constraints, while university researchers and administrators feel that the business community lacks an appreciation for the role and processes of universities [Siegel et al., 2003a]. Research groups are concerned that industry collaboration could interfere with their research programs [Ramos-Vielba et al., 2016]. Researchers also believe that there is a scepticism in industry and it lacks interest or is not willing to work with academics [Schubert and Bjørn-Andersen, 2012; Hughes and Kitson, 2012; Gilsing et al., 2011; Baldini et al., 2007; Hall et al., 2003].

Table 4.1: Categories of Barriers to University-Industry Collaboration

Category	Barriers identified in the literature	Perspective
Cultural barriers	Difference in motivation, goals, values, and processes Lack of mutual appreciation Differing time-frames Perceived length of academic research Quicker business requirements	Both
Legal barriers	Disagreements regarding IP rights, ownership, publishing Contract negotiations Information leakage	Both
Administrative barriers	Lack of established processes and resources Inflexible bureaucracy	Both
Motivational barriers	Insufficient rewards and recognition for collaborative efforts	Both, primarily university
Contextual barriers	High cost, time, and effort Difficulty in maintaining balance between regular duties and UIC Difficulty in identifying stakeholders	Both, primarily university
Communication barriers	Lack of awareness of research Lack of information about benefits, and opportunities out of UIC Ineffective communication Difficulty in contact	Industry
Relevance barriers	Unclear or unaligned relevance of academic research to industry Perceived insufficient benefits Limited industrial ability to utilize research results	Both, primarily industry
Credibility barriers	Loss of prestige of a research group Career damage Decline in research rigor	University

For example, Judith Berman, when describing the experiences of university researchers and industry practitioners seeking to collaborate via an Australian Research Council (ARC) Linkage Projects program [Berman, 2008], noted that one of the academic researchers engaged in the project remarked: 'Industry isn't concerned with the science - only with the practical solution to the specific industry problem. They need persuading that the scientific work is essential.' Conversely, industry partners see an opportunity for creating commercially viable outcomes by engaging and supporting research through the linkage grants.

The primary objective of universities is to create and disseminate knowledge through education and research, and to prepare the future workforce according to social expectations. Industry aims to generate maximum profits, either short or medium term, by utilizing knowledge to its full market potential within a competitive business environment [Ivascu et al., 2016; Dealtry et al., 2005]. It has also been pointed out that individual university researchers may have a purely academic orientation with little interest in collaborating outside the university [Siegel et al., 2003a]. This indicates that the motivations of individual staff may differ from their parent organizations [NSW and Sydney Business Chamber, 2014].

This lack of alignment in goals and agenda between the academic world and industry, and individuals and organizations creates a disconnect that makes it difficult to collaborate [Australian Industry Group, 2015].

Another concern regarding the success of UIC are the time-frames adopted by the two sectors [Rybnicek and Königsgruber, 2019; Ghauri and Rosendo-Rios, 2016; Davey et al., 2016; Ramos-Vielba et al., 2016; Wallin et al., 2014; Hughes and Kitson, 2012; Schubert and Fisher, 2009; Elmuti et al., 2005]. There is a perception that academic research is often conducted over a long time-frame [Pettigrew, 2001], which could be attributed to the fact that it does not have commercial purpose as a primary objective. While industry is interested in immediate results to meet their business goals with short-term engagements, universities often have a focus on long-term basic research to add to deep knowledge [Muscio and Vallanti, 2014; Dealtry et al., 2005]. Industry is concerned about 'time to market' as it is critical for business success. It requires adept knowledge at the right time to commercialise their product and process innovations. It can derive maximum benefits from their product and innovation only by offering the product to the consumers before any competitors hit their market [Siegel et al., 2003a].

An industry partner complained: 'Academics are notorious for taking a long time to do research, whether it's due to teaching commitments or because the work is linked to the requirements of a PhD...two months of work with a professional agency is closer to two years for academics...this is a big issue.' [Berman, 2008].

4.2.2 Legal barriers

Legal issues associated with intellectual property (IP) rights, ownership, publishing and contracts present barriers to UIC [Garcia et al., 2018; Ramos-Vielba et al., 2016; Goduscheit and Knudsen, 2015; Muscio and Vallanti, 2014; Hughes and Kitson, 2012].

Disagreements regarding the ownership of IP, and the revenue share asssociated with it are common and often indicate a lack of trust between parties. While industrial firms claim that universities are often too aggressive, over-value their IP, and lack understanding of business and the commercial risks involved, universities are often concerned that they may not receive the revenue they deserve [Davey et al., 2016; Dooley and Kirk, 2007; Siegel et al., 2003a; Hall et al., 2001]. This lack of understanding leads to unrealistic expectations that make negotiations between the two parties difficult and act as an obstacle to a successful partnership.

While universities aim to share knowledge with a wider audience through journals and conference proceedings, industry is invariably interested in maintaining secrecy in order to gain a competitive edge in the market [Davey et al., 2016; Muscio and Vallanti, 2014; Dooley and Kirk, 2007]. Industry perceives risks of information leakage in the process of UIC [Davey et al., 2016; Gilsing et al., 2011].

4.2.3 Administrative barriers

There are administrative barriers to UIC, including lack of established procedures for collaboration [Muscio and Vallanti, 2014]. Both university researchers and businesses perceive that university bureaucracy and inflexibility act as barriers to UIC [Rybnicek and Königsgruber, 2019; Garcia et al., 2018; Galán-Muros and Plewa, 2016; Davey et al., 2016; Goduscheit and Knudsen, 2015; Hughes and Kitson, 2013; Tartari et al., 2012; Hughes and Kitson, 2012; Baldini et al., 2007; Siegel et al., 2003a]. This perceived inflexibility is attributed to the challenge of alignment of goals among the various stakeholders [Frølund et al., 2018]. The administrative processes, while believed to be cumbersome and not well-defined, are also not designed to handle each and every situation. Literature also indicates that university TTOs act as obstacles as they do not have the marketing, technical and negotiation skills required to enable successful university-industry technology transfer [Alexander et al., 2018; Goduscheit and Knudsen, 2015; Siegel et al., 2003a].

4.2.4 Motivational barriers

Inadequate reward systems within academia have been cited as a barrier to effective UIC [Franco and Haase, 2015; Schubert and Bjørn-Andersen, 2012; Hughes and Kitson, 2012; Baldini et al., 2007; Siegel et al., 2003a]. Reward systems and performance appraisal in universities are normally based on publications and income from research [Miller et al., 2016]. Individual researchers find that collaborative research does not have a positive impact on their career as it is not usually considered during their performance assessment [Muscio and Vallanti, 2014; NSW and Sydney Business Chamber, 2014].

If the efforts of researchers engaging with the business community are not rewarded and university promotion and tenure practices do not value involvement in UIC, it may well demotivate researchers from engaging in such activities [Miller et al., 2016; Perkmann et al., 2013]. It therefore appears that a 'lack of recognition from colleagues/deans' is a significant barrier to academics engaging in UIC [Schubert and Bjørn-Andersen, 2012].

'Insufficient rewards' has also been identified as a constraint for businesses though the notion of rewards will differ between both academics and businesses [Hughes and Kitson, 2012].

4.2.5 Contextual barriers

A significant barrier for academics is the high cost, time and effort associated with project acquisition [Garousi et al., 2016; Franco and Haase, 2015; Schubert and Bjørn-Andersen, 2012; Gilsing et al., 2011], or patenting [Baldini et al., 2007]. The overhead costs associated with industry projects are too high as researchers need to gain sufficient funding to support the time taken off from teaching activities and the costs of maintaining a team [Latham, 2008]. Excessive teaching loads do not leave enough time for research [Alrajhi and Aydin, 2019; Baldini et al., 2007]. Maintaining a balance between academic duties and UIC activities is challenging for academics [Davey et al., 2016]. This indicates that a 'lack of time to fulfill all university roles' [Muscio and Vallanti, 2014; Hughes and Kitson, 2012] acts as a barrier to UIC. Similarly, industrial researchers find that high overheads of UIC in terms of money and time [Gilsing et al., 2011], and a lack of resources and experience in managing UICs, act as barriers to UIC [Hughes and Kitson, 2013, 2012]. Both, university and industry complain about lack of funding for UIC [Davey et al., 2016].

Often, researchers struggle to evaluate the commercial potential of their research [Baldini et al., 2007], and face difficulty in identifying industrial partners [Davey et al., 2016; Muscio and Vallanti, 2014; Hughes and Kitson, 2012; Gilsing et al., 2011].

Universities also cite the limited ability of business to utilise research results as a barrier to UICs [Davey et al., 2016].

4.2.6 Communication barriers

Inefficient communication is a further barrier to effective collaboration [Ripoll Feliu and Diaz Rodriguez, 2017; Garousi et al., 2016; Goduscheit and Knudsen, 2015; Uyarra, 2010; Kaufmann and Tödtling, 2001]. This includes a lack of awareness of research activities/results [Davey et al., 2016]; a lack of information regarding the benefits of UIC, opportunities arising out of UIC [Davey et al., 2016], and the relevance of research [Ripoll Feliu and Diaz Rodriguez, 2017]; and ineffective communication of the mechanisms and contacts for collaboration [Davey et al., 2016; Hughes et al., 2011].

Ineffective communication of relevance of the research results to industry is perceived as a barrier as emphasized by Straub and Ang: 'Any academic journal written by researchers for researchers as the primary audience is simply not targeted for practitioners' [Straub and Ang, 2008]. Practitioners find access to research results difficult [Gilsing et al., 2011] as the findings are published in conferences or journals, which are less attractive and obscure to them, and often exist behind 'paywalls'.

These aspects may lead to difficulties in identification of UIC partners, which acts as another barrier [Hughes and Kitson, 2012].

These communication related barriers indicate that there is a need for universities to establish more effective, and probably innovative, mechanisms for information dissemination.

4.2.7 Relevance barriers

The relevance of research is often unclear to industry or not aligned with industry requirements [Garousi et al., 2016; Fateh Rad et al., 2015; Muscio and Vallanti, 2014; Schubert and Fisher, 2009; Starkey and Madan, 2001]. For example, industry may find that research topics do not address problems that are of interest. This is a barrier to UIC [Hughes et al., 2011]. Unclear or misaligned relevance of research may lead to perceived insufficient benefits from collaboration, which acts as a barrier for businesses [Hughes and Kitson, 2013]. Firms also complain that the knowledge developed at universities is often too general or theoretic to address their specific needs [Gilsing et al., 2011].

4.2.8 Credibility barriers

A study by Ramos-Vielba et al. [Ramos-Vielba et al., 2016] showed that research groups perceive barriers associated with the risk to scientific credibility due to industry collaboration. They fear loss of prestige, damage to individual careers, and a decline in research rigor.

While the Ramos-Vielba study focuses on science-based UIC, the general idea that issues around credibility can present barriers to UIC, may be applicable within the broader context of UIC considered in this thesis. For this reason, and to enable further exploration, the category of 'credibility barriers' has been included in the proposed categorisation of barriers. The barriers in this category are listed in Table 4.1 and were derived from [Ramos-Vielba et al., 2016].

4.2.9 Other categorisations

While, for the purposes of this thesis, barriers are categorized as described above and summarized in Table 4.1, they can also be organised in terms of scope (individual, organization, or UIC as a whole system) or time frame (short, medium or long term).

4.2.9.1 Scope

In terms of scope, individual barriers are created due to an individual's characteristics, interests, and skills. For example, inadequate reward systems may cause a lack of motivation that acts as a barrier that restricts an individual's involvement in UIC.

Organisational barriers are the characteristics of an organisation that pose a challenge to establishing and managing successful UIC. Legal barriers, administrative barriers, inadequate reward systems, and inefficient information communication are the barriers that need to be dealt with at an organisational level.

Barriers at the UIC level refer to the barriers arising out of the differences in the characteristics of the organisations involved and they need to be dealt with collectively by the organisations involved. These include cultural barriers, contextual barriers, and relevance barriers.

Understanding these levels of the barriers can help in identifying the level at which improvement approaches should be adopted. While we can categorise the barriers at different levels, it is to be noted that they may be interconnected. For example, overcoming an individual barrier related to inadequate reward systems needs to be dealt with at an organisational level. Similarly, dealing with barriers related to the relevance of research will also raise awareness of the commercial value of research.

4.2.9.2 Time frame

Barriers can also be organised based on how long it typically takes to overcome them, which depends on the complexity of a barrier. This categorisation is also influenced by the findings in the reviewed literature such as by Kashyap and Agrawal [Kashyap and Agrawal, 2019], where the categorisation is based on the time required for strategic planning to eliminate these barriers.

Barriers such as inadequate reward systems, inefficient information communication, and relevance of research can be addressed in short time-frames ranging from 6 months to 1 year.

Administrative barriers, and contextual barriers will require a medium-term strategy. These will require engagement between organisations to understand the costs and time involved, and adapting as per the requirements of stakeholders within the UIC context.

Cultural barriers involve human aspects, are often complex, and would typically require a long-term plan to develop alignment. Similarly, legal barriers, ranging from lack of common understanding of IP to resolving ownership issues, may require a long-term plan.

Understanding time-frames can help in planning strategies for overcoming UIC barriers.

4.3 Qualitative study involving industry practitioners and university researchers

It is evident from the above review that there are various barriers to effective UIC that need to be overcome. In order to further validate the motivation to address the problem of UIC, multiple meetings of practitioners and academic researchers were designed and organised to explore the current state of UIC within the Australian Capital Territory (ACT) region, where the researcher is based and conducting the research.

4.3.1 Domain of interest

Note that the main focus of the research at the time of the study was UIC within the field of Software Engineering. As such the meetings focused on this domain.

However, as the work progressed the focus of the research presented in this thesis became more general. As indicated below, results of the study presented in this section are applicable to the more general domain of UIC.

4.3.2 Research purpose

The purpose of this exploratory research was to investigate the state of UIC within the ACT through the experiences of industry practitioners and academic researchers. This investigation was carried out in order to:

- substantiate the results of the literature review regarding barriers to UIC.
- identify additional barriers to UIC, primarily to ensure that no regional specific barriers exist.
- identify measures that could be adopted to improve UIC.

4.3.3 Research approach

A qualitative approach to this research was adopted. The research purpose guided the selection and design of the research methodology of this study. This section elaborates the rationale for the choice.

Qualitative research encompasses a set of interpretive activities for scientific inquiry spanning different disciplines, varied fields, and several subject matters. It comprises varied methods and approaches, specifically with the purpose of enhancing the understanding of a social phenomenon or human experience [Denzin and Lincoln, 2011, pg. 6].

There are various compelling reasons to support the selection of a qualitative approach such as the nature of the research question, the need to explore the topic, the presentation of a detailed view of the topic under study, and the setting of the research [Creswell, 2007, pp. 17-18]. A qualitative research method appeared to be suitable for this exploratory study as the purpose of the study was to understand the state of UIC in ACT and the barriers to it. The study also qualifies for the selection of a qualitative method as it investigates a complex phenomenon that is difficult to measure quantitatively [Curry et al., 2009]. For example, interactions within UIC, challenges, and individual behaviours may be difficult to measure quantitatively. Further, the study intended to explore the topic of UIC by eliciting insights from participants based on their experiences and then presenting the details of those insights.

Meetings involving academic researchers and industry practitioners provided an optimal way to gain insight into the problem of UIC. They satisfy the usage of qual-

Table 4.2: Focus Group Meeting Participants

Type of Study	Participant details
Meeting 1	3 Industry Practitioners each with more than 10 years of industry experience.
Meeting 2	2 Industry Practitioners each with more than 10 years of industry experience. One university researcher with more than 3 years of experience
Meeting 3	Manager of a Technology Transfer Office (TTO)
Meeting 4	Manager from industry with experience in conducting a UIC study for the Australian Federal Government

itative methods 'to generate data necessary for a comprehensive understanding of a problem, and to gain insights into potential causal mechanisms' [Curry et al., 2009].

The study was to be conducted in a natural setting rather than through an experimental setup. Further, the researcher intended to participate as an active learner in the process rather than an expert, for which a qualitative approach is suitable [Creswell, 2007].

According to Curry et al. [Curry et al., 2009], 'qualitative methods should be considered when the research aim is to develop sound quantitative measurement processes or instruments'. The researcher intended to utilise the research results to inform the design of the practices framework (Chapter 7), and the UIC maturity model (Chapter 8).

In addition, the human-centric nature of UIC in the Software Engineering domain [Seaman, 1999] (and more generally) makes the qualitative data collection process an essential instrument to gather substantial information.

4.3.4 Design of the study

The methodology used to conduct this qualitative research and details of the participants are described in this section.

4.3.4.1 Ethics approval

University ethics approval was required before undertaking this research. The applicable ethics documentation is included in Appendix D.

4.3.4.2 Sampling

Sampling is the process of selecting a set of people for a study. The dominant strategy for sampling in qualitative research is purposeful sampling [Hoepfl et al., 1997] in contrast to probability sampling that relies on statistical probability theory [Curry et al., 2009], where a sample is randomly selected with each member of the research population having equal probability of being selected. The aim of purposeful sampling is to identify information-rich cases [Patton, 1990] or participants [Pope and Mays, 1995] based on their relevance to the research question or phenomenon of interest in the study. Patton [Patton, 1990] has described sixteen types of purposeful sampling including snowball or chain sampling, and criterion sampling. In this research, three of those sixteen purposeful sampling strategies were utilized, namely criterion sampling, snowball sampling, and convenience sampling as described below.

- **Criterion sampling.** In order to ensure the quality of results, a criterion sampling strategy was used to identify participants satisfying predetermined criteria. In alignment with the research goal of deepening the understanding of UIC within the ACT, the participant selection criteria defined included the following considerations:
  - Because software engineering research and practice were the focus at the time, the participant needed to be a researcher in Computer Science or an expert in the software industry in Canberra.
  - The participants were required to have a minimum of 5 years of experience in the field of interest to ensure that they were 'information-rich'.
  - The participants should have either engaged in a form of UIC or have a keen interest in engaging to ensure the relevance of their inputs to the study.
- **Snowball sampling.** The snowball sampling strategy was used in order to increase the number of eligible participants. In this strategy, the initial set of participants identified above were asked to identify additional potential participants possessing the characteristics that were of research interest.
- **Convenience sampling.** The convenience sampling approach appears to be probably the most commonly used approach in qualitative research [Chism et al., 2008]. In this approach, participants are selected on the basis of easier access due to their proximity and accessibility through acquaintances. The approach was used in this study to select participants located in the ACT.

Twenty participants from industry and academic research were selected by applying the above-mentioned sampling strategies. Invitations for the meetings were sent to them through email during April 2016. The invitations included a Doodle poll [Doodle, 2016] attached for scheduling the meetings.

Since many of the interested participants were not available at the same time, the researcher decided to conduct an initial meeting on the day when most of the participants were available. Additional meetings were organized to cover the remaining interested participants based on their availability. In this way, eight participants in total with diverse backgrounds attended meetings during April-May 2016. Table 4.2 summarizes the profiles of the participants.

The number of participants is small, but the value of their individual experience in addition to the diversity of their workplaces validates the importance, quality and richness of the data collected. The sample size in qualitative research is generally smaller than that of quantitative studies [Curry et al., 2009]. Also, theoretical saturation, the point of information redundancy where new concepts cease to emerge, determined the adequate sample size [Morse, 1995; Curry et al., 2009]. Saturation in a qualitative study depends on the richness of data, rather than the quantity of data [Morse, 1995]. In this study, saturation was achieved after 4 meetings due to a richness of data and cohesiveness of the sample [Morse, 1995].

4.3.4.3 Data collection methodology

Qualitative research involves in-depth interviews, observation, focus groups, and document review as primary methods of data collection [Curry et al., 2009]. This research utilized meetings for interviews. There are various reasons for the selection of these data collection methods, including the probability of high return rate and effective communication. The probability of high return rate is due to the researcher's ability to motivate the participants. Communication is effective as there is an opportunity to seek instant clarification regarding a question or response. Given the fact that UIC is a complex phenomenon, it is important that the researcher and participants have a consistent understanding of the topic and questions under research. If the participants want to verify their understanding of a question, they can do so immediately by speaking to the researcher. On the other hand, if the researcher needs any clarification regarding a response, he/she has an opportunity to discuss it with the respondent. There are also opportunities to gather additional information by asking questions connected to the responses and exploring the topic further.

As described in the literature, interviews can be conducted in three forms: structured, unstructured, and semi-structured [Corbetta, 2003, pg. 269]. These forms vary in terms of the degree of flexibility and freedom available to the interviewer and the respondents. Structured interviews are '... interviews in which all respondents are asked the same questions with the same wording and in the same sequence' [Corbetta, 2003, pg. 269]. The rigidity of the structured interview does not leave space for exploring new or additional pieces of information through probing, which is a valuable aspect of semi-structured interviews. Unstructured interviews are open-ended and have no specific direction. Semi-structured interviews were selected for this study, which, though having a guiding direction, also provided enough opportunity to explore new information. Moreover, semi-structured interviews provide flexibility to the researcher to reframe a question in order to increase understanding and consistent interpretation of a question by the participants.

The meetings were semi-structured in order to elicit similar information from the participants, while providing them enough opportunities to express their views and discuss their experiences around UIC and ideas to improve it. These meetings generally lasted for about two hours each. The discussions were recorded on a digital device for further analysis. This resulted in four recordings. Although digital recordings are a means of ensuring accuracy and makes data readily accessible to other researchers [Curry et al., 2009], the researcher also took notes during the meetings to serve as a backup in the event of a recording failure.

4.3.5 Data analysis and results

An iterative process (listening to the recordings multiple times), which is generally practised for qualitative studies [Curry et al., 2009], was followed to analyse and code the data recorded during the four meetings. The approach to this data analysis process included the following two steps:

- **Data familiarisation** - The researcher began the process of data analysis with data familiarisation, where the researcher looked at the data as a whole to gain understanding. Recordings were carefully listened to and transcribed.

- **Coding** - Data familiarisation was followed by coding. Open coding, 'the interpretive process by which data are broken down analytically' [Corbin and Strauss, 1990], appeared suitable, and was adopted. During this step, a careful thorough reading approach was adopted, where data was read line-by-line to analyse and break it down into relevant categories. Initially, the researcher used participants' own terms to code the data. As the data was analysed iteratively multiple times, new relevant categories emerged for logical grouping of the data.

Table 4.3: Identified Barriers and associated improvement Approaches

Barriers to UIC	Approaches to improving UIC
Lack of visibility of research	Collaborative platform
Commercialization barriers	A broader view of impact Proactive role of universities Development of entrepreneurial skills
Misaligned goals	Proactive role of universities Awareness of product life-cycles
Misalignment of time frames	Awareness of product life-cycles
Difference in mindset	Awareness of product life-cycles A broader view of Impact
Lack of safe collaboration mechanisms	Collaborative platform Improve alumni relationships Highlight mutual benefits
Complexity of UIC	Diversity of approaches

The researcher gained a thorough understanding of the data by following the above approach, and identified two categories of comments:

- **Barriers to UIC**

  Many comments provided further evidence of the barriers found in the earlier studies considered during the literature review described in Section 4.2. They confirm that there are various challenges to successful collaboration between university and industry.

- **Approaches to improving UIC**

  Other comments identified and discussed approaches to improving UIC.

Comments were then extracted from the transcripts and placed into one of the above categories. Analysis of these categorised comments using open coding and following the inductive approach (Section 3.4) resulted in a list of barriers to UIC and associated approaches, which may help overcome them. These results are summarised in Table 4.3 and discussed below.

4.3.5.1 Lack of visibility of research

One of the main concerns raised by industry practitioners is the lack of visibility of university research. Universities and industry may be working towards solving problems in a common area of interest, however, there is no mechanism readily available to access information about the current state and scope of research underway in universities. Business practitioners find it difficult to know how much progress has been made by universities in their fields of interest. If available, this knowledge could help minimise duplication of effort and improve the possibility of collaboration. It became apparent from this research that digital platforms have been under-utilised and that there is a need to focus on providing an effective online medium to connect people for the purpose of UIC. While the creation of new platforms appears to be appropriate, there is also a need to more effectively utilise existing digital platforms. For example, the visibility of university research and associated contact information can be made more readily available on university websites.

The emergence of web platforms has changed the way scientific information is disseminated and researchers communicate. To address the lack of visibility of university research, universities could create a new or utilize existing **collaborative platforms**, where people from industry and universities can reach out to each other to discuss ideas and achievements. Appendix I provides some details regarding a proposed digital platform.

4.3.5.2 Commercialization barrier

Industry participants believe that the outcome of university research can improve software engineering tools and practices used in industry. They see a commercialisation opportunity for universities within the context of collaboration with industry. However, both universites and industry are concerned about sharing information, principally due to intellectual property concerns. University Technology Transfer Offices (TTOs), which are actually expected to facilitate this, do not seem to be popular with industry practitioners. They act as a barrier because of the differing mindset and lack of required skills for encouraging collaboration.

Another identified barrier to commercialization was the difficulty in finding suitable industry partners. This indicated that the commercial potential of university research may not be realised because of the difficulty in finding suitable commercial organisations.

Researchers need to be educated and trained to have a **broader view of the impact** of their work. They should think beyond the narrow confines of their research outcome as a publication, to the real-world application of their research. There is a need to create awareness among researchers about pitching their research within a broader context. Of course, universities need to reward researchers who create broad impact.

Participants expressed the view that universities need to play a more **proactive role** in the commercialization of research results. They need to demonstrate the applicability of research for industry in a relevant context and promote their research outcomes. Considering this approach, a model to improve adoption of research tools by industry is recommended [Awasthy et al., 2016] (Reproduced in Appendix A).

It is also worth exploring the application side of research within universities in order to increase its Technology Readiness Level (TRL) [Mankins, 1995] so that it can be more easily commercialized. Industry cannot be expected to commercialise research at very low TRLs. If the universities don't increase the TRL, there is no one else to do the job for them. Increasing TRL within the university has a potential to support the research of other users of the technology within the university leading to a win-win situation across disciplines in the university. However, at the same time, a positive response within a university does not mean that commercialization will be easy. Industry and universities are still very different types of organization operating under very different constraints.

Participants also had a view that improving research adoption is a matter of passion. Researchers need to try to network and promote their research. Universities need to develop **entrepreneurial skills** among researchers in order to drive research adoption. They need to employ people with entrepreneurial characteristics and the ability 'to make things happen'. Along with this, universities need to work towards employing and preparing staff who are both academically qualified to understand the research and its significance, and can talk the language of business and marketing people. One way to achieve this is to invest in graduate and post-doctoral students as they possess the required expertise, and are often more open to alternative career pathways rather than a standard academic career. Universities can also utilise the potential of retired academics by appointing them as adjunct or visiting faculty.

4.3.5.3 Misaligned goals

Another major concern expressed by industry participants is that researchers tend to work without enough concern or knowledge about the potential value of their work to industry, and that they lack understanding of industry expectations. However, for researchers this implies their taking responsibility to drive adoption of what they are building. Participants believe that all the capabilities intrinsic to achieving this are present in academia but there is a problem with alignment of goals or incentives. While, the primary goal of industry is revenue generation through exploitation of ideas within short time-frames, academic researchers aim at wider dissemination of their research results through publications. Researchers are generally unaware of the business domain regarding requirements to create a product and where they fit in the world beyond their research.

Earlier, it was discussed how a **proactive role** by universities might help projects overcome commercialization barriers. This approach is also relevant and applicable to better alignment of universities and industry goals. Participants had a view that researchers need to gain a better understanding of the requirements of business and users around them. This would help universities align their research goals for greater impact.

The participants recognized the value of **awareness among researchers about product life-cycles**. They noted that understanding real products and their creation processes would broaden the perspective of researchers about business and help them overcome the misalignment of goals and lead to increased engagement between researchers and industry.

4.3.5.4 Misalignment of time frames

To survive in a dynamic market, industry seeks to derive quick and financially viable output while universities focus on longer-term research. Universities need to find ways to collaborate with industry to produce results within industry time-frames. Participants believe that successful short-term collaboration has the potential to lead to long-term mutual benefits due to increased trust and commitment.

Awareness about product life-cycles discussed earlier is applicable as an approach to overcome barriers related to misalignment of time-frames. Working closely with industry will provide researchers with an opportunity to understand business requirements, broaden their perspective of the business world, and value their time-related expectations. This increased understanding is expected to better align the time-frames.

4.3.5.5 Difference in mindset

Industry participants raised concerns about the difference in mindset of industry and researchers. Industry practitioners are interested in exploiting an idea or research results to their full market potential. Researchers often focus only on their research and ignore its application to real-world problems. This indicates that they do not recognize the real value of businesses in utilizing the full potential of research results. As one of the participants commented, 'Thinking that marketing is a small bit is not right. Business people are equally important to take ideas to new levels'.

The **broader view of impact** and **awareness about product life-cycles** discussed earlier, as improvement approaches, are applicable within the context of 'difference in mindset'. Working closely together is expected to create more understanding, as well as mutual respect for goals and organizational expectations, leading to better alignment in mindset.

4.3.5.6 Lack of safe collaboration mechanisms

Another major barrier mentioned by the industry participants is the lack of a mechanism for safe collaboration. It is difficult to find and develop trust with the right collaborator. Most people are not inclined to discuss their problems in open environments.

The importance of **a collaborative platform** to overcome the barrier related to the lack of visibility of research was discussed earlier. The approach is also valid in the context of creating a safe collaboration mechanism. However, there is a concern about the willingness of people to share their research ideas. This can be addressed by adopting a university strategy to encourage and reward networking, and sharing of ideas.

The participants highlighted the value of universities' greatest asset: its people, especially alumni. Universities should focus on **improving alumni relationships**. They should maintain a connection with alumni and share their progress within the university. While alumni could be considered trustworthy partners providing safer mechanism for collaboration, good and continued relationship with alumni can also contribute to increased industry engagement, funding for research, donation, and broader societal impact.

It is recommended to **highlight the mutual benefits** of collaboration. Participants had a view that universities should demonstrate the benefits of collaboration, such as industry funding, and commercial application of research. While, a researcher might be seeking funding for research, a business gains a competitive edge and reputation in the market. For example, a participant noted that a relationship with the Australian National University provides benefits to industry in terms of enhanced credibility and reputation. This approach is expected to create a trusting environment and encourage individuals to engage in collaborations.

4.3.5.7 Complexity of UIC

Participants in the meetings agreed that UIC is often a complex problem. The barriers to UIC are related to individual as well as organisational behaviour and strategy. Behavioural barriers such as trust and mindset issues are more challenging to address than other barriers.

The complexity of UIC cannot be dealt with using any single approach. It needs an intervention with a diversity of approaches that are context-specific to move closer towards a solution so that benefits can flow to a wider community. Universities and industry need to identify and apply a collaboration mechanism and improvement approaches that are most suitable to their context.

4.3.6 Threats to validity

I understand that the sample size of the qualitative research is small and focused on the area of Software Engineering. It does not necessarily represent the entire population of university-industry relationships. However, the value of the individual experience of the participants, which is on average more than 10 years in the software engineering field, validates the importance and quality of the data collected.

Most of the participants in the study were from industry, which made it difficult to achieve a balanced view regarding the barriers to collaboration and measures to deal with them. However, an insight was gained into measures that could be adopted by universities from an industry practitioner perspective.

The results of this study are specific to UIC within the ACT. There may be concern regarding generalisation of its conclusions to other settings outside of Australia due to geographic and industry differences.

Table 4.4: Corresponding Barriers identified in the Qualitative Study and the Literature Review

Qualitative Study Barriers	**Literature Review Barriers**	**Literature Review Barrier Categories**
Lack of visibility of research	Lack of awareness of research Ineffective communication	Communication barriers
Commercialization barrier	Unclear relevance of research Difficulty in Identifying stakeholders Inflexible bureaucracy	Relevance barriers Contextual barriers Administrative barriers
Misaligned goals	Difference in goals	Cultural barriers
Misalignment of time-frames	Differing time-frames	Cultural barriers
Difference in mindset	Difference in motivation Lack of mutual appreciation	Cultural barriers
Lack of safe collaboration mechanisms		Cultural barriers
Complexity of UIC		Administrative barriers

4.3.7 Summary of results

The results of the qualitative study fulfil the original research purpose outlined in Section 4.3.2. The barriers identified in the qualitative study substantiate some of the results of the literature review regarding barriers to UIC, though they are referred to using different terminology. By following the deductive approach (Section 3.4) to data analysis, the results from the review and the study could be mapped as shown in Table 4.4.

In terms of contribution to knowledge, two additional barriers were identified as a result of the qualitative study that were not explicitly recognised in the existing literature. It is to be noted that the novel classification developed in this chapter is wide enough to place these two barriers into the categories listed. There were no additional barriers pointed out based on the regional context of the study.

4.4 Conclusion

In this chapter, I have presented findings from a survey of existing literature, and qualitative research involving practitioners and researchers in the field of Software Engineering within the ACT. Various barriers to collaboration were identified in the investigated literature. These barriers were categorized as cultural barriers, legal barriers, administrative barriers, motivational barriers, contextual barriers, communication barriers, relevance barriers, and credibility barriers. Barriers were also organised in terms of 'scope' (individual, organisational, and UIC level barriers) and 'time-frames' (short-term, medium-term, and long-term barriers).

A qualitative study was conducted to substantiate the results of the literature review regarding barriers to UIC, to ensure that no regional specific barriers exist, and to identify measures that could be adopted to improve UIC. The study confirms that, despite clear benefits, UIC faces many barriers such as cultural differences, lack of visibility of university research, and lack of collaboration mechanisms. The study also provided insights into possible approaches to overcome these barriers. It emphasised the role of universities, and identified some measures that can be adopted by universities to bridge the gap and improve collaboration. These include a more proactive role for universities in improving the adoption of university research by demonstrating its applicability, establishing a collaborative platform, and education and awareness among researchers regarding business needs and constraints.

In the following chapter, I propose a novel framework for evaluating and improving UIC, which will, in part, help to overcome the barriers identified in this chapter.

Chapter 5

A Framework for Improving University-Industry Collaboration

'A problem never exists in isolation; it is surrounded by other problems in space and time. The more of the context of a problem that a scientist can comprehend, the greater are his chances of finding a truly adequate solution' - Attributed to Russel L. Ackoff

In Chapters 2 and 4, I established the importance of University-Industry Collaboration (UIC) and showed that, despite its many benefits, there are numerous challenges in establishing effective UIC. This thesis addresses these challenges by developing a framework that can be used by organisations to evaluate and improve their UICs. The aim of this chapter is to provide an overview of the entire framework in advance of its elaboration in later chapters.

This chapter begins by exploring the diversity of UICs, and how we can make sense of and deal with this diversity using the Cynefin sense-making framework. I then introduce the proposed UIC Framework along with a brief introduction to the following tools, which have been developed as part of the framework to help organisations evaluate and improve UICs.

- UIC Systems Model (Chapter 6),
- UIC Practices Framework (Chapter 7), and
- UIC Maturity Model (Chapter 8).

5.1 The nature of problems

A problem is considered to exist when there is an existing goal but the knowledge of clearly defined ways to reach that goal is unknown or lacking [Hayes, 2013; Fischer et al., 2012]. This means that a problem can be conceptualized as composed of a current given state, a desired goal state, and gaps or obstacles between the given and goal states [Mayer, 1992].

5.1.1 Simple problems

A problem is considered simple when the cause and effect relationship is known, and there are established practices or techniques that can be used to solve it.

5.1.2 Complex problems

While some problems can be solved using well understood and practised techniques, many are complex and more difficult to solve. These complex problems are characterized by the breadth of knowledge required to understand the situation, the level of difficulty in comprehending and applying the concepts involved in designing a solution, the level of knowledge and skills required to solve the problem, and the degree of non-linearity of the relations among the variables within the problem space [Jonassen and Hung, 2008].

5.1.3 Wicked problems

Wicked Problems are problems that are difficult to define clearly. They have many interdependencies and multiple causes. According to Head [Head et al., 2008], a wicked problem is 'inherently resistant to a clear statement of the problem and resistant to a clear and agreed solution'. They are distinguished by three key dimensions: (1) knowledge uncertainty, (2) value confict among multiple stakeholders and (3) dynamic complexity, in that they have no unique and final solution(s) or outcome(s) [Dentoni et al., 2018].

Given that wicked problems are difficult, and often impossible, to solve, I find Conklin's [Conklin,Jeff, 2007] viewpoint relevant that in the absence of clear and definitive solutions, you don't 'solve' a wicked problem specifically. Instead, you help stakeholders in developing and negotiating a shared understanding and meaning about the wicked problem and its possible solutions. In most cases, the best possibility is to try some measures that can improve the complex situation for a particular set of stakeholders or from a specific set of perspectives. The objective of the work in these situations is coherent action, not a final solution [Conklin,Jeff, 2007], which releases the manager of the problem from 'the impossible task of finding the one correct response' [Balint et al., 2011, pg 6].

Problems involving solutions that require change in the behaviours and mindsets of large groups of individuals are most likely to be wicked problems [Conklin,Jeff, 2007]. There may be numerous participants or stakeholders in such problems with a variety of cultural, educational and professional backgrounds, world-views, agendas, and responsibilities. The nature of the problem space is dynamic. Stakeholders such as individuals, organizations, or groups of people, may leave or join the problem space at any given point in time based on the impact of the wicked problem on them [Weber and Khademian, 2008]. In addition, an attempt to create a solution often results in changing the understanding of the problem [Rittel and Webber, 1973]. Classic examples of wicked problems include economic, environmental, and political issues such as climate change, drug trafficking, terrorism, population health and poverty.

5.2 UIC complexity

UIC complexity can vary from simple to chaotic. For example, a UIC such as 'organising a guest lecture' may be simple, and a 'joint research programme' may be complex.

UIC might, also, be considered a wicked problem, because:

- The intent of the UIC may be unclear.
- The context of the UIC may change over time.
- The UIC may involve many stakeholders with evolving and conflicting views that are difficult to resolve.
- Actions may have unintended consequences.
- Different actions will be required at different times.
- Actions may impact stakeholders in different ways.

A well-established approach is required to make sense of the varying complexity of UIC and to act appropriately when dealing with such variability.

5.3 Selecting an approach to dealing with UIC complexity

A suitable approach to dealing with UIC complexity should satisfy the following requirements:

- **R1.** The approach must recognise different types of problem complexity (eg. simple, complex and wicked) and that each type of complexity needs to be addressed using different approaches. This requirement recognises that a 'one size fits all' approach is inappropriate when dealing with UIC activities of varying complexity.
- **R2.** The approach must provide guidance in dealing with different types of complexity. This requirement will ensure that users can follow specific guidelines appropriate to UIC activities of varying complexity.
- **R3.** The approach should be well-documented and supported by on-line resources. This requirement will help users understand the approach and how it is used.
- **R4.** The approach should be widely used in diverse fields. This requirement will reduce any risk associated with applying the approach to UIC.

There are several approaches that support decision-making in complex environments. Some representative approaches that appear frequently in literature are:

- The Cynefin framework [Snowden and Boone, 2007],
- The Goals and Methods Matrix [Turner and Cochrane, 1993], and
- Stacey's matrix [Stacey, 1996].

Each of the above approaches were reviewed against the requirements stated above. These reviews resulted in the following findings:

- The Goals and Methods Matrix approach focuses on project management by categorising projects into four well defined types based on uncertainty around project goals and the methods used to achieve those goals (R1). While some guidelines for dealing with each type of project are provided, they are limited and focussed on project management techniques rather than providing a more general approach to problem solving and decision making (R2).
- The Cynefin framework and Stacey's matrix focus on problem solving and are similar approaches in many respects. They both recognise varying levels of problem complexity (R1) and provide effective guidelines for dealing with such problems (R2).
- The Cynefin framework presents clearer strategies for dealing with different levels of complexity (R2) than the other two approaches as elaborated in Section 5.3.2.

- The Cynefin framework is well supported by on-line resources (R3) as elaborated in Section 5.3.3.
- The Cynefin framework has been applied in a broad range of domains (R4) as elaborated in Section 5.3.4.

Based on the above findings, the Cynefin framework was selected as an appropriate and practical approach for dealing with UIC complexity.

5.4 The Cynefin sense-making framework

The **Cynefin Framework** [Snowden and Boone, 2007], depicted in Figure 5.1, is a framework used to make sense of problems. It can guide us in assessing a situation and responding by using thinking and approaches that are most appropriate to the current situation.

This section provides an overview of the Cynefin Framework in terms of how it satisfies the requirements described in Section 5.3.

5.4.1 Satisfaction of R1 - Recognition of problem domain.

The Cynefin framework comprises the five problem domains depicted in Figure 5.1 and described below. Three of these domains recognise the different types of problem discussed in Section 5.1 - Simple, Complicated, and Complex (Wicked). At any point in time, a given problem will fit into one of these domains and is best dealt with using thinking appropriate to the domain.

As problems are considered in a particular domain and understanding improves, problems may move to new domains where different thinking is required. This movement is usually in a clockwise (Figure 5.1) direction towards the simple or obvious domain.

- **Simple or Obvious.** This is the domain of 'known knowns', where the relationship between cause and effect is obvious to most people. There exists a well-established or accepted best practice to achieve a solution for such problems. Examples of simple problems include scholarship selection, loan-payment processing, accounting problems.
- **Complicated.** This domain of 'known unknowns' is also referred to as 'Knowable', where cause and effect relationships exist, but can only be understood through analysis, some form of investigation, and/or application of expertise. There is a possibility of multiple applicable solutions for problems within this

domain. Examples of complicated problems include building aircraft, taxation, and surgery.

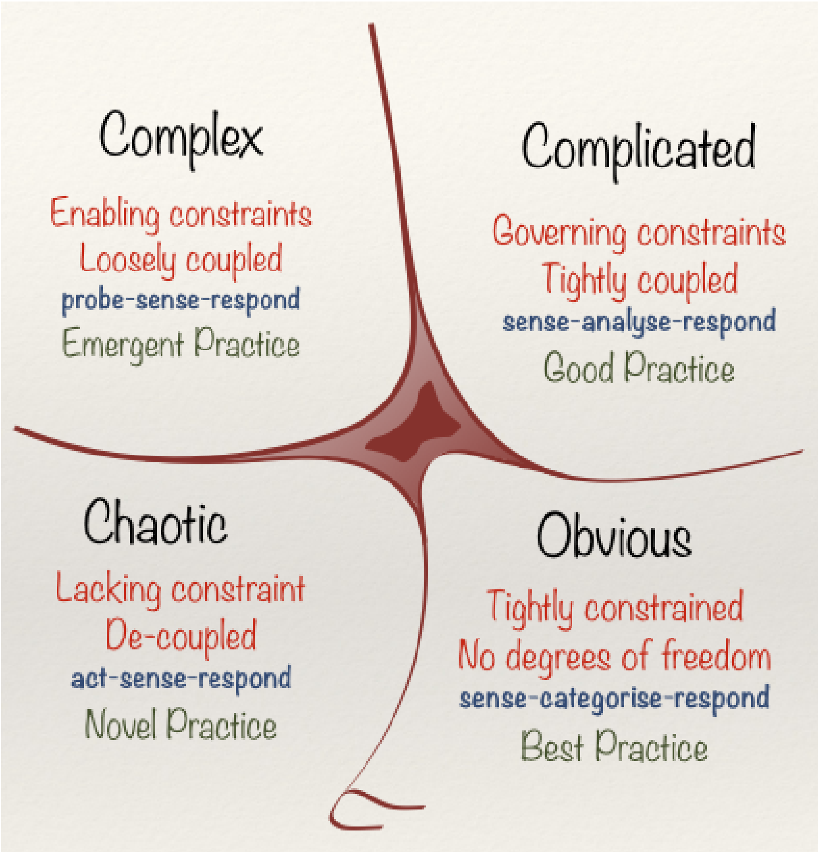

Figure 5.1: Domains of the Cynefin framework; the dark domain in the centre is disorder. [Snowden and Boone, 2007]

- **Complex.** This domain of 'unknown unknowns' is signified by an inability to predict relationships between cause and effect in advance. They can only be perceived in retrospect. There may not be one right solution. Examples of complex problem domains include economics, criminal justice, and war.

- **Chaotic.** In this domain, there is no clear relationship between cause and effect. Chaotic situations evolve rapidly and often have significant negative impact. There is no time to probe the problem as in the Complex domain or to carry out expert analysis as in the Complicated domain. However, something needs to be done to restore order and move the problem to one of these more manageable domains. Examples of chaotic problems include terror attacks, natural disaster, economic crisis, and pandemics.

- **Disorder.** Problems are in this central domain when it is not clear which of the other domains apply, and there is lack of consensus due to the domain being viewed differently from the perspective of different stakeholders.

5.4.2 Satisfaction of R2 - Guidance for dealing with each type of complexity.

The value of the Cynefin framework lies in the fact that it acknowledges the varying complexity arising out of a situation, and discards a uniform approach to all situations. Instead, it proposes the use of different approaches in each of the four Cynefin domains as described below.

1. **Simple or Obvious.** The recommended approach to thinking in this domain is to:

   - **Sense** - Establish the facts related to the problem situation.
   - **Categorize** - Organize these facts into known categories.
   - **Respond** - Apply well-established best practices or solutions for the category.

   The above approach is recommended as the problems within this domain are familiar to most people due to their repeated occurrence. They have gained sufficient understanding of the cause and effect relationships involved by learning from these repetitions [French, 2013]. Their understanding and prior experience have generated a set of standard responses and an ability to predict the consequences of any action. That is, they have developed a set of best practices, which can be applied to solve such problems.

2. **Complicated.** The recommended approach for this domain is to:

   - **Sense** - Establish the facts related to the problem situation.
   - **Analyse** - Experts analyse the available data and identify possible solutions. They then use their knowledge to recommend the most suitable solution.
   - **Respond** - Apply the solution recommended by the experts.

   The above approach is recommended because expertise is required to understand the cause and effect relationships involved and to make appropriate decisions regarding solutions. The consequences of any action cannot be predicted with certainty. Experts need to gather data to gain better understanding of the situation, analyse that data in order to identify suitable responses, and apply expert knowledge to respond with the most suitable solution with some predictable consequences.

3. **Complex.** The recommended approach in this context is to:

    - **Probe** - Explore the problem domain by designing experiments to uncover patterns, and gain more knowledge.
    - **Sense** - During experimentation observe patterns and results.
    - **Respond** - On the basis of the information gathered through experimentation encourage more of what works and discourage what does not work. Continue this process of experimentation to discover emerging solutions until a satisfactory solution is discovered.

    The above approach is recommended because the cause and effect relationships involved in complex problem environments can only be understood in retrospect. In such environments, experimentation is required to learn what practices work (i.e. have a positive effect on the problem) and what practices don't work. This experimentation needs to be designed in such a way that it doesn't make the situation worse and can be continued until a satisfactory solution is found. This may lead to finding practices that will help move the problem to one of the ordered domains (complicated or simple).

4. **Chaotic.** The recommended approach in this context is to:

    - **Act** - The immediate requirement in this domain is to act quickly to contain the situation.
    - **Sense** - After achieving a controlled state, assess to find patterns.
    - **Respond**- Respond with actions, which will move the problem from chaotic to the complex or complicated domain.

    The above approach is recommended because it limits further impact of the problem in order to give stakeholders the time required to transform the problem to complex or complicated.

5. **Disorder.** The unknown causality in this domain makes it difficult to know which methods will work well. Problems in this domain are considered harmful and need to be moved to one of the other four domains. The main goal in this situation is to gather more information. One way to deal with a problem in this domain is to breakdown the situation into its constituent parts and assign each part to one of the other four domains.

5.4.3 Satisfaction of R3 - Documentation and support

The Cynefin framework is one of the most well-known and comprehensively developed models for dealing with varying levels of complexity [Browning and Boudès, 2005]. It is well-documented and supported by online resources including those provided by Cognitive Edge [Cognitive Edge, 2005].

5.4.4 Satisfaction of R4 - Broad adoption

The Cynefin framework has proven its broad applicability in areas such as health promotion [Van Beurden et al., 2011], process model deployment in different business environments [Lepmets et al., 2014], selection of software development approaches [O'Connor and Lepmets, 2015], dealing with the challenges of electronic records management [Childs and McLeod, 2013; McLeod and Childs, 2013], and managing cybersecurity risk [Dykstra and Orr, 2016].

5.5 The proposed UIC Framework

In the previous section, the Cynefin framework was presented as an effective approach to thinking about UIC. It was noted that particular collaborations will sit in different domains depending on their complexity. In addition, in Section 5.4.2, it was noted that different kinds of thinking is required in each of the Cynefin domains.

In order to help stakeholders make sense of varying levels of UIC complexity and improve them, a novel framework is proposed consisting of the following tools to be used in conjunction with the Cynefin sense-making framework to analyse, evaluate and improve the effectiveness of UIC. The tools are described in detail in subsequent chapters of this thesis.

- **A UIC Systems Model.** A UIC Systems Model has been developed to clearly define the concepts involved in UIC and the relationsips between them. That is, it defines a 'language' that can be used to describe and discuss UICs.

  This model can be used to help stakeholders better understand UICs. It can be used to understand the purpose of a collaboration within its environment, the nature of such environments (including barriers), the elements involved (such as people, organisations, equipment, facilities, IP and finance), how all of these things are related, and importantly, how they evolve over time.

  This UIC Systems Model can be used to identify the appropriate Cynefin domain for each aspect of a given UIC.

  The UIC Systems Model is described in Chapter 6.

- **A UIC Practices Framework.** A UIC Practices Framework has been developed to provide a comprehensive set of practices that can be used by stakeholders to overcome barriers and enable success factors relevant to a UIC. Such application of practices is expected to improve effectiveness of UICs.

  The UIC Practices Framework framework can be used by experts to improve collaboration in the complicated or simple domains of the Cynefin Framework. It can also be used to guide the design of experiments to understand collaborations in the complex domain. Experimental results may identify effective practices thus allowing us to move to the complicated domain. Experiments may also identify new practices that can be added to the UIC Practices Framework.

  The UIC Practices Framework is described in Chapter 7.

- **A UIC Maturity Model.** A UIC Maturity Model (UICMM) has been developed, which can be used by experts to assess the maturity of an organization's UIC efforts, and guide their improvement. Such an assessment would fall into the complicated domain. In the complex domain, the UICMM can also be used to guide the design of experiments for improving collaborations along with helping structure the evaluation process.

  The Maturity Model is described in Chapter 8.

5.5.1 Application of the proposed UIC Framework

The proposed UIC Framework is applied using an iterative process comprising the following steps.

- Describe the UIC using the UIC Systems Model and UIC Practices Framework.
- Identify the activities required to complete the UIC.
- Allocate activities to appropriate Cynefin domains.
- Complete each activity in accordance with the recommended Cynefin approach and using applicable UIC Framework tools.
- Review progress and iterate, if required.

The process is fully described and demonstrated in Chapter 9 using example scenarios in a range of different UIC contexts. The examples provided help increase understanding of the process and illustrate the potential of the proposed UIC Framework as a tool for practical application by universities and industry.

Note that the proposed UIC Framework offers flexibility in its application. The tools within the framework can be used within the process elaborated in Chapter 9, or on their own. For example, if an organisation intends to assess their UIC maturity, they could use the UICMM as a stand-alone tool.

5.5.2 Evaluation and improvement of the proposed UIC Framework

As described in Chapter 3, a two-phase evaluation approach is adopted to evaluate the proposed UIC Framework. The scenarios presented in Chapter 9 serve as Phase One descriptive evaluations that establish the utility and applicability of the proposed framework. Chapter 10 presents details of a strategy for future real-world evaluation and improvement of the framework in Phase Two.

5.6 Conclusion

In this chapter, I have outlined a proposed UIC Framework for evaluating and improving UIC. The framework is based on use of three tools to support thinking and action within each domain of the Cynefin sense-making framework.

The UIC Systems Model can be used during the formation of a UIC to improve understanding of the UIC context.

The UIC Practices Framework can be utilised to improve effectiveness of UICs by identifying and applying appropriate practices.

The UIC Maturity Model can be used to evaluate and improve UICs by assessing an organisation's UIC maturity and identifying areas for improvement.

The next three chapters describe the UIC Systems Model, the UIC Practices Framework, and the UIC Maturity Model.

Chapter 6

A University-Industry Collaboration Systems Model

6.1 Introduction

This chapter describes a UIC Systems Model, the first of three tools that can be used in conjunction with the Cynefin Framework to understand and improve UIC.

The chapter starts with an introduction to Systems Thinking, an approach that can be used to understand and improve systems. I then identify UIC as a 'System' and present a proposed UIC Systems Model, which defines a 'language' for describing UICs. This model aims to help stakeholders better understand UICs. The model has been evaluated for its validity as described in Section 6.7. Its evaluation in a real-world setting is part of future work as detailed in Chapter 10.

The chapter concludes with an overview of how this UIC Systems Model can be used as a standalone tool, or in conjunction with the Cynefin framework to understand and improve UIC. A complete description of such usage is provided in Chapter 9.

6.2 Systems Thinking

This section intends to help in developing an understanding of Systems Thinking (ST). It aims to introduce Systems Thinking as a basis for establishing the need to treat UIC as a 'system' and development of a UIC Systems model. It does not provide an exhaustive coverage of the field. Instead, it focuses on those key aspects of ST that are relevant and applicable to UIC. Readers who are not familiar with ST may find the following works interesting and useful to gain further understanding of the field:

- Systems Thinking, Systems Practice [Checkland, 1999],

- Systems Concepts in Action: A Practitioner's Toolkit [Williams and Hummelbrunner, 2010].

6.2.1 What is Systems Thinking

Systems thinking is a discipline that emphasises a holistic view of a system, with a focus on interrelationships within and outside the system, and emerging patterns based on dynamic cause and effect, in order to understand the behaviour of complex systems and identify measures to improve their performance.

There has been no significant change in fundamental systems ideas over the years and 'the systems approach' continues to include the following:

1. 'Viewing the situation holistically, as opposed to reductionist view, as a set of diverse interacting elements within an environment.

2. Recognising that the relationships or interactions between elements are more important than the elements themselves in determining the behaviour of the system.

3. Recognising a hierarchy of levels of systems and the consequent ideas of properties emerging at different levels, and mutual causality both within and between levels.

4. Accepting, especially in social systems, that people will act in accordance with differing purposes or rationalities' [Mingers and White, 2010].

6.2.2 What is a system

In this section, a picture is developed of what a system is by discussing the following key perspectives:

- System Structure and Purpose

- System Boundaries - Open and Closed Systems

- System Complexity

- System Types

It is acknowledged that this is not a complete list and that there may be other perspectives. However, these perspectives have been selected as they are relevant and applicable to UIC as described in this section. They provide an adequate basis for establishing the characteristics of a system and recognizing UIC as a system.

6.2.2.1 System structure and purpose

There are various definitions of system. In simple terms, 'a system can be defined as a group of interacting, interrelated, or interdependent parts that form a unified whole having a specific purpose' [Kim, 1999].

Ackoff [Ackoff, 1999] provides a more comprehensive definition of a system as an entity with the following properties:

1. **Function** - A system as a whole is defined by its purpose or function(s) in one or more of its containing systems. For example, universities are systems that undertake education and research within the higher education system, as well as the broader socio-economic system.

2. **Components** - A system comprises at least two parts that are required for the system to maintain its defining properties or achieve its defining functions. These 'essential' parts must satisfy the following conditions.

   (a) The components of a system can affect the behaviour or properties of the system. This means that changes in the behaviour of individual parts will cause a change in the behaviour of the system as a whole. If we can take away any component from a system without affecting the system's behaviour, it can not be considered a system but rather just a collection of parts. For example, a motivated researcher can be viewed as a component of a research group, which is a system. The individual behaviour of this researcher will have an effect on the behaviour of the group.

   (b) There are dependencies between the parts. The effect of the properties or behaviour of each essential part depends on the behaviour or state of at least one other part of the system. For example, properties and behaviour of the teaching and research department in a university are affected by the behaviour and properties of the finance department.

   (c) Subsystems or groups of essential parts also can affect the properties and behaviour of the whole system. This means that the essential parts of a system are interconnected. However, no essential part can effect the whole independently as its effect depends on at least one other essential part outside the group. For example, a university's performance is affected by the behaviour and properties of teaching and research department, whose behaviour is affected by the behaviour and properties of the finance department.

The above properties can be summarised as: A system as a whole cannot be taken apart without losing its essential properties or its ability to carry out its defining functions. The defining function of the system cannot be carried out by any part of the system independently.

6.2.2.2 System boundaries - open and closed systems

A key characteristic of a system is its boundary. The boundary of a system denotes the scope of interest or concern of the system and separates it from its environment. The environment refers to a set of entities outside a system that influences the system and is influenced by the system [Kramer and De Smit, 1977].

An 'Open' system is one in which the parts of a system interact with the surrounding environment. There is an inflow and outflow between the system and its environment [Von Bertalanffy, 1956, pg.39]. Such systems take inputs from their environment and transforms them into desired outputs, which have an effect on the system as well as its environment [Sheffield et al., 2012]. For example, a university is a system with a defined boundary. While there are many interactions occurring between the parts of academia such as students, researchers and teachers, there are also interactions with the external environment including businesses and government organizations. Hence, a university is an open system.

A 'Closed' system is considered to be operating in isolation from its environment [Von Bertalanffy, 1956, pg.39]. That is, there is no interaction between the system and its environment. All the interactions happen within a specific system. Any changes within the environment do not have any influence on the operation of the closed system. In general, the concept of closed system is rarely applicable to real-world systems such as UIC.

6.2.2.3 System complexity

Systems can be described in terms of their complexity. However, there is a lack of consensus regarding the definition of complexity. For example, according to Sheffield et al. [Sheffield et al., 2012], as the number of parts and their interactions increase, so does the system's complexity. They group systems into four types based on the number of components and interactions among them as depicted in Figure 6.1.

Other authors view complexity in terms of uncertainty or unpredictability [Vidal and Marle, 2008; Snowden and Boone, 2007; Stacey, 1996]. Stacey used the degree of certainty and the level of agreement among stakeholders to analyse complexity [Stacey, 1996]. Vidal and Marle [Vidal and Marle, 2008] define complexity as the property that makes it difficult to understand, predict, and have control over a system's behaviour. They identify four necessary but non-sufficient conditions for system complexity as size factors, variety, interdependencies and interrelations

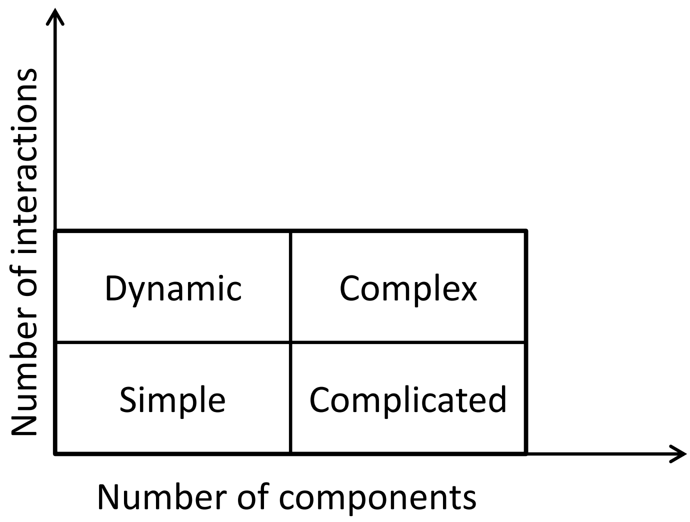

Figure 6.1: Types of systems and projects

within the system, and context-dependence. In the Cynefin framework [Snowden and Boone, 2007], complexity is discussed in terms of predictability as a relation between cause and effect. When cause and effect within a system is clear, the system is considered to be 'simple', and when it is not clear, a system is considered to be 'complicated'. When cause and effect is not predictable, a system is considered to be 'complex'.

These two views of complexity conflict. For example, a modern processor chip with billions of transistors and connections would be categorized as complex according to Sheffield et al. [Sheffield et al., 2012]. However, according to the alternative view, it would more appropriately be treated as complicated because, despite the large number of parts and interactions, its behaviour is predictable. As another example, Sheffield et al. [Sheffield et al., 2012] would classify relationships between two humans, involving fewer components but possibly higher interactions, as dynamic. However, such relationships are very often unpredictable and would be complex according to [Vidal and Marle, 2008; Snowden and Boone, 2007; Stacey, 1996].

As discussed in Chapter 5, in this thesis the Cynefin framework is adopted as a model for making sense of problem complexity. That is, the complexity of a system is defined in terms of predictability. Hence, complex systems are those in which behaviour cannot be predicted by observing the parts of a system and how they interact.

6.2.2.4 System types

There are many ways to categorize systems. The following examples, relevant to the discussion of UIC, illustrate this diversity:

- **Social Systems -** A social system is a system involving interactions and functional relationships among several individuals according to a pattern in order to achieve a goal. To gain an understanding of the performance of a social system, the system classification presented by Ackoff as shown in Table 6.1 is useful [Ackoff and Gharajedaghi, 2003]. This classification is based on the ability of the parts of a system or whole to make a choice. These choices lead to certain behaviour and results that impact the performance of a system.

  According to this classification UIC is a social system, in which the choices are made by the two parts (university and industry) individually as well as a whole, which influence the performance/effectiveness of UIC.

Table 6.1: Types of System

System	Part	Whole	Example
Deterministic	No choice	No choice	Machine
Ecological	Choice	No choice	Nature
Animate	No choice	Choice	Person
Social	Choice	Choice	Healthcare

- **Natural and Designed Systems -** According to Checkland, there are five classes of system [Checkland, 1981]. Two major types of systems are categorized as *Natural Systems* and *Designed Systems*. Natural systems can be investigated and described by man for the purpose of deeper learning and understanding. Designed Systems include three types of systems created by humans: *designed physical systems*, *designed conceptual systems*, and *human activity systems*. The fifth class of systems, *transcendental systems*, include the systems that are beyond human knowledge. UIC belongs to the category of Designed systems, specifically human activity systems, as described below.

- **Human Activity Systems -** An important type of designed system is the Human Activity System. These systems are assemblies of people and set of activities linked together as a whole in order to pursue and accomplish a purpose [Checkland and Holwell, 1998]. UIC is a Human Activity system consisting of various stakeholders and other components interoperating for a specific purpose.

6.3 UIC as a system

The word collaboration derives from the latin *com* and *laborare* - meaning labor together. Collaboration is 'the coming together of diverse interests and people to achieve a common purpose via interactions, information sharing, and coordination of activities' [Jassawalla and Sashittal, 1998]. The main idea is that by collaborating, people combine their ideas, expertise, abilities, insights, and resources in order to perform a group activity, and accomplish more than they could achieve as separate individuals [DeMarco and Lister, 2013; Dean et al., 2006].

Within the context of this thesis, I define University-Industry Collaboration (UIC) as:

> a joint effort and relationship between a university and industry involving people, sharing of resources, and coordination of activities to achieve a common purposeful objective.

In Section 6.2.2, the concept of 'System' is described from various perspectives. Based on this discussion, UIC can be considered as a system. Specifically:

(a) **UIC comprises interacting components** (Section 6.2.2.1). UIC comprises interactions among universities, industry, projects and many other components [Rossi and Rosli, 2015; Keast and Mandell, 2014; Acworth, 2008]. The behaviour or properties of a UIC (as a system) depend on the behaviour or properties of its components, which themselves rely on the behaviour or properties of other components within the UIC.

(b) **UIC has purpose** (Section 6.2.2.1). UICs have varied purposes, including the creation of new knowledge, and education [Hughes and Kitson, 2012; Kaymaz and Eryiğit, 2011].

(c) **UIC is an open system** (Section 6.2.2.2). The components of a UIC interact with their environment that includes business, governments, and legal regulations, which influence the UIC as a whole [Galan-Muros and Davey, 2017].

(d) **UIC is often a complex system** (Section 6.2.2.3). UIC is considered to be a complex adaptive system with universities and industry as its interconnected subsystems [Metcalfe, 2010]. There are multiple stakeholders with a diversity of perspectives interacting within the system [Galan-Muros and Davey, 2017; McCabe et al., 2016; Acworth, 2008], which, in many cases, makes it difficult to predict the system behaviour.

(e) **UIC is a Human Activity System** (Section 6.2.2.4). UIC is a system consisting of various human stakeholders and other components interoperating for a specific purpose [Keast and Mandell, 2014; Acworth, 2008].

6.4 The UIC Systems Model

This section presents a proposed UIC Systems Model, a key component of the overall approach to evaluating and improving UIC presented in this thesis. A model is defined as 'a schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics' (dictionary definition as per [Rood, 2007]). For the purpose of this research, 'model' indicates a conceptual model, herein of UIC.

6.4.1 Model purpose

A model is created for a purpose and the purpose here is to:

- provide a language for describing and discussing UICs by defining the elements of UIC and how they interact to form a system.
- facilitate deeper understanding of UIC.

6.4.2 Modelling approach

Modelling refers to the process of creating a model to represent something physical, abstract or human.

Because the purpose of the UIC Systems Model is to provide a language for describing and discussing UIC, the researcher chose to describe elements of UIC and the relationships between them using a formal language. Specifically, the researcher chose to model UIC using a Unified Modelling Language (UML) [OMG, 2007] Class model. Such models have been used successfully for many years to formally describe a broad range of subjects.

6.4.2.1 Modelling notation

Unified Modelling Language (UML) Class models are usually represented using UML Class Diagrams. The Class Diagram for the UIC Systems Model is depicted in Figure 6.2.

The boxes in the diagram represent classes of UIC system elements. The name of each class and the attributes that characterize members of each class are written inside the boxes. For example, all of the organizations involved in a UIC are represented by the ***Organization*** class. Each one of these organizations is characterized by two attributes - the 'name' of the organization and its 'location'. Similarly, all ***barriers*** that restrict collaboration between stakeholders, are represented by the ***Barrier*** class. Each barrier is characterized by a 'name' and a 'description'.

The lines between the classes represent associations between members of classes. These associations are annotated with phrases, which describe the nature of the associations, and multiplicities (number ranges) that describe how many members of a particular class can be associated with members of another class.

The meaning of the multiplicities is as follows:

- 0..1 - zero or one.
- 1..1 - exactly/always one.
- 0..* - zero or more.
- 1..* - at least one.

The best way to read the class diagram is to form sentences from class names, association phrases and multiplicities. For example, parts of Figure 6.2 can be read as follows.

- ***Benefit*** - *motivates - zero or more* - ***Stakeholders***.
- ***Stakeholders*** - *follow processes to complete - zero or more* - ***UIC Activities***.
- ***Barriers*** - *restricts collaboration between - zero or more* - ***Stakeholders***.
- ***UIC Activities*** - *contribute to the delivery of - at least one* - ***UIC Outcome***.

Reading the model in this way describes the language of UIC.

6.4.2.2 Model evolution

During development of the UIC Systems Model, the use of a formal language encouraged deep thought. As the model evolved and was used in Chapters 9 and 10, its formal nature generated much discussion around the elements to be included or excluded and, in particular, the nature of relationships between them. An example of this was the late addition of the ***process*** concept and associated relationships between ***process***, ***practice***, ***stakeholder*** and ***UIC Activity*** as described in Section 6.4.3.

The researcher considers the version of the UIC Systems Model depicted in Figure 6.2 to be a solid basis for the work presented in this thesis and future refinement as it is used during real-world evaluation and improvement of the UIC Framework discussed in Chapter 10.

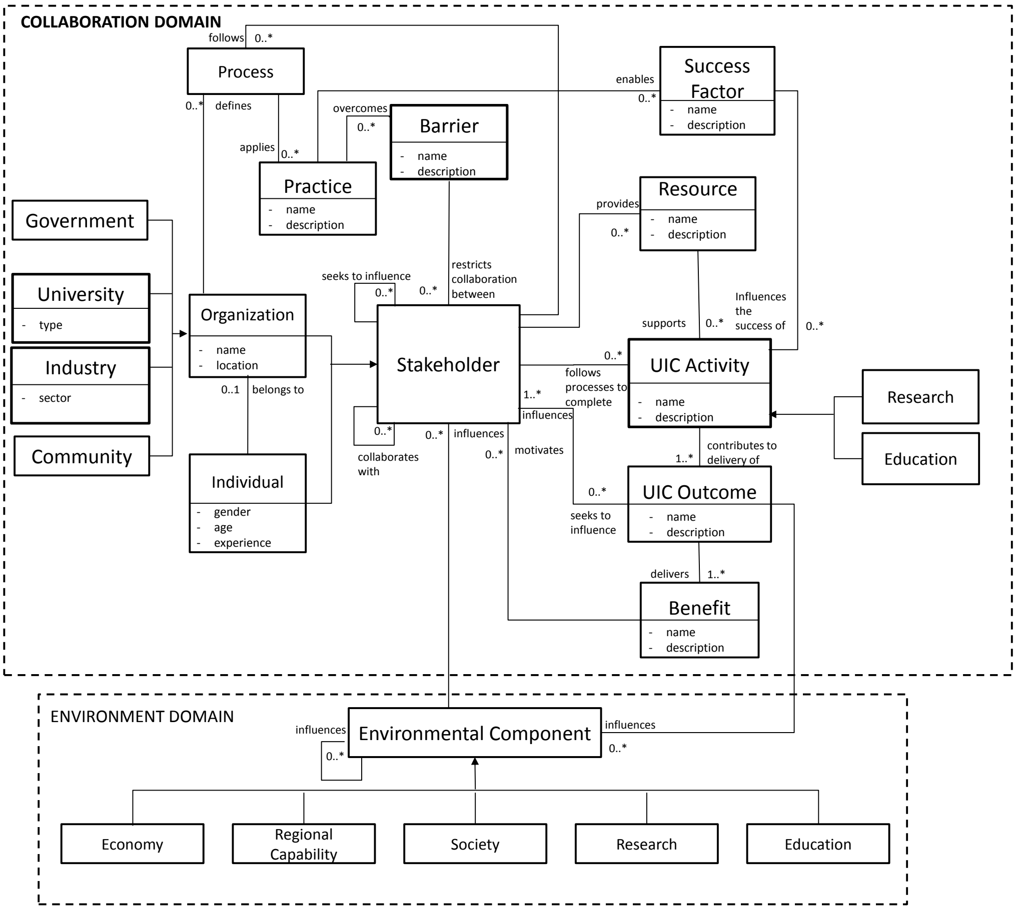

Figure 6.2: University-Industry Collaboration Systems Model

6.4.3 Elements of the UIC Systems Model

The proposed UIC Systems Model is based on the material presented in Chapters 2 and 4. It comprises two domains: the collaboration domain and the environment domain, as described below and depicted in Figure 6.2.

6.4.3.1 Collaboration Domain

This domain represents the collaboration system and includes the following classes:

- **Stakeholders.** These are ***individuals*** or ***organizations*** that are involved in, or are impacted by collaboration. Based on the Triple Helix model [Etzkowitz and Leydesdorff, 2000], organizational stakeholders in collaboration broadly include ***universities***, ***industry,*** and ***government***. Other examples of ***stakeholders*** include TTOs, Research Collaborations Offices, legal office, etc. These stakeholders are expected to directly engage in some form of collaboration in order to derive its various benefits.

Realizing the ***benefits*** of UIC, government *seeks to influence* universities and industry to engage in more UICs. That is, the government is taking measures to encourage UIC as discussed in Section 2.1.6. On the other hand, University and Industry *seek to influence* government, which means they have an impact on the decision-making of government regarding UIC.

Universities and Industry also *seek to influence* each other. For example, universities influence industry by providing resources such as access to advanced expertise and equipment. Industry influences universities by providing funding, research inputs such as interesting problems, and creating workforce need.

While universities, industry and government are stakeholders directly involved in UIC, there are other individuals and organizations, referred to here as Community, that are directly or indirectly influenced by UIC but are not directly involved.

- **Benefits.** UIC ***outcomes*** *deliver benefits* for universities, industry, and society as discussed in Chapter 2. These ***benefits*** are expected to *motivate* ***stakeholders*** to engage in various types of collaborations.

- **UIC Activity.** UICs require the completion of a broad set of ***UIC activities***. An activity, here, refers to a task that needs to be completed as part of the UIC. For example, agree on IP, order equipment, recruit a post doctoral fellow, exchange information. Stakeholders *follow processes to complete* such ***UIC activities***, which, in turn, *contribute to the delivery* of ***UIC outcomes***.

- **Barriers.** Despite its ***benefits***, establishing effective UIC is challenging. ***Barriers*** are the factors that act as impediments and *restrict collaboration between* ***stakeholders***. ***Barriers*** are described in Chapter 4.

- **Success factors.** These are the factors that enable or positively *influence the success* of ***UIC Activities*** leading to effective collaborations. ***Success Factors*** are discussed in Chapter 7 (Section 7.2).

- **Practices.** A ***practice*** is a well-articulated specific action, or measure taken within an organization to *overcome* ***barriers*** and/or *enable* UIC ***success factors***.

  In this thesis, ***practices*** include the approaches to improving UIC described in Chapter 4 (listed in Table 4.3 and described in Section 4.3) and the practices described in the UIC Practices Framework presented in Chapter 7.

- **Process.** ***Stakeholders*** *follow processes to complete* ***UIC Activities***. They are often described in documents or represented as step-by-step procedures. They may also be implemented using online tools such as form processing systems.

  An important aspect of ***processes*** is that they are usually designed to *apply* ***practices*** that *overcome* specific ***barriers*** and/or *enable* specific ***success factors***.

- **Resources.** ***Resources*** *support* the ***UIC Activities***. They include finance, space, equipment, human resources, skills, and expertise. The availability of such resources *support* ***UIC Activities*** which *contribute to delivery of* UIC ***outcomes***.

- **UIC Outcome.** This refers to the results of UIC, which should be ideally articulated clearly as objectives at the beginning of a collaboration. Successful collaborations achieve valuable outcomes for universities and industry. The ***UIC Outcomes*** are expected to *deliver* the ***benefits*** that motivated the UIC.

  UIC Outcomes influence existing and future collaborations through feedback because successful collaboration will have a tendency to lead to more UICs in the future.

  UIC Outcomes are also expected to influence the environment in which collaboration is operating by producing results that are useful within the environment. For example, outcomes related to education can be a future-ready workforce. The workforce will in turn influence the environment, which includes society to which the workforce belongs, the region's capability that includes a skilled workforce, and the economy to which the workforce contributes through their professional work.

6.4.3.2 Environment Domain

This domain represents the Environment within which a UIC operates. It includes the following elements:

- **Economy.** The Economy encompasses all the activities related to production, consumption, and trade of products and/or services.

- **Regional Capability.** This is a region's ability to provide, enable, and utilize the resources required for social and economic development of the region. Within the context of this research, the capability specifically means the availability of resources to encourage collaboration and facilitate their effectiveness within a geographic region. Research, education, community, and outcomes of UIC influence this capability of a region.

- **Society.** A society, here, refers to a large group of people belonging to a geography under consideration. Individuals engaging in a UIC belong to a society, which means society influences UIC. On the other hand, ***UIC Outcomes*** may influence individuals in a society to engage in UICs or create a skilled workforce that can play a positive role in effective UICs.

- **Research.** This includes activities aimed at creation or discovery of new knowledge, and sharing knowledge for solving problems. UICs influence research by providing opportunities for faster knowledge creation, validation of that knowledge, gaining feedback to influence future research, and identifying commercialisation opportunities.

- **Education.** This encompasses activities aimed at knowledge dissemination and skills enhancement in an educational institution, including the learning experience gained through UICs and influence on the curriculum design.

As shown in the model, outcomes of a UIC influence the economy, regional capability, society, research, and education within its operating region. The economy is impacted by the creation of new products and skilled work-force through UICs. The economy, in turn, has an effect on the availability of resources for UICs. UICs seek to influence education in multiple ways such as increasing understanding of academics about industry requirements leading to influence on curriculum that is better aligned with industry needs, and creating future-ready workforce as discussed in Section 2.2. The workforce will in turn influence the environment, which includes society to which the workforce belongs, the region's capability that includes a skilled workforce, and the economy to which the workforce contributes through their professional work. UICs influence society in terms of impact on human resources, opportunities, and the economy.

6.5 Discussion

A UIC Systems Model defining the elements of UIC and the relationships between them has been presented. In this section, I will discuss related work.

The studies discussed in this section ([Rybnicek and Königsgruber, 2019; Galan-Muros and Davey, 2017; Fateh Rad et al., 2015]) represent the efforts parallel to this research as they were conducted during the same time-period as this research and study UIC, the topic of this research. They also adopt a similar view of considering UIC as a system. These parallel efforts indicate the importance of the research presented in this chapter.

A comparison between the proposed UIC Systems Model and the UBC ecosystem framework [Galan-Muros and Davey, 2017] shows that they are similar in terms of bringing together various aspects of the UIC ecosystem, which are fragmented across the literature. Both of these works make a theoretical contribution to the UIC field of study by providing mechanisms for improving the understanding of UIC. The 'supporting mechanisms' within the UBC ecosystem framework are ***practices*** in the proposed UIC Systems Model. The UBC ecosystem framework studies the UBC context (Environment domain in the UIC Systems Model) in detail, which is not part of the detailed analysis in this thesis. However, it is acknowledged that the environment will influence the UIC process and vice-versa as indicated by the 'Environment Domain' in the UIC Systems Model. The UBC ecosystem is the most comprehensive model of UIC the researcher has come across.

While the UBC ecosystem framework contributes to the understanding of different aspects relevant to UIC, it does not explicitly recognize the type of relationships between these aspects in the framework presentation. The proposed UIC Systems Model provides a formal language of UIC (including relationships), which can be used to more formally describe UICs as demonstrated in the scenario descriptions in Chapter 9.

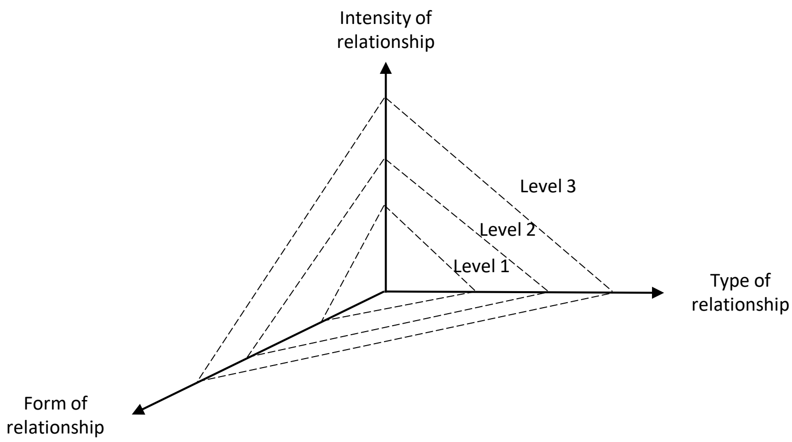

Figure 6.3: Three axes of relationship in UIC (Adopted from [Fateh Rad et al., 2015])

Another work [Fateh Rad et al., 2015] is similar to the work presented in this chapter in terms of the lens (systems thinking) adopted to study UIC. One of the valuable contributions of the work is the static three-dimensional model used to depict the organization of UIC as depicted in Figure 6.3. The three dimensions are 'type of relationship', 'form of relationships', and 'intensity of relationship'. The type of relationship includes education relationships, research relationships, and innovation-leading

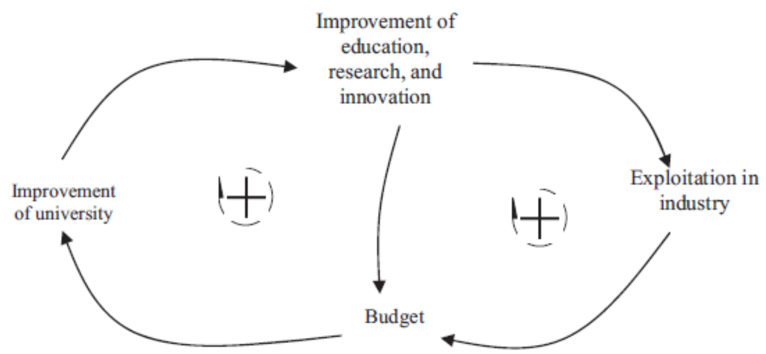

Figure 6.4: Synergy model of collaboration between industry and university (Adopted from [Fateh Rad et al., 2015])

relationships. The form of relationship can be individual, project, and organisational. The intensity of the relationship grows from limited interaction, independent partners to dependent partners. This model is valuable for understanding that these three dimensions are interconnected with strong relationships among them. If one of the dimensions is changed, it will have an influence on the other two dimensions. The understanding of such influences is useful when an organisation is considering increasing the level of collaborations.

Fateh Rad et al. [Fateh Rad et al., 2015] also presented a synergy model of collaboration between university and industry as depicted in Figure 6.4. The model captures UIC from a financial (budget) perspective. While, 'finance' is identified as one of the most important benefits for universities (Section 2.2), there are several other aspects of collaboration that can not be overlooked such as the benefits relating to the relevance of research, and barriers such as cultural barriers. Hence, the Synergy model has limitations regarding the range of aspects considered.

Rybnicek and Konigsgruber [Rybnicek and Königsgruber, 2019] have presented a conceptual model of factors influencing the success of UIC. The model is based on an extensive review of research published on UIC. It categorizes success factors into four categories: institutional factors, relationship factors, output factors, and framework factors. Like [Fateh Rad et al., 2015], this model has a limitation regarding the range of aspects considered as it mainly focuses on success factors.

The proposed UIC Systems Model shows that UIC is influenced by multiple factors such as benefits, barriers, practices, and resources. We need to understand and identify the factors that have the greatest influence in a given UIC context. Addressing the relevant factors by applying appropriate practices is expected to create desired outcomes. The inter-connections within the model indicate that practices will have an impact on factors that are not directly addressed by them. For example, a practice applied to enable a success factor may help to overcome a barrier.

To summarise, the Systems Model presented in this chapter has the following features:

- The model was developed using a Systems approach to UIC.
- It is formally represented using a UML class diagram. Such a formal model provides a common 'language' for discussing UIC that has clear meaning. For example, the word 'barrier' when discussed in the context of UIC would have the meaning captured in this model, and in particular, the relationships.
- It is comprehensive in terms of the variety of UIC aspects considered.
- It is based on a review of existing UIC literature.

It is to be noted that the Systems Model has been designed to be applied at an organisational level. For example, industry may have multiple motivations to engage with a university. In order to fulfil these motivations, diverse types of UIC may be required. The model allows the communication of those motivations, further discussion from different perspectives, and then facilitating informed decision-making regarding the selection of those varieties of UICs. However, the model can also be used for similar purposes in the case of a single UIC, at a department level or a project level.

6.6 Application of the UIC Systems Model

The UIC Systems Model developed in this chapter provides a tool for analysis and communication among stakeholders. It will help stakeholders to develop a shared understanding of UICs being considered.

The proposed UIC Systems Model can be used in conjunction with the Cynefin sense-making framework as part of the proposed UIC Framework, or as a standalone tool as described in the following sections.

6.6.1 Using the UIC Systems Model with the Cynefin sense-making framework

As discussed in Section 5.4, the Cynefin framework can help us make sense of problems and select appropriate approaches to solving them.

The UIC Systems Model can be used in conjunction with the Cynefin framework to select the appropriate approach to dealing with activities involved in a UIC. Chapter 9 provides details of the process to be applied for such usage along with example scenarios of application.

6.6.2 Using the UIC Systems Model as a standalone tool

As discussed in Chapter 2, there are multiple and diverse forms of UIC available to universities and industry. However, knowledge of these diverse forms by itself is not sufficient to understand how these UICs can be used to gain their intended benefits. In addition, there are various factors influencing the operation of each type of UIC. The UIC Systems Model can be used to gain an increased understanding of these factors and interrelationship among them. This is expected to improve decision-making among stakeholders.

6.7 Evaluation and improvement of the UIC Systems Model

As described in Chapter 3, a two-phase evaluation approach is adopted during this research. Phase one involves descriptive evaluation using illustrative scenarios, logical arguments, and expert evaluation. Phase two involves real-world evaluation and improvement of the model's utility and effectiveness, as detailed in Chapter 10.

A wide range of tests can be adopted to validate a model [Barlas, 1989; Senge and Forrester, 1980]. Structural validity tests check whether the structure of the model is an adequate representation of the real-system structure. The model structure can be compared with descriptive knowledge of real-system structure. The UIC Systems Model passes the validity test on the basis that it is grounded in existing literature related to UIC, and successfully captures the details of UIC as illustrated in Chapter 9.

Section 9.3 in Chapter 9 presents scenarios that demonstrate use of the UIC Systems Model. These demonstrations also serve as descriptive evaluations of the UIC Systems Model.

The model achieves its purpose of providing a language for describing and discussing UICs, and improving understanding of UIC elements and their interrelationships.

6.8 Conclusion

In this chapter, I presented concepts related to 'Systems' and 'Systems Thinking' in order to gain a deeper understanding of the Systems Approach. I then explained UIC as a system. A UIC Systems Model was developed that defines the various elements of UIC and their interrelationships. The model brings these elements together to provide a holistic and formal view of UIC. The model was assessed for its structural validity and utility.

The model will assist in informed decision-making by providing a well-defined common language for discussion among stakeholders regarding relevant aspects of UIC from different perspectives. The model can be used by industry practitioners, researchers and other stakeholders as a standalone tool, or in conjunction with the Cynefin framework to understand and improve UIC as described in Chapter 9.

Having described a model to improve understanding of UIC, in the next chapter, we will discover the practices that can be adopted to improve the effectiveness of UIC operation.

Chapter 7

A University-Industry Collaboration Practices Framework

'The point of equifinality is that it highlights the fact there are multiple routes to the same destination.' - [Ackoff et al., 2010]

In Chapter 5, a proposed framework for evaluating and improving UIC was outlined. Along with a UIC Systems Model (Chapter 6) and a UIC Maturity Model (Chapter 8), the proposed UIC Framework makes use of the UIC Practices Framework described in this chapter.

The UIC Practices Framework is based on information gathered through the review of existing literature and qualitative study of barriers to UIC described in Chapter 4, as well as success factors and best practices for UIC explored in this chapter. The resulting framework can be used as a standalone tool, or in conjunction with the Cynefin framework to understand UICs and improve their effectiveness.

7.1 Introduction

Factors are the aspects that influence UIC. In Chapter 4, barriers were discussed, that is, the factors that act as impediments or pose challenges to the success of UICs. In this chapter, I discuss success factors, the factors that positively influence UICs. The UIC Practices Framework is based on practices that help overcome the barriers or enable these success factors for effective UICs.

As described in Chapter 6 (Section 6.4.3), within the context of this thesis, 'practice' is defined as follows:

> A ***practice*** is a well-articulated specific action, or measure taken within an organization to *overcome* ***barriers*** and/or *enable* UIC ***success factors***.

In order to facilitate implementation of appropriate practices, a UIC practices framework is proposed based on the following considerations:

- The lack of a practical framework for establishing successful collaboration is acknowledged in the reviewed literature [Noble et al., 2017; Philbin, 2008; Buys and Bursnall, 2007].
- The literature around practices for successful collaboration is fragmented. This indicates a need for a comprehensive unified practices framework.
- In order for a practice to be adopted as a standard one it needs to be clearly articulated. Siegel's [Siegel et al., 2003b] comment in the context of TTO that 'there is a need to simply document the nature of these [organizational] practices' is equally valid for UIC, in general.
- In addition, there is a requirement for and interest in the recommendation of 'best practices' that can be used as a reference [Philbin, 2008] by UIC stakeholders. This again points to the need for documentation of UIC practices.

The research presented in this chapter aims to address the above considerations regarding availability of a comprehensive set of practices for practical application by proposing a UIC Practices Framework.

Based on practices identified through a review of existing literature and proposed during the qualitative research described in Chapter 4, a framework of practices is proposed, which can be used by stakeholders to improve the effectiveness of UICs. The underlying hypothesis for this framework is that the application of practices suitable to a particular context will improve the effectiveness of UIC.

7.2 Foundations of the UIC Practices Framework

The UIC Systems Model described in Chapter 6 defines UIC practices, barriers and success factors. Specifically, it shows that practices are used to overcome barriers and to enable success factors. A relationship exists between these three elements and it was noted that practices adopted to enable a success factor may help overcome a barrier and vice versa. Barriers and success factors form the basis of the UIC Practices Framework as illustrated in this section.

7.2.1 Barriers to UIC

Barriers to UIC were categorized and discussed in Chapter 4. They were categorized as cultural barriers, legal barriers, administrative barriers, motivational barriers, financial barriers, communication barriers, relevance barriers, and credibility barriers. Practices in the UIC Practices Framework aim to help stakeholders overcome these barriers.

7.2.2 Success factors for UIC

The established benefits of UICs and associated potential barriers or challenges emphasise the need to explore the success factors behind effective UICs. I started the process of identifying the success factors with a review of this literature. This review uncovered a fragmented discussion around 'success factors'. This fragmentation can be inferred from Table 7.1, which shows that none of the existing literature covers all the success factors.

This fragmentation indicated that there is scope and a need to develop a comprehensive and coherent set of success factors that influence the initiation, formation, and effective management of UIC.

In order to improve the understanding and documentation of success factors, a new classification for success factors has been developed. I followed an iterative process of data analysis that included a combination of inductive and deductive approaches (Section 3.4) to develop the classification. The process began with Thune's classification [Thune, 2011] and resulted in adding, removing, and combining categories from other sources in the literature. For example, in the existing literature, communication is categorised under 'process factors' [Thune, 2011] or 'project management' [Barnes et al., 2002]. However, it appeared that communication is an important aspect as discussed in Section 7.3.6, and the emphasis required in terms of best practices for effective communication qualify it to be a separate category. Similarly, the significant influence of individuals involved in UICs, led to a separate categorisation of 'Personnel'.

The development of this classification was also influenced by the process of inspiration [Langley, 1999], or insight, intuition, and creativity of the researcher. Such influence is considered as an inevitable and uncodifiable feature (can not be transformed into explicit knowledge) [Weick, 1989].

Table 7.1 depicts the final classification of success factors and lists the factors in each category.

UIC is also affected by 'environmental' factors such as encouraging government policies and legislations, success history of collaboration, participation and interest of the community, and corporate stability [John et al., 2015; Barnes et al., 2002; Freeth, 2001; Kerka, 1997]. They provide an impetus to collaboration.

Studying the effect of environmental factors has not been considered within the scope of this study as the main stakeholders identified for this research are university and industry, and they do not have much control over most of the environmental factors.

7.2.3 Categorization of UIC practices

Because practices exist to overcome barriers and enable success factors, it is appropriate to categorize practices using the same categories as barriers or success factors. Once success factors were categorized as discussed above, it was noted that the categorization of success factors can adequately categorize the practices. Therefore, it was decided to categorize practices using the success factor categorization developed above in Section 7.2.2, depicted in Table 7.2, and summarized below.

- **Contextual.** This category covers practices, barriers and success factors that play a major role during the initiation and formation of a UIC.
- **Organizational.** This category covers practices, barriers, and success factors at organizational level that influence the success of a UIC. Organizational characteristics such as strategy and vision of a university, and absorptive capacity of an industry play an important role in establishing effective UICs.
- **Cultural adaptation.** This category covers practices, barriers and success factors related to differences in the cultural and organisational operation of universities and industry. These practices help universities and industry to adapt to the each other's cultures and requirements.
- **Operation and Management.** This category covers practices, barriers and success factors associated with effective operation and management of UICs.
- **Personnel.** This category covers practices, barriers and success factors associated with identifying suitable people for UIC. Motivated people play an important role in establishing collaboration and determining its outcome [John et al., 2015]. Individuals with an understanding of both academic and business worlds are considered the driving force behind successful partnerships [Plewa et al., 2013; Edmondson et al., 2012; Santoro and Betts, 2002]. 'Boundary spanners' have been identified as key players in establishing and sustaining relationships [Thune, 2007; Calder, 2007].
- **Communication.** Communication forms the very basis of a successful relationship [Thomas and Paul, 2018]. This category covers practices, barriers and success factors associated with communication. Communication encompasses

Table 7.1: Success Factors influencing University-Industry Collaboration

Category	Success factors	References
Contextual	Motivation	[Thune, 2007]
	Understanding of the diversity of UICs	[John et al., 2015; Edmondson et al., 2012; Perkmann and Salter, 2012; Bruneel et al., 2010; D'Este and Patel, 2007; Santoro and Bierly, 2006; Bloedon and Stokes, 1994]
	Partner selection	[Sjöö and Hellström, 2019; Rybnicek and Königsgruber, 2019; John et al., 2015; Perkmann and Salter, 2012; Thune, 2011; Plewa and Quester, 2007; Mora-Valentin et al., 2004; Barnes et al., 2002; Potworowski, 1989]
	Resource availability	[Sjöö and Hellström, 2019; Rybnicek and Königsgruber, 2019; Thune, 2011; D'Este and Patel, 2007; Galán-Muros and Plewa, 2016]
Organizational	**University:**	
	Strong academic leadership,	[John et al., 2015; Edmondson et al., 2012]
	Collaboration as a part of mission,	[John et al., 2015; D'Este and Patel, 2007]
	Conducive environment for engagement	[Sjöö and Hellström, 2019; John et al., 2015; Schofield, 2013; Edmondson et al., 2012; D'Este and Patel, 2007; Prigge, 2005]
	Technological relatedness	[Barbolla and Corredera, 2009; Philbin, 2008; Santoro and Bierly, 2006]
	Industry:	
	Strong commitment	[Thune, 2011]
	Absorptive capacity	[Barbolla and Corredera, 2009; Santoro and Bierly, 2006]
	Corporate stability	[Barnes et al., 2002]
Cultural adaptation	Adaptation	[Rybnicek and Königsgruber, 2019; Schofield, 2013; Perkmann and Salter, 2012; Prigge, 2005]
	Agreed timescale	[Edmondson et al., 2012; Perkmann and Salter, 2012]
	Balanced priorities	[Schofield, 2013; Barnes et al., 2002]
Operation and Management	Project selection	[Schofield, 2013; Perkmann and Salter, 2012; Philbin, 2008; Calder, 2007]
	Process management, Teamwork and Project manager	[Galán-Muros and Plewa, 2016; Schofield, 2013; Perkmann and Salter, 2012; Thune, 2011; Barnes et al., 2002; Barbolla and Corredera, 2009; Rohrbeck and Arnold, 2009; Potworowski, 1989]
	Win-win scenario ensuring equality	[Rybnicek and Königsgruber, 2019; Edmondson et al., 2012; Prigge, 2005]
	Formalization	[Perkmann and Salter, 2012; Thune, 2011]
	Shared vision and strategy	[Rybnicek and Königsgruber, 2019; Edmondson et al., 2012]
	Clear benefit	[Edmondson et al., 2012; Thune, 2011; Barnes et al., 2002; Barbolla and Corredera, 2009]
	Tangible outcome	[Thune, 2011; Barnes et al., 2002; Bloedon and Stokes, 1994; Potworowski, 1989]
	Wide impact	[Edmondson et al., 2012]
Personnel	Motivated and skilled	[Rybnicek and Königsgruber, 2019; John et al., 2015; Schofield, 2013; Barbolla and Corredera, 2009; D'Este and Patel, 2007]
	Boundary spanners / Agent	[Sjöö and Hellström, 2019; Edmondson et al., 2012; Philbin, 2008; Calder, 2007; Valentín, 2000; Bloedon and Stokes, 1994]
Communication	Information dissemination	[Rybnicek and Königsgruber, 2019; Schofield, 2013; Edmondson et al., 2012]
	Frequency, Diversity, Quality	[de Wit-de Vries et al., 2019; Rybnicek and Königsgruber, 2019; Edmondson et al., 2012; Rohrbeck and Arnold, 2009; Philbin, 2008; Thune, 2011; Mora-Valentin et al., 2004; Barnes et al., 2002]
Social capital	Positive attitude from partners	[Galán-Muros and Plewa, 2016; Bruneel et al., 2010; Thune, 2007; Mora-Valentin et al., 2004]
	Mutual respect and obligations	[Sjöö and Hellström, 2019; Bruneel et al., 2010; D'Este and Patel, 2007]
	Trust, Commitment	[Sjöö and Hellström, 2019; de Wit-de Vries et al., 2019; Galán-Muros and Plewa, 2016; Schofield, 2013; Edmondson et al., 2012; Bruneel et al., 2010; Philbin, 2008; Thune, 2011; Plewa and Quester, 2007; Santoro and Bierly, 2006; Mora-Valentin et al., 2004; Barnes et al., 2002]
	Common understanding	[Rybnicek and Königsgruber, 2019; Sjöö and Hellström, 2019; Schofield, 2013; Barbolla and Corredera, 2009; Calder, 2007; Potworowski, 1989]
	Access to resources with quality and amount of access	[D'Este and Patel, 2007; Santoro and Bierly, 2006]
	Continuity of personnel	[Thune, 2007; Barnes et al., 2002]
Legal	Transparent policy and processes	[Sjöö and Hellström, 2019; Dollinger et al., 2018; Schofield, 2013; Edmondson et al., 2012; Rohrbeck and Arnold, 2009; Santoro and Bierly, 2006; Potworowski, 1989; Prigge, 2005]
	Clear policy on publication	[Rohrbeck and Arnold, 2009; Valentín, 2000]
	Clearly defined IP rights	[Edmondson et al., 2012; Dollinger et al., 2018; Perkmann and Salter, 2012; Santoro and Bierly, 2006; Valentín, 2000; Potworowski, 1989]

several aspects such as codification (information dissemination), cooperatives, meetings, networks, and agreements [Kaymaz and Eryiğit, 2011]. Effective communication is a critical factor in the success of UIC as it can influence trust creation and maintenance, networking, and sharing of goals, which are important for fostering effective UICs [de Wit-de Vries et al., 2019; Thomas and Paul, 2018].

- **Social capital.** This category covers practices, barriers and success factors related to social capital. Social capital refers to the qualities and resources that encourage and support individual or collective action for the mutual benefit of people in a social network [Bourdieu; Portes, 1998]. The factors in this category play a crucial role in formation and success of UICs [Thune, 2007; Kerka, 1997].
- **Legal.** This category covers practices, barriers and success factors associated with legal aspects of UIC including the negotiation of intellectual property rights.

The next section presents the UIC Practices Framework developed to enable success factors and overcome barriers to effective UIC.

7.3 UIC Practices Framework

In this section, the UIC Practices Framework is described. The framework is organised as a coherently integrated and comprehensive set of practices to overcome the barriers and enable the success factors identified in Table 7.2. The framework is primarily based on the practices identified in the reviewed literature. However, it is further informed by the improvement approaches proposed during the qualitative study described in Chapter 4, which are mainly for action from universities.

Table 7.2 summarizes the UIC Practices Framework. It shows the practices involved along with the success factors enabled and barriers overcome by each of the practices. It also provides the source of each practice in the framework. LR denotes 'Literature review' and QS denotes the 'Qualitative Study' presented in Chapter 4 (Section 4.3). It is to be noted that a practice does not necessarily have to both enable a success factor and overcome a barrier. Some practices only enable a success factor without a barrier that they directly overcome. This is indicated by rows with empty values in the barriers column of Table 7.2.

Each of the practices are described in the following sub-sections.

Table 7.2: UIC Practices Framework

Practice Category	Recommended Practice	Source	Success Factors Enabled	Barriers Overcome
Contextual	Understand the diversity of UICs.	LR	Understanding of the diversity of UICs	
	Identify the motivation for Collaboration.	LR	Motivation, Technological relatedness	Unclear or unaligned relevance of research, perceived insufficient benefits
	Select an appropriate partner.	LR	Partner selection, Resource availability, Absorptive capacity, Corporate stability	Difficulty in identifying stakeholders, limited industrial ability to utilize research results
Organizational	Adopt policies to encourage/facilitate UIC.	LR	Conducive environment, Resource availability	Administrative barriers
	Adopt strategies to encourage Collaboration.	LR	Collaboration as part of mission, Strong academic leadership	Administrative barriers
	Create a conducive environment for collaboration.	LR	Conducive environment	High cost, time, and effort; Difficulty in maintaining balance between regular duties and UIC, lack of established processes, inflexible bureaucracy
	Set up rewards and incentives.	LR	Conducive environment	Insufficient rewards and recognition for collaborative efforts
	Improve alumni relationships.	QS	Trust, Mutual respect and obligations	Lack of mutual appreciation, Unclear or unaligned relevance of academic research
Cultural adaptation	Understand each other's mission, processes, and adapt as appropriate.	LR, QS	Adaptation	Difference in motivation, goals, values, processes, Complexity of UIC
	Develop a shared vision of collaboration project.	LR	Balanced priorities	Difference in goals, Relevance barriers
	Create awareness of time requirements and agree upon time-scales.	LR, QS	Agreed time-scales	differing time-frames; perceived length of academic research; quicker business requirements
Operation and Management	Ensure a win-win situation.	LR	Win-win scenario ensuring equality	
	Establish realistic and mutually agreed aims	LR	Project selection, Shared vision and Strategy, Clear benefit	
	Manage collaborations.	LR	Process management, Teamwork and Project manager	Complexity of UIC
	Ensure fair and appropriate contributions from all stakeholders.	LR	Formalization	

	Aim at results aligned with industry goals.	LR	Clear benefit	Relevance barriers
	Plan for evaluation of collaboration.	LR	Tangible outcome, Wide impact	
Personnel	Identify and appoint suitable people.	LR	Motivated and skilled individuals	
	Appoint boundary spanners and/or agents.	LR	Boundary spanners / Agent	
	Ensure leadership involvement	LR	Strong leadership	
Communication	Establish effective communication.	LR	Frequency, Diversity and Quality of communication	Ineffective communication, lack of information about benefits, and opportunities
	Maintain accessible contact information	LR, QS	Quality of communication	Difficulty in contact
	Establish an effective dissemination strategy	LR, QS	Information dissemination	Lack of awareness of research
Social Capital	Adopt measures to increase trust and commitment.	LR	Trust, Commitment, Access to resources with quality and amount of access Continuity of personnel	Lack of safe collaboration mechanisms, Complexity of UIC
	Ensure mutual obligations, and common understanding.	LR	Positive attitude from partners, Mutual respect and obligations, Common understanding	Lack of mutual appreciation
Legal	Develop a common understanding of Intellectual Property (IP).	LR	Transparent policy and processes	Disagreements regarding IP rights
	Negotiate and clearly articulate IP rights.	LR	Clear policy on publication, Clearly defined IP rights	Disagreements regarding IP rights, ownership, publishing; contract negotiations; Information leakage

LR denotes 'Literature review' and **QS** denotes the 'Qualitative study' presented in Chapter 4 (Section 4.3)

7.3.1 Contextual practices

7.3.1.1 Understand the diversity of UICs

Stakeholders should gain an understanding of the diversity of UICs.

In order to select a suitable mechanism, it is important to gain understanding of the variety of interactions possible between collaboration partners. Researchers emphasise the importance and need to understand the nature of partnerships, given a variety of collaborations are available to achieve different objectives [John et al., 2015; Farrell, 2010; D'Este and Patel, 2007; Bloedon and Stokes, 1994]. The diversity and nature of UICs have been discussed earlier in Chapter 2. Different types of UICs have different degrees of involvement and duration, and offer specific benefits such as application and commercialization, and enhanced capability to build competitive advantage. An understanding of the nature of those types will allow the stakeholders to make an informed decision about selecting an appropriate partnership.

A portfolio of the variety of UICs suitable to meet different requirements improves the effectiveness of collaboration [Bloedon and Stokes, 1994] by making required information about UICs available to the stakeholders [Tartari et al., 2012]. This can be attributed to the possibility of making an informed decision in selecting a type of UIC suitable to the particular context, for achieving the set objectives, and according to the characteristics of the knowledge under exchange within the context [Cassiman et al., 2010]. The characteristics of knowledge include explicit versus tacit, discipline, and the characteristics of individuals and organisations involved in the process [Bekkers and Freitas, 2008].

Several barriers to UIC exist as discussed in Chapter 4. An increased breadth of interaction is expected to overcome some of the cultural barriers to collaboration [Bruneel et al., 2010]. In addition, usage of a variety of UICs helps to ensure research efficiency, and gaining access to a variety of scientific and technical resources [Schartinger et al., 2002].

In addition to the literature reference for this practice, it is also supported by Ashby's Law of Requisite Variety [Ashby, 1961]. According to the Ashby's Law, the variety of challenges in a system need to be dealt with by an equal or greater variety of responses. UIC is, often, a complex system (as established in Chapter 6) with multiple factors influencing the system. In accordance with Ashby's Law, a combination of UIC types will help deal with these influencing factors leading to improved UIC [Landry et al., 2010].

7.3.1.2 Identify the motivation for collaboration

Identification of motivations for collaboration is considered as a key collaboration capability [Chartered Accountants Australia and New Zealand and RMIT, 2017].

It is important to identify motivations and common areas before co-working or collaborating [Perkmann and Salter, 2012] as it will lead to increased commitment [Gorschek et al., 2006]. It will improve the effectiveness of collaboration.

UIC offers several benefits, which will motivate stakeholders to collaborate. Motivations vary from short-term problem solving to building long-term technological capability [Peças and Henriques, 2006; Potworowski, 1989]. Evidence of significance and strategic importance of collaborative research to the partner is also a motivating factor for collaboration [Barnes et al., 2002]. 'Business needs what the university has to offer because they won't succeed unless they innovate' [Chartered Accountants Australia and New Zealand, 2017].

Identification of motivations requires due time, discussion and deliberation. Such discussions can help overcome barriers such as unclear or misaligned relevance of research, and perceived insufficient benefits.

When identifying the motivation for collaboration, it is often important to consider other factors. For example, if the motivation is problem-solving, stakeholders should select a problem that possesses intellectual rigour and is motivating for both the partners. The problem should complement the academic expertise and be relevant to industry. Universities should also aim to select a generalizable problem within the partner organization as it will have a wider applicability leading to greater impact for the organization and the partnership. Such selection of a problem and solving it with a consideration of application is expected to enhance the impact of solving the problem.

Similarly, if the motivation is technology transfer, absorptive capacity of the partnering firm needs to be considered. Absorptive capacity can be defined as the capability of an organization to engage in a knowledge transfer activity with another institution in order to assimilate the information acquired during the process for creation of new knowledge and economic gain [Cohen and Levinthal, 1990]. It is considered as an additional attribute that contributes to successful technology transfer and sustained collaborative activities [Rahm et al., 2013; Philbin, 2008]. Technological relatedness (i.e. field of interest similar to academic research) and technological capability of industry increase its absorptive capacity [Santoro and Bierly, 2006]. For successful transfer of knowledge and technology, industrial partners should have the internal capability to absorb the research fully and transform it into marketable products [John et al., 2015].

On the other hand, if motivation for the university is to improve graduate skills through practical learning, the university may collaborate with industry for educational purposes. This collaboration can be in the form of internships or student group projects. Such experiences motivate each stakeholder. Students gain valuable employment-related skills and a better understanding of the role that they can play in society. Industry are exposed to new and emerging ideas, can influence curriculum, and are able to develop a pipeline of future employees. The university develops a better understanding of industry needs and challenges, and is able to respond through curriculum development and other collaborations including joint research projects.

The following recommendations are part of this practice:

- Universities should utilise a company's research portfolio to identify motivation and to determine opportunities for collaboration [Greitzer et al., 2010]. Industry is highly motivated to strike a partnership that will allow it to achieve something that it can't on its own. They reach out to universities to access the latest research.

- Research problem or motivation should be selected by conducting a joint workshop between industry partners and academics [Schubert and Fisher, 2009].

7.3.1.3 Select an appropriate partner

The reviewed literature indicates the significance of selecting appropriate partners [Mora-Valentin et al., 2004; Potworowski, 1989]. Selection of an appropriate partner increases the effectiveness of collaboration. In order to select appropriate partners a method should be established to assess them. This will help in overcoming barriers such as difficulty in identifying stakeholders, and limited industrial ability to utilize research results.

When selecting a partner, it is important to recognize the variety of potential stakeholders. For example, Universities and Basic Research Institutes (e.g., Max-Planck Gesellschaft in Germany), Start-Up Companies, Applied Research Institutes (e.g., Fraunhofer Gesellschaft in Germany), Research based Companies (e.g., Siemens Corporate Technology), Development based Companies (e.g.,Siemens Business Units), and Consulting Companies are potential stakeholders [Rombach and Achatz, 2007].

In addition to recognizing the diversity of potential partners, it is also important to assess them against applicable indicators of success such as:

- Consider their goals, motivations and mutual benefits [Perkmann and Salter, 2012; Thune, 2011; Barnes et al., 2002; American Association of State Colleges and Universities, 1987].

- Past experience and industrial familiarity [Potworowski, 1989] also influence collaboration success [Mora-Valentin et al., 2004]. Prior experience with stakeholders is important to consider because earlier short-term successful partnerships imply trusted relationships, which may lead to long-term strategic partnerships. At the same time, past failure may hinder future collaboration opportunities.

- Identification of complementary skills and objectives in matching collaborators is among the best practices for collaboration [Sandberg et al., 2011; Strieter and Blalock, 2006; Barnes et al., 2002; Potworowski, 1989]. 'The higher the complementarity of capabilities between partners, the higher the likelihood of mutual trust and the higher the level of mutual commitment' [Chartered Accountants Australia and New Zealand, 2017; Das and Teng, 2000].

- According to some studies geographic proximity plays a role and provides a clear advantage for initiating, establishing and maintaining collaborative relationships when stakeholders are located in the same region [Laursen et al., 2011; Tornatzky et al., 2002; Fritsch and Schwirten, 1999].

Finding industry partners is a very demanding and time-consuming process [Schubert and Fisher, 2009]. However, an appropriate partner selection will lead to increased commitment to UIC in their areas of interest [Sandberg et al., 2011].

7.3.2 Organizational practices

7.3.2.1 Adopt policies to encourage/facilitate UIC

Policies must be adopted to encourage and support successful UICs.

The importance of policies in sustaining collaboration is recognized in the literature [Dollinger et al., 2018; Buys and Bursnall, 2007; Tornatzky et al., 2002; Stankiewicz, 1986]. Long-term development of industrially relevant academic R&D resources, communication, reduction of the financial/material costs of interaction, the resolution of organisational conflicts, and filling roles, which can facilitate collaborations at the university-industry interface have been identified as key policy areas for universities to overcome barriers to UIC [Stankiewicz, 1986].

Universities have begun to adopt measures such as creating and revising policies to meet the requirements of dynamic research environment and encourage UIC [Holbrook and Dahl, 2004]. For example, policies that aim to increase UIC at MIT have been instrumental in establishing successful partnerships with industry. MIT has established a successful Industry Liaison Program to facilitate engagement between the university and corporates worldwide [John et al., 2015].

Literature also indicates that regional and national policies play a role in encouraging knowledge transfer from universities to industry, which signifies the need for policy initiatives at those levels [Siegel et al., 2007].

7.3.2.2 Adopt strategies to encourage collaboration

Collaboration partners should adopt strategies to encourage collaboration [Siegel and Wright, 2015; John et al., 2015; Edmondson et al., 2012]. Successful collaborations are often the result of stakeholder commitment shown by making collaboration a part of their strategy and providing strong leadership [Rahm et al., 2013; Edmondson et al., 2012]. A good strategy for collaboration will include deliberate and informed planning in order to utilise existing collaborations and develop new collaborations. Such a strategy would address flexibility in working, investment in developing industrially relevant research and development resources, focus on creating long-term partnerships, and encouraging multi-disciplinary research.

The following recommendations are part of this practice:

- Include collaboration as part of the mission statement. Literature establishes the value of addressing 'collaboration' as part of an organisation's mission statement in creating successful collaboration. Collaboration influences the strategy of both universities and industry through mission [Philbin, 2008]. Universities that excel at collaboration often address collaboration as part of their mission statement. For example, the mission statement of the Imperial College London includes: 'We foster multidisciplinary working internally and collaborate widely externally' [John et al., 2015]; the goals of North Carolina State University include: '... fostering new partnerships, both internally and externally' [Tornatzky et al., 2002].

- A university's strategy should reflect the intent to engage with industry in terms of consideration of priorities, allocation of resources based on the type of UIC, and choice of area of emphasis as collaboration varies in type and extent among different disciplines [Siegel et al., 2007].

- Adopt a strategy with an objective to create long term partnerships and allow flexible working arrangements [Greitzer et al., 2010; Gorschek et al., 2006; Potworowski, 1989].

- Develop longer term collaborations. Longer term collaborations are expected to create more significant results for companies as industry can commercialize existing knowledge and innovative academic research results [Calder, 2007]. In order to create longer term collaborations in the future, industry can adopt a strategy to engage with university researchers even if the research is not directly supported through a contract [Greitzer et al., 2010] or not aligned with company's current area of operation [Sandberg et al., 2011].

- Cross-disciplinary research capacity is considered a key to successful collaboration [Edmondson et al., 2012]. The current business environment is pushing industries towards increased and faster innovation, which is often stimulated by and necessitates cross-disciplinary work. Universities should, therefore, develop and encourage multi-disciplinary programmes that deeply engage industry [Dollinger et al., 2018]. One way to foster cross-disciplinary engagement is to set-up an on-campus multidisciplinary institute in collaboration with industry to bring together experts from both worlds and across disciplines.

7.3.2.3 Create a conducive environment for collaboration

Organisations should create a conducive environment for collaboration which includes overall administrative support and supportive operational units [Dollinger et al., 2018; Edmondson et al., 2012; Prigge, 2005; Zinser, 1985]. For example, extensive university support and industrial participation in establishing research objectives and reviewing research progress and results should be ensured. Other aspects are internal organisational support for collaboration from initiation to utilisation of the UIC results, establishing new operational structures to encourage UIC, and promoting cross-disciplinary research. Such measures will encourage individuals and organisations to form UICs. These measures will also help in overcoming barriers such as high cost, time, and effort, difficulty in maintaining balance between regular duties and UIC, lack of established processes, and inflexible bureaucracy.

The following recommendations are part of this practice:

- internal support for technical and management oversight of UICs from contract through to exploitation of outputs [Greitzer et al., 2010].

- assigning accountability for the uptake of the output of collaboration by industry [Greitzer et al., 2010].

- establish support for UIC from senior officials [Prigge, 2005].

- adding appropriate resources for UICs, including Technology Transfer Offices [Siegel et al., 2003c].

- establish new structures to ensure successful collaboration [Edmondson et al., 2012; Prigge, 2005]. For example, the Center of Knowledge Interchange (CKI) established by Siemens at their partner university campuses [Edmondson et al., 2012] act as a single point of contact to manage strategic partnerships with universities. Another example is the restructuring of IP Management at UC Berkeley by establishing the new Intellectual Property and Industry Research Alliances office (IPIRA) [Burnside and Witkin, 2008]. The IPIRA provides services to academics to support their research, and facilitates collaboration.

7.3.2.4 Set up rewards and incentives

A system of incentives should be created in universities to recognize the efforts of academics participating in UIC. A similar approach could be adopted in industry.

Universities interested in improving UIC need to recognise and value the efforts of individuals involved in such collaborations [Nielsen, 2017; Chartered Accountants Australia and New Zealand, 2017; Veilleux and Queenton, 2015; Buys and Bursnall, 2007]. Rewards and incentives are expected to influence the motivation and level of engagement of individuals leading to more effective collaborations [Tseng et al., 2018; Potworowski, 1989]. They will help to overcome motivational barriers to UIC.

The following recommendations are part of this practice:

- Universities should design incentive systems that encourage researchers to engage with industry for utilization of research output to its full market potential [Walter et al., 2002].

- Associate funding, rewards, and promotions with the impact and relevance of collaborative projects [Nielsen, 2017; Strieter and Blalock, 2006; Starkey and Madan, 2001]. For example, the Industry Liaison Program at MIT adopts a revenue sharing scheme to offer incentives to university staff collaborating with industry [John et al., 2015].

- Establish formal awards and conduct acknowledgement events to recognize academics for industry engagement, inventions, and entrepreneurship [Tornatzky et al., 2002].

7.3.2.5 Improve alumni relationships

Universities should maintain a connection with their graduates working in industry. Through these connections universities can discuss industry problems and understand ways of working together to solve them. In addition, these alumni can become mentors for the present cohort of students, which will influence the future workforce.

Working with alumni figured as an important factor during the qualitative research presented in Chapter 4. Participants highlighted the value of alumni in building relationships with industry. Such relationship building can help overcome some of the cultural barriers such as a lack of mutual appreciation.

Alumni are considered among the greatest assets of a university [Chi et al., 2012]. On-going relationships with alumni can contribute to industry engagement in the form of guest lectures or internships [Matlay, 2011], and can provide funding for research and education [Straujuma and Gaile-Sarkane, 2018]. They can offer a practical perspective on research and education based on their experience [Matlay, 2011], which can help overcome relevance barriers such as unclear or misaligned relevance of academic research.

The importance of alumni is also emphasised by Prem Yapa of RMIT, who says that, 'By developing long-term relationships with the university, graduates help the university to re-learn' [Chartered Accountants Australia and New Zealand, 2017]. Successful entrepreneurs among alumni can guide the creation of curriculum and training [Phillips, 2018].

By leveraging their alumni network, universities can establish strong relationships with industry and increase their chances of developing more effective and successful collaborations [John et al., 2015].

7.3.3 Cultural adaptation practices

7.3.3.1 Understand each other's mission, processes, and adapt as appropriate

Industry and university leaders need to develop an understanding of each other's mission and processes. Stakeholders need to listen to each other and seek ways to work together. While differences in the culture and philosophies of collaborating partners often bring more creativity to the table, strategic alliances between them need to be nurtured carefully over a period of time to arrive at desired stability in the relationship [Ehrismann and Patel, 2015].

In Chapter 4, cultural differences were identified as one of the main barriers and challenges to UIC. There is a need for universities and industry to adapt to the each other's cultures and requirements [Burquel, 1997]. Partners should learn about each other, allow each other to express themselves, consider their perspectives, accept differences, and appeal to their highest motives. Developing mutual understanding of mission [Rohrbeck and Arnold, 2009] and processes will help to overcome the cultural barriers through adaptation [Prigge, 2005]. A practical way to achieve this could be to begin collaboration at a small scale, such as internships or research co-supervision so that partners gain experience and mutual understanding of their capabilities.

It is important for universities to listen to industry [Edmondson et al., 2012] and familiarise university researchers with the partner industry and management practices followed by them [Potworowski, 1989] in order to gain better understanding of the business world. This is important as industries are like customers of universities, who are usually investing resources in UICs.

The following recommendations are part of this practice:

- Create personal linkages as they will provide an opportunity for industry and universities to better understand each other [Prigge, 2005]. 'Ensure that everyone has a voice and is treated respectfully' [Strieter and Blalock, 2006]. A collaboration is likely to fail if the partners lack listening skills and understanding. For example, partnerships in which Nokia continued investing heavily in terms of money while university was not listening to the company, eventually failed with no meaningful results for the comapny [Edmondson et al., 2012].

- Industry should be 'proactive in their efforts to bridge the cultural gap with academia' [Siegel et al., 2003c]. This was also recommended during the qualitative study presented in Chapter 4.

- Learn conflict management in the process of UIC so that differences can be overcome [de Wit-de Vries et al., 2019].

- Adopt measures to increase awareness among researchers about products and their development life-cycle as emphasised in the qualitative study detailed in Chapter 4. The participants of the study expressed the view that understanding the real product of a business and its contributing environment will lead to increased effectiveness of UIC by reducing the cultural gap. It will also broaden the perspective of researchers about their own work.

7.3.3.2 Develop a shared vision of collaboration project

UIC stakeholders must work together to develop a shared vision.

Stakeholders should share their own vision [Greitzer et al., 2010] as a starting point for developing a common vision among collaborators [Rohrbeck and Arnold, 2009; Strieter and Blalock, 2006]. This requires identifying common ground [Siegel et al., 2003a]. Creating a shared vision will increase the sense of shared ownership of collaborative work and help overcome cultural and relevance barriers. Once a shared vision is established, stakeholders should proceed slowly with their UIC.

7.3.3.3 Create awareness of time requirements and agree upon timescales

UIC partners should consider the mutual time requirements and agree upon a time-line for UICs.

Differing time-frames are considered one of the main cultural barriers to collaboration (Sections 4.2 and 4.3.5). In order to overcome this barrier, it is important that stakeholders understand each other's timing requirements. For example, universities should understand timing requirements associated with the commercialisation of university research in a competitive market [Siegel et al., 2003c]. Such understanding can be developed by familiarising researchers with industrial practices [Potworowski, 1989] and adopting measures to increase awareness among researchers about products and their development life-cycle as emphasised in the qualitative study detailed in Chapter 4.

Stakeholders should jointly agree to time-scales and follow them strictly [Schubert and Fisher, 2009]. 'Agreeing upon time-scales' is among recommended practices for overcoming barriers related to time-frames (Sections 4.2 and 4.3.5), and has proven to be a success factor for UICs [Barnes et al., 2002].

Participants in the qualitative study described in Chapter 4 suggest that universities should identify areas where they can collaborate with industry to produce results in shorter time-frames than is typically the case. For example, projects that run over a semester are preferable to projects that run over several years. They note that successful short-term collaboration has a potential to lead to long-term mutual benefits.

7.3.4 Operation and management practices

7.3.4.1 Ensure a win-win situation

Stakeholders should identify a win-win situation and agree upon it. A win-win situation is where each stakeholder gains benefits out of UIC.

The perspective of each partner should be considered regarding the value of collaboration to ensure that there is some benefit in it for each partner [Chartered Accountants Australia and New Zealand, 2017]. Proper attention must be paid to ensure that the benefits of collaboration are commensurate with the time, effort and investment of the companies [Chartered Accountants Australia and New Zealand, 2017; Barnes et al., 2002].

For successful UIC, an appropriate balance is required between academic and industrial objectives and priorities [Barnes et al., 2002]. Ensured mutual benefits are expected to have greater impact on success and lead to better results [Edmondson et al., 2012; Barnes et al., 2002]. Thus, 'win-win' scenarios are considered imperative [Prigge, 2005].

7.3.4.2 Establish realistic and mutually agreed aims

Literature emphasises the value of realistic and mutually agreed aims. UIC partners should have discussions during the early phase of collaboration to clearly identify, define and agree upon the objectives of collaboration. It is important to 'define specific collaboration outputs that can provide value to the company' [Greitzer et al., 2010]. Clear definition of deliverables during UIC formation leads to more effective collaborations [Potworowski, 1989].

The following recommendations are part of this practice:

- Make realistic aims for a UIC [Chartered Accountants Australia and New Zealand, 2017].
- Ensure mutual agreement on the goals and objectives when commencing a UIC [Chartered Accountants Australia and New Zealand, 2017].

7.3.4.3 Manage collaborations

It is important to manage UICs to ensure success. The main aspects of management are related to objectives, roles and responsibilities, planning and execution, risk management, and progress monitoring. Adopting a framework to manage the collaboration process will help in monitoring, course-correction during the collaboration process, and achieving the set goals.

Good project management has been identified as a UIC success factor [Butcher and Jeffrey, 2007] in analysis of case study based projects [Barnes et al., 2006, 2002]. A successful collaboration requires informed planning [Zinser, 1985], proper preparation, aligned goals of collaboration partners [Dean et al., 2006], regular contact, and progress monitoring [Nielsen et al., 2013; Thune, 2011; Barbolla and Corredera, 2009; Peças and Henriques, 2006; Potworowski, 1989].

The following recommendations are part of this practice:

- 'Clearly define the problem' [Strieter and Blalock, 2006].
- 'Clearly define the objectives' [Barnes et al., 2006]. If there is no clarity regarding the objectives of a UIC, or the partners are not sure about the benefits for them, it will be difficult to drive the partnership successfully. Clarity in objectives can be achieved by spending time in understanding each other's requirements and defining the project's strategic context as part of the selection process for collaboration opportunities [Greitzer et al., 2010].

- Define UIC processes and a plan of work [Strieter and Blalock, 2006] and follow it.
- Define roles and responsibilities to ensure timely progress and its monitoring.
- Minimize risk by recognizing and documenting risks/impediments up-front and agreeing upon a risk-mitigation strategy [Gorschek et al., 2006; Prigge, 2005].
- Clearly define project milestones and employ regular progress monitoring [Barnes et al., 2006].

7.3.4.4 Ensure fair and appropriate contributions from all stakeholders

UIC partners must consider everyone's perspective and ensure fair contributions. There should be clear articulation of the amount of active contribution expected from the partners at the beginning of the UIC.

The following recommendations are part of this practice:

- Ensure clear communication of the role of each partner in a collaboration [Barnes et al., 2002].
- Agree upon and clearly communicate the responsibilities of each UIC partner from the very beginning [Barnes et al., 2002].
- Identify and agree upon key performance indicators for a UIC. Ensure clear division of labour and management in accordance with them [Rohrbeck and Arnold, 2009].
- Reach agreement that contributions are fair and appropriate.

7.3.4.5 Aim for results aligned with industry goals

It is important to aim for results aligned with industry goals. A strong interest in utilising the outcomes of UIC is a significant factor in the success of UIC [Schofield, 2013; Barbolla and Corredera, 2009]. The characteristics identified regarding research results that lead to successful collaboration are industry need-orientation, industry goal alignment, deployment impact, industry benefits, and innovativeness [Sandberg et al., 2011].

Often, there is a lack of communication regarding the relevance of university research to industry. It is recommended that universities should adopt a strategy to demonstrate the impact and benefits of their research results to industry. This will help overcome relevance barriers, and lead to increased adoption and commercialization of research output by industry. One way to demonstrate the impact and benefits of research is outlined in [Awasthy et al., 2016] (reproduced in Appendix A).

7.3.4.6 Plan for evaluation of collaboration

It is important to plan for evaluation of UIC. Stakeholders need to agree upon performance indicators and utilize these indicators to measure the success of UIC.

The following recommendations are part of this practice:

- 'Create measures to assess the impact of academic research on practice' [Starkey and Madan, 2001].

- Evaluate UIC to provide evidence of outcomes and impact [Chartered Accountants Australia and New Zealand, 2017; Strieter and Blalock, 2006]. Impact of research on industry practice should be assessed [Starkey and Madan, 2001] as evidence of the outcome associated with greater impact leads to successful collaborations [Schubert and Fisher, 2009]. This can be attributed to greater commitment from the partners owing to the significance of results.

- Use the results of evaluation to determine if the collaboration requires modification, improvement, expansion to maximize success or should be terminated [Strieter and Blalock, 2006].

7.3.5 Personnel practices

7.3.5.1 Identify and appoint suitable people

Appointing the right and capable people is important for the success of a UIC. The characteristics of individuals influence the effectiveness of collaboration. Universities and industry should identify and appoint staff and faculty who are suitable for UIC.

Motivated individuals play an important role in establishing collaborations and determining their outcomes. Individuals with an understanding of both academic and business worlds are often the driving force behind successful partnerships [Plewa et al., 2013; Edmondson et al., 2012; Santoro and Betts, 2002]. In addition, '...achieving a high level of collaboration depends on participants who contribute an openness to change, a willingness to cooperate, and a high level of trust' [Jassawalla and Sashittal, 1998].

As recognized earlier, universities and industry are often complex systems. Hence, individuals who understand the dynamics of both systems are expected to play an effective role in UICs. The benefits of hiring such people have been demonstrated by top universities in terms of industry engagements [The Australian National University, 2017; Tornatzky et al., 2002]. They hired nationally prominent scientists with backgrounds in industry and/or entrepreneurship.

The following recommendations are part of this practice:

- 'Select researchers who will understand company practices and technology goals' [Greitzer et al., 2010].
- Develop a pool of academics with business experience and deep understanding of industry [Edmondson et al., 2012].
- Hire individuals with experience in industry [Siegel et al., 2003c].
- Industry should 'hire technology managers with university experience' [Siegel et al., 2003c].

7.3.5.2 Appoint boundary spanners and/or agents

UIC partners should identify and appoint individuals as boundary spanners and/or agents dedicated to improving the effectiveness of UIC.

The term 'boundary spanners' is widely used to refer to an individual who can cross the formal boundaries of a department or organisation and/or has a cross-disciplinary or inter-organizational social network in which they operate [Chartered Accountants Australia and New Zealand, 2017]. They have a key capability to stimulate communication within their network and mobilize or reconfigure various required resources. 'Boundary spanners' have been identified as key players in establishing and sustaining effective UICs [Thune, 2007; Calder, 2007].

Boundary spanners influence the success of a collaboration in various ways:

- they act as a conduit for dissemination of tacit knowledge [Chartered Accountants Australia and New Zealand, 2017],
- they enable wider dissemination of research results to teams engaged in development and manufacturing within stakeholder companies, and
- they provide feedback from industry practitioners to academic researchers to help in maintaining research relevance and alignment with the industry requirement [Greitzer et al., 2010].

Several researchers extol the worth of an 'agent' or a champion [Bstieler et al., 2015] in ensuring actual knowledge transfer during UIC [Calder, 2007; Prigge, 2005;

Bloedon and Stokes, 1994]. These agents also perform monitoring, management and administration of UIC. Further endorsing the idea of an agent is the Process Model [Philbin, 2008] in which collaboration agents are an important element. According to the model, an agent is responsible for personally driving the collaboration forward and achieving its set objectives.

The following recommendations are part of this practice:

- 'Hire managers/research administrators with a strategic vision, who can serve as effective boundary-spanners' [Siegel et al., 2003c]".

- 'Select boundary-spanning project managers with three key attributes: In-depth knowledge of the technology needs in the area of interest; the inclination to network across functional and organizational boundaries, and the ability to make connections between research and opportunities for product applications' [Greitzer et al., 2010].

- Industry should identify and appoint individuals, who can play the role of an agent or champion in UIC.

7.3.5.3 Ensure leadership involvement

UIC partners should ensure leadership involvement. The success of a collaboration is influenced by leadership involvement through encouraging engagement, creating a conducive environment, and demonstrating commitment.

Collaborative initiatives driven by top leadership are expected to motivate the engagement of researchers and practitioners. A study confirms that the priority given by senior management to new product development through collaboration with external partners affects the level of collaboration [Jassawalla and Sashittal, 1998].

Leaders have decision making power to ensure that right people are allocated to drive collaborations, budget decisions are appropriate and timely, and required resources are available. This is expected to increase the chances of UIC success.

Entrepreneurial behaviour of a leader has the potential to directly impact the effectiveness of an organisation by inspiring other individuals to engage [John et al., 2015; Walter et al., 2002]. For example, the senior leadership at MIT that encouraged collaboration with industry laid critical foundations for successful UICs, and entrepreneurship [John et al., 2015].

7.3.6 Communication practices

7.3.6.1 Establish effective communication

Communication among participants is critical in order to coordinate work and manage UIC effectively. Stakeholders should adopt measures to improve communication between them, such as regular contact to meet and talk, encouraging bi-directional flow of information, and using virtual meeting tools. This will help overcome barriers such as a lack of information about benefits and opportunities. If UIC partners are geographically separated, utilising various modes of communications such as mobile, and digital media will be effective. Digital modes are also useful and effective during challenging situations requiring individuals to communicate in virtual environment.

Improvement in frequency and quality of communication between university and industry [de Wit-de Vries et al., 2019; Plewa et al., 2013; Thune, 2011; Butcher and Jeffrey, 2007; Santoro and Bierly, 2006; Kerka, 1997], especially bi-directional communication [Kaymaz and Eryiğit, 2011; Schartinger et al., 2002] are the key ingredients for successful collaborations [Mora-Valentin et al., 2004]. In addition, communicating the progress of UIC and its benefits within an organisation will encourage individuals to engage in future collaborations [Buys and Bursnall, 2007].

The following recommendations are part of this practice:

- Establish strong communication linkages between stakeholders [Greitzer et al., 2010].
- Conduct face-to-face meetings on a regular basis as required and when possible [Greitzer et al., 2010].
- 'Develop an overall communication routine to supplement the meetings' [Greitzer et al., 2010].
- Encourage exchange or mobilisation of individuals, both company to university and university to company [Greitzer et al., 2010].
- Encourage a two-way exchange of information between UIC partners [Edmondson et al., 2012].
- Organize co-located, shared and open office space and team-building activities to improve communication [Rohrbeck and Arnold, 2009].
- Organizations should build broad awareness of UICs within their organizations [Greitzer et al., 2010].

- Industry should provide feedback to the university team on alignment of UICs with their needs [Greitzer et al., 2010].

7.3.6.2 Maintain accessible contact information

Universities should maintain an accessible record of research results and associated contact persons. This will help overcome barriers such as difficulty in identifying relevant contacts.

A lack of visibility of university research projects and associated contacts was identified as a barrier to UIC during the qualitative study described in Chapter 4. Industry found it difficult to find the right collaborator to talk to with confidence and trust. In the reviewed literature, this lack of visibility of research is identified as a need to improve the search processes between companies and academics.[Chartered Accountants Australia and New Zealand, 2017]. An unstructured search process based on informal networks is considered ineffective in identifying relevant and appropriate contacts.

The following recommendations are part of this practice:

- Establish single points of contact and coordinating structures via which companies can explore potential research relationships [Tornatzky et al., 2002].

- Create databases of faculty interests, resources and competencies, and associated Web-based search engines that help companies find faculty members, equipment, facilities, and projects that match their needs [Tornatzky et al., 2002]. An example of this is ANU's TechBroker [Flint, Shayne, 2018] application.

7.3.6.3 Establish an effective dissemination strategy

Universities should establish an effective dissemination strategy.

Dissemination is a planned process of communicating research findings with consideration of the target audience. Effective dissemination enables the audience to quickly maximise benefits from research outputs [Wilson et al., 2010]. It will help overcome barriers such as a lack of awareness of research, and lack of information about benefits, and opportunities [Garousi et al., 2016].

Dissemination of research results should target participants, who can translate them into practice [Ripoll Feliu and Diaz Rodriguez, 2017; Fritz, 2016; Edwards, 2015]. This will provide benefits to the wider community [Knoepke et al., 2019]. It could also lead to obtaining new funding sources from organisations interested in the research results [Chen et al., 2010]. In some disciplines such as medical research, dissemination of research findings is emphasised as an ethical responsibility of a researcher [Pearn, 1995].

However, there are challenges to wide and timely dissemination [Chen et al., 2010]. The involvement of multiple and different types of stakeholders partly contributes to making the process of dissemination more complex [Alexander et al., 2018]. In addition, the narrow definition of dissemination among academics as publication in journals could delay the impact of discoveries [Group et al., 2013].

A lack of visibility of research results has been cited as a barrier to university-industry collaboration in the literature [Starkey and Madan, 2001] and during the qualitative study described in Chapter 4.

All these factors indicate that there is a need for academics to improve the dissemination of their research results with consideration to access and relevance of work, and style of academic writing [Straub and Ang, 2008; Starkey and Madan, 2001].

At a broader level, the qualitative study described in Chapter 4 identified a need to communicate the capabilities, results of research, and potential impact of these results in order to encourage industry interest in UIC.

The following recommendations are part of this practice:

- Highlight successful UICs on university websites. For example, the universities with a history of successful UICs had demonstrated their efforts to disseminate the value of research output by highlighting and extolling the successes of partnerships on university Web sites and through media, developing myths and stories about industrial engagement or entrepreneurial success, and promulgating them [Tornatzky et al., 2002].

- Universities must work towards strengthening their dissemination strategy and using elements of marketing for sharing research results, and their relevance in order to attract new partners. They should use a variety of channels to enhance the dissemination of results leading to improved industrial adoption of research such as increased contact with consumers of knowledge, validating the applicability of research results in a client-centric way, and formally creating new positions as knowledge brokers in academia.

- Communicate the value of research. Progress reports should be made available at various stages of collaboration. Communicating the benefits of a UIC can stimulate future collaborations.

7.3.7 Social capital practices

7.3.7.1 Adopt measures to increase trust and commitment

Collaboration partners need to adopt measures that help develop and support trust and commitment among them.

The existence of mutual trust is an important factor leading to more open communication and effective knowledge sharing between various stakeholders. Greater trust is also expected to increase confidence among partners, improve conflict resolution, allow more flexibility in relationships, and reduce control [Santoro and Bierly, 2006]. It contributes to the success of UIC.

Commitment, along with trust, is also a significant factor influencing the renewal of relationships between collaborators [Plewa and Quester, 2007]. Commitment refers to the dedication of an organization in terms of management support and resources allocated to UIC. Strong commitment by stakeholders is a key success factor for any collaboration [Plewa and Quester, 2007; Barnes et al., 2002; Santoro and Gopalakrishnan, 2001; American Association of State Colleges and Universities, 1987]. On the industry side, a strong commitment leading to a continued interest in projects during their development stages and in their results is a significant factor for fostering successful UIC [Rahm et al., 2013; Barbolla and Corredera, 2009; Peças and Henriques, 2006; Mora-Valentin et al., 2004]. High levels of commitment are expected to result in extensive participation from industry personnel in establishing research agendas followed by reviewing research progress and results.

Trust and commitment are interdependent and influence each other. Greater commitment leads to greater trust.

The following recommendations are part of this practice:

- 'Establish and nurture trusting working relationships between collaborators' [Strieter and Blalock, 2006].
- 'Create an environment of trust and transparency' [Rohrbeck and Arnold, 2009]. The importance of a trusting environment was also noted during the qualitative study described in Chapter 4. Trust was deemed necessary to encourage disclosure and discussion of ideas.
- Ensure that there is a commitment from industry in the form of resource allocation and involvement of managers with a clear definition of their roles in the UIC project [Peças and Henriques, 2006].
- Select and work on areas of interest of stakeholders in UIC, which increases commitment.

7.3.7.2 Ensure mutual obligations, and common understanding

Any successful relationship requires a positive attitude from partners, mutual respect and commitment to the collaborative venture [Dryden and Erzurumlu, 1996; Prigge, 2005]. In order to ensure a positive attitude and mutual respect from partners, it is important to pay due consideration during selection of partners and projects. Practices related to appropriate partner selection and collaboration project were discussed in Section 7.3.1 and Section 7.3.4 respectively. I have discussed practices related to common understanding in Section 7.3.3.

7.3.8 Legal practices

7.3.8.1 Develop a common understanding of Intellectual Property

UIC partners should develop a common understanding of IP.

Intellectual property rights are an important factor in many UICs. The process of identifying possible IP, decisions to protect it, and patent portfolio management is challenging. All UIC stakeholders must develop a common understanding around Intellectual Property (IP).

The following recommendations are part of this practice:

- Clearly articulate information related to IP to improve understanding of IP.
- Information related to invention disclosure and the patenting process should be made available to staff to increase their understanding of various aspects associated with IP. For example, institutions demonstrating excellent technology transfer functions in a US study ensured 'extensive informational outreach to faculty members to familiarize them with principles and operations of the technology transfer function' [Tornatzky et al., 2002]. Such access to information and clear understanding will help overcome legal barriers associated with information availability.

7.3.8.2 Negotiate and clearly articulate intellectual property rights

UIC partners should negotiate intellectual property rights, and clearly articulate the agreed terms [Dollinger et al., 2018]. Intellectual property negotiations have been formidable barriers to forming effective UICs. In order to prevent IP from becoming a stumbling block, partners should minimize constraints on information and universities should not seek to over-protect IP.

The following recommendations are part of this practice:

- Establish shared and enforceable guidelines limiting disclosure restrictions, and limiting conflicts of interest [Schofield, 2013; Burnside and Witkin, 2008; Santoro and Betts, 2002; Valentín, 2000].

- Articulate clear policy regarding publication and IP rights after negotiation [Rohrbeck and Arnold, 2009; Potworowski, 1989].

- Establish a legal framework for the collaboration. For example, framework utilisation for negotiations has proven to be successful in the case of Hewlett Packard (HP) and UC Berkeley, which led to the adoption of a similar approach in another agreement negotiation between HP and UC Davis [Burnside and Witkin, 2008].

- Design contracts that include exclusivity clauses. Consider providing IP rights, or the exclusive licensing right of UIC results to the industry stakeholders [Valentín, 2000; Webster and Etzkowitz, 1991] to build stronger relationships.

- Minimize constraints on information sharing [Valentín, 2000].

- Adopt more flexibility while negotiating agreements [Siegel et al., 2003c]. A study of universities, including US leaders in industry-sponsored research, indicates the importance of simplifying research contract language and using novel forms of packaging relationships (e.g., master agreements, strategic partnerships) [Tornatzky et al., 2002]. Another example is the new Intellectual Property and Industry Research Alliances office (IPIRA) established at the UC Berkeley. The IPIRA was established with an objective of streamlining relations with industry by acting as a 'one-stop shop' for UIC. It has led to faster contract negotiations with industry.

- Stakeholders must adopt a mature attitude to see the value of a UIC in terms of benefits other than just IP.

7.4 Application of the UIC Practices Framework

The proposed UIC Practices Framework can be used in conjunction with the Cynefin sense-making framework as part of the proposed UIC Framework, or as a standalone tool as described in the following sections.

7.4.1 Using the UIC Practices Framework with the Cynefin sense-making framework

- **Obvious Domain.** Within the obvious domain, the framework can be utilised to identify 'best' practices that can be used to ensure the effectiveness of UICs.
- **Complicated Domain.** Within the complicated domain, the framework can be utilised by experts to identify an appropriate set of practices that can be used to ensure the effectiveness of UICs.
- **Complex Domain.** Within the complex domain, experts can utilise the framework to design experiments to test the effectiveness of specific practices in a particular context. These experiments are expected to lead to emergence of new or best practices. As effective practices emerge, the UICs may move into the complicated domain, where experts can better manage them.
- **Chaotic Domain.** Within the chaotic domain, experts can select practices that they hope will immediately restore some kind of order and move the problem to the complex domain where more time can be used to find practices that are effective.

The detailed process for using the UIC Practices Framework within the UIC Framework is described in Chapter 9.

7.4.2 Using the UIC Practices Framework as a standalone tool

UIC stakeholders can use practices recommended by the proposed UIC Practices Framework to make informed decisions during the various stages of UICs. Better decisions will result in more effective UICs.

7.5 Evaluation and improvement of the UIC Practices Framework

As described in Chapter 3, a two-phase evaluation approach is adopted during this research. Phase one involves descriptive evaluation using illustrative scenarios, logical arguments, and expert evaluation. Section 9.3 in Chapter 9 presents scenarios that demonstrate the use of the UIC Practices Framework. These demonstrations also serve as descriptive evaluations of the UIC Practices Framework.

Phase two involves real-world evaluation and improvement of the framework, as detailed in Chapter 10.

7.6 Conclusion

In this chapter, a UIC Practices Framework is proposed to improve the effectiveness of UIC. The framework is based on a review of barriers, success factors and practices for collaboration described in existing literature as well as findings of the qualitative study involving industry practitioners and university researchers detailed in Chapter 4. As a consequence, the framework has its foundation in the existing literature as well as observations and experiences of the real-world.

During development of the framework an opportunity was identified to propose a new categorization scheme for success factors (Table 7.1) and practices (Table 7.2).

Often, the complex nature of the UIC process makes it difficult to guarantee success. However, the proposed practices framework is expected to improve the effectiveness of collaboration as it adopts a holistic view of collaboration and focuses on the success factors for, and barriers to UIC. It attempts to provide necessary guidelines for establishing and sustaining successful collaborations by providing a comprehensive and coherently integrated set of UIC practices that stakeholders can access in a single location.

The UIC Practices Framework can be used as a standalone tool, or in conjunction with the Cynefin framework to help universities and industry establish UICs, which are expected to be more effective and successful. While the framework includes practices for collaboration, it is not prescriptive. The practices are dynamic and may change with accumulation of knowledge and experience from use of the framework.

While the UIC Practices Framework focuses on universities and industry, it is expected to find wider applicability as the practices covered in the framework are based on general success factors and barriers that seem relevant to other contexts. Hence, the practices could be generalized to other organizational collaborations.

In order to assess the UIC maturity of an organisation on the basis of applied practices, a UIC Maturity Model is proposed in the next chapter.

Chapter 8

University-Industry Collaboration Maturity Model

In order to understand and improve University-Industry Collaboration (UIC), it is important for stakeholders to analyse and assess their collaborative capability. One way to conduct such assessment is by using maturity models, which have been applied successfully to assess capability in many domains including software development, quality assurance, knowledge management, and business processes.

In this chapter, I propose the UIC Maturity Model (UICMM) - a collaboration maturity model based on the practices framework presented in Chapter 7, and existing maturity models relevant to collaborations. The UICMM is intended to be a useful benchmarking tool for a range of stakeholders including universities and industry to assess and benchmark their collaborative capability. The underlying hypothesis while developing this maturity model is that a higher level of maturity indicates increased collaboration and improved outcomes.

8.1 Introduction

An organization engaged in collaboration would be interested in analyzing and evaluating the effectiveness of their collaborative efforts in order to identify and adopt possible improvements, and predict the likelihood of their success. A maturity model for collaboration can serve as a tool in assisting the planning of collaborations and evaluating their effectiveness. The use of maturity models is considered as a practical and widely accepted way for assessing organizations. In general, these models include progressive levels of maturity that can be achieved in a stepwise manner, allowing organizations to plan to achieve higher levels of maturity and evaluating their outcomes on achieving the planned levels.

A UIC Maturity Model (UICMM) is developed, which can be used by experts to assess an organisation's level of UIC maturity and guide their improvements.

8.2 What is a Maturity Model?

In general, 'maturity' can be defined as 'the state of being complete, perfect or ready' [Simpson et al., 1989]. That state is achieved through the transition of an entity from an initial level of maturity to a more advanced level, through intermediate levels. Thus, maturity implies evolutionary progress through a series of maturity levels. Maturity models provide a framework to describe and achieve such evolutionary progress.

The concept of maturity models originated in the early 1980s at IBM when Watts Humphrey and his colleagues noticed a positive correlation between the quality of the processes followed during software development and the quality of the software developed. It was observed that process improvement is evident as a series of steps. Humphrey [Humphrey, 1989] took his ideas to the Software Engineering Institute (SEI) at Carnegie Mellon University, where the maturity model framework was formulated [Paulk, 2009]. The term 'maturity model' was introduced and popularized by the SEI with development of the Capability Maturity Model (CMM) [Paulk, 2009; Chrissis et al., 1995] that later evolved into the CMM Integration (CMMI) [Chrissis et al., 2003]. These models were developed to assess the maturity or capability of software development processes in organizations.

Thus, a Maturity model is a tool used to assess and improve maturity of an organization's capabilities in a particular area of operation. They can be used:

- to assess and compare an organization's current situation,
- to identify opportunities for optimization,
- to establish goals and recommend actions for increasing the capability of a specific area within an organization, and
- as an instrument for controlling and measuring the success of an improvement action [Hain and Back, 2011; Hain, 2010; Becker et al., 2009].

The underlying idea of any maturity model is that organisations operating at higher levels of maturity are likely to be conducting the subject activity (eg. software engineering) more successfully. So, organisations working at higher levels of the UICMM are likely to be undertaking more effective and successful UICs. That is, a maturity model is a kind of proxy for direct evaluation of the output of a target activity. For example, use of the CMM is a proxy for evaluating the quality of software produced by a software engineering process. Those operating at higher levels of the CMM are likely to be producing higher quality software. So if we assess an organisation at low levels of the UICMM, they are unlikely to be engaging in effective UICs. Those at higher levels of maturity, are likely to be engaging in successful UICs. So, use of the UICMM is a proposed 'approach' to evaluating UICs within the context of a given organization. Moving up the maturity levels, implies 'improvement' of UICs undertaken by the organisation.

8.2.1 Maturity Model structure

Fraser [Fraser et al., 2002] identified the following basic components of maturity models:

- 'a number of levels (typically three to six),
- a descriptor for each level (such as the CMM's differentiation between initial, repeatable, defined, managed, and optimising processes),
- a generic description or summary of the characteristics of each level as a whole,
- a number of dimensions (often referred to as Key Process Areas),
- a number of elements or activities for each dimension, and
- a description of each element or activity as it might be performed at each level of maturity.'

8.3 Existing Maturity Models

In this section existing Maturity Models across a number of domains are reviewed. I consider these maturity models in order to deepen understanding of the various maturity models existing in literature, and to inform development of the proposed UICMM.

Maturity Models in the domains of knowledge management, and interoperability are considered as these domains are closely related to collaboration, and can play a significant role in improving its effectiveness.

I then look, in detail, at Maturity Models that specifically deal with various forms of collaboration.

One of the earliest documented Maturity Models is Crosby's Quality Management Maturity Grid (QMMG) [Crosby, 1979] that was developed for the purpose of evaluating the status and development of a firm's quality management approach.

In the area of software engineering processes, the Capability Maturity Model (CMM) has been proposed as an attempt to guide software organizations in enhancing software quality [Chrissis et al., 1995]. The CMM is intended to determine the current process maturity, guide the selection of process improvement strategies, and identification of the most critical areas for improvement of software quality and processes by software organizations. The model has gained considerable acceptance worldwide and has been regarded by many as the industry standard for defining software quality process [Paulk, 2009; Herbsleb et al., 1997; van der Pijl et al., 1997]. In the CMM, five levels of maturity are defined, namely initial, repeatable, defined, managed, and optimizing. Each maturity level is described by a unique set of characteristics that should be demonstrated by an organisation at a particular level.

With the integration of systems engineering, software engineering, and integrated process and product development, CMM evolved into CMM Integration (CMMI) [Paulk, 2009]. According to the SEI, CMMI helps 'integrate traditionally separate organizational functions, set process improvement goals and priorities, provide guidance for quality processes, and provide a point of reference for appraising current processes.'

Various maturity models have also been proposed in the knowledge management (KM) domain. Paulzen and Perc proposed a Knowledge Process Quality Model (KPQM) based on the ideas of quality management and process engineering [Paulzen et al., 2002]. A General Knowledge Management Maturity Model (G-KMMM) [Teah et al., 2006], based on the review, comparison and integration of existing Knowledge Management Maturity Models (KMMM), assesses the maturity of people, process and technology aspects of KM development in organizations.

In the domain of interoperability, a few maturity models have been proposed [Van Staden and Mbale, 2012; Clark and Jones, 1999] and reviewed [Guédria et al., 2008]. Levels of Information System Interoperability (LISI) [C4ISR Architecture Working Group and others, 1998] is a widely recognized model for system of systems interoperability. The main focus of LISI is on technical interoperability and interoperational complexity between systems. Other models include Organizational Interoperability Maturity Model [Clark and Jones, 1999], NATO C3 Technical Architecture (NC3TA) Reference Model for Interoperability, Levels of Conceptual Interoperability (LCIM) Model, Layers of Coalition Interoperability, and The System of Systems Interoperability (SOSI) Model [Morris et al., 2004]. Gottschalk proposed a maturity model for interoperability in digital government focusing on interoperability of system, process, knowledge, value, and goal [Gottschalk, 2009].

In addition to Maturity Models developed in technical domains such as software engineering, knowledge management, and interoperability, they have also been developed in domains such as security, user experience, customer service, project management, health care, learning, marketing, analytics, risk and fraud.

The existence of such vast number of maturity models in a diversity of areas as described above indicates their wide acceptance, use and value as an assessment tool.

8.3.1 Existing collaboration Maturity Models

In this section, I review various maturity models proposed for improving collaboration. These models are described below and summarized, along with their associated KPAs, in the Table 8.1. While the list of models is not exhaustive, it is representative of relevant maturity models.

8.3.1.1 Collaboration Maturity Grid (CMG)

The Collaboration Maturity Grid (CMG) [Fraser et al., 2003] is used to examine the issues faced by organisations during outsourcing activities, and provide guidance to managers involved in collaborations.

The CMG is based on a review of new product introduction (NPI) literature, a qualitative study involving practitioners, and case studies of firm-firm collaboration. Feedback from practitioners during the development of the model adds relevance to it and increases its potential application.

The model considers the complete lifecycle of a collaborative development project with the mapping of relevant factors at each phase of the lifecycle. It identifies the following seven 'Key Process Areas' and defines criteria associated with them at each maturity level.

- 'collaboration strategy,
- structured development process,
- system design and task partitioning,
- partner selection,
- project initiation,
- partnership management, and
- partnership development'.

The model has proven to be useful through field-testing in inter-firm collaboration contexts.

8.3.1.2 Crowdsourcing Ideation Maturity Assessment Model (CIMAM)

The Crowdsourcing Ideation Maturity Assessment Model (CIMAM) [Boughzala et al., 2014] is a maturity model for the assessment of ideation processes in crowdsourcing projects. It can assist organizations in the selection of effective crowdsourcing platforms, determining the most suitable idea, and managing evaluation practices for selected projects.

The CIMAM is based on a literature review of maturity models, crowdsourcing, and a conceptual model for crowdsourcing [Pedersen et al., 2013]. Its development follows the Design Science approach. The model defines six KPAs, referred to in the model as 'themes' (adapted from [Pedersen et al., 2013]), as depicted in Table 8.1. For each KPA, the model identifies the criteria that must be met to achieve each level of maturity.

Unlike other collaboration maturity models discussed in this section, the CIMAM places a strong emphasis on technology as crowdsourcing can not be operated without a digital platform. The process of application of the model is documented and it has been validated against Hevner's design science guidelines [Hevner et al., 2004]. While the model considers collaboration, its application is limited to crowdsourcing.

8.3.1.3 Collaboration Maturity Model (Col-MM)

The Collaboration Maturity Model (Col-MM) [Boughzala and de Vreede, 2012] is proposed for assessing an organization's team collaboration quality. It is generic-enough to be applied to any type of collaboration, and can be used by practitioners for self-assessments.

The development of Col-MM, like CIMAM, is based on the Design Science approach. It involved engagement with a focus group of professional collaboration experts, which contributed to increased relevance and applicability of the resulting model. The model defines the same levels of maturity as the CIMAM, and is one of the most comprehensive models in terms of the various KPAs of collaboration covered. These KPAs, referred to in the model as 'areas of concern', are based on the suggestions of experts, making them relevant to practice. The model clearly articulates the criteria associated with each KPA with their descriptions indicating an evolutionary progress from lower levels to higher levels of maturity. The process for application of the model is well-documented and it has been validated in real-world settings.

8.3.1.4 Enterprise Collaboration Maturity Model (ECMM)

The Enterprise Collaboration Maturity Model (ECMM) presents a process improvement approach for organizations participating in a collaborative network. A collaborative network comprises of geographically distributed and usually heterogeneous organizations collaborating over a digital network to achieve a common goal [Camarinha-Matos et al., 2009].

The model is used to assess organizations participating in a network, both as a stand-alone company and with respect to the network [Alonso et al., 2010]. The results of this assessment provide organizations with their current state of collaboration, the requirements they are expected to satisfy in order to reach the next level of maturity, as well as a roadmap and improvement plan for doing so.

The structure of ECMM is based on CMMI building blocks. The model defines seven KPAs, referred to as 'domains' in the model, and further identifies an exhaustive list of more specific process areas within each KPA. However, the characteristics of the KPAs at each level of maturity are not described, which may lead to difficulty in assessing the maturity level of an organisation. On a positive note, the process of application of the model is clearly documented.

8.3.1.5 Collaboration Engineering Maturity Model (CEMM)

Collaboration Engineering is an approach to the design and deployment of collaborative processes [Kolfschoten and De Vreede, 2009; Briggs et al., 2003].

The Collaboration Engineering Maturity Model (CEMM) was proposed to help improve Collaboration Engineering (CE) processes. The approach has two dimensions: the phases of the collaboration engineering approach and the maturity levels corresponding to each phase [Santanen et al., 2006]. The model assists with monitoring and assessment of Collaboration Engineering processes.

Regarding development of the CEMM, it is derived from the Software Process Improvement and Capability dEtermination (SPICE) model [ISO/IEC, 2004]. If we analyse the design of the maturity model, it focuses on the various phases of collaboration. Unlike other maturity models, it uses these phases for maturity level assessment instead of associating any Key Process Areas with the maturity levels.

Table 8.1: Collaboration Models in the Existing Literature

Model	Levels	Key Process Areas (KPAs)	Inspiration	Context
CMG	4 levels: Level 1, Level 2, Level 3, and Level 4	collaboration strategy, structured development process, system design and task partitioning, partner selection, project initiation, partnership management and partnership development.	CMMI, KMMM and BPMM	Outsourcing, Distributed Development
CIMAM	4 levels: Ad-hoc, Exploring, Managing, and Optimizing	Problem, Process, Governance, People (Crowd, Individual, Problem owner), Technology, Outcome	Maturity Model literature	CrowdSourcing
Col-MM	4 levels: Ad-hoc, Exploring, Managing, and Optimizing	Collaboration characteristics, Collaboration Management, Collaboration Process, Information and Knowledge Integration	Maturity Model literature and Focus Group	Team collaboration in an organization
ECMM	4 levels: Performed, Managed, Standardized, and Innovating	Project and Product Management, Business Process and Strategy, Customer Management, Collaboration, Legal Environment and Trust, Organisation, Systems and Technology, Innovation	CMMI	Business in a networked environment
CEMM	4 levels: Provisional, Predictable, Managed, and Optimized	Phases of Collaboration Engineering	Maturity Model literature	Collaboration Engineering Processes
CollabMM	4 levels: Ad-hoc, Planned, Aware, and Reflexive	Communication, coordination, group memory and awareness	CMMI, KMMM and BPMM	Team collaboration within an organization.
DPMM	3 levels: initiation, consolidation, and high-productivity	Belief and willingness , Personnel communication skills, Utilization of distributed technology infrastructure, Critical mass (team size), Understanding cultural differences, Managerial training, Setting shared business goals, Tailoring business goals, Budgeting and cost structures, Devising mechanisms for division of labor, Product development tools and processes, Consistency in project management processes, Ownership and responsibilities, Knowledge transfer, Top-management communication channels, Performance monitoring, Managing complexity, Managing social networks, Enabling social communication via technology, Nurturing and leveraging core competencies, Interorganizational innovation management, Best practices management, Contract management and nurturing partnership, Managing symbiotic relationship and continuous development	CMMI, KMMM and BPMM	Distributed Development

8.3.1.6 Collaboration Maturity Model (CollabMM)

The Collaboration Maturity Model (CollabMM) was inspired by existing maturity models such as CMMI, KMMM and Business Process Maturity Model (BPMM) [Rosemann et al., 2004], and aims to organize a set of practices for enhancing collaboration in business processes [Magdaleno et al., 2011, 2009].

The CollabMM is defined based on four KPAs: communication, coordination, awareness, and memory, which were identified through a review of groupware research literature. The activities associated with these KPAs at each maturity level are defined. However, the activities need clear articulation for each maturity level to indicate their evolutionary progress. It is acknowledged by the authors of the model that the levels definitions and the measurements of each level need to be formalized. The model has been applied in two organizations and the limitations identified during the application of the model led to the identification of a roadmap for its evolution [Magdaleno et al., 2011].

8.3.1.7 Distributed Process-Maturity Model (DPMM)

The Distributed Process-Maturity Model [Ramasubbu et al., 2005] has 3 levels of maturity, and features 24 KPAs mapped to four concepts for distributed development: mutual knowledge, technology readiness, collaboration readiness, and coupling in work (mechanisms for division of labour).

Development of the DPMM has a theoretical grounding in existing literature related to distributed development. Its development was driven by the requirement to evaluate the performance of distributed development, limitations of the CMM and ISO 9001 to conduct such assessment, and the need to identify best practices for improving performance in the context of its application.

Similar to the CIMAM [Boughzala et al., 2014], the DPMM emphasises use of technology, which is an essential factor for distributed development. Unlike other collaboration maturity models, the DPMM places the KPAs themselves at different levels of maturity instead of defining evolutionary progress of characteristics for KPAs. For example, the concept 'coupling in work' does not have a KPA defined at level 1.

The model has been validated using expert evaluation and data collection from real-world projects.

Table 8.2: Key Process Areas (KPAs) of UICMM in relation to KPAs of other Maturity Models

UICMM	CMG	CIMAM	Col-MM	ECMM
Contextual	Partner selection		Collaboration characteristics	Collaborative customer relationship management, Customer evaluation, Open innovation
Organizational	Collaboration strategy	Governance Technology	Collaboration characteristics	Business management Measurement analysis Resource management Organization innovation Training and competency development Organizational process performance
Cultural adaptation				
Operation and Management	Project initiation Structured development process System Design and Task Partitioning	Problem Process Governance	Collaboration characteristics	Collaborative project management Configuration management Process and Product assurance Requirements management Business governance Collaborative business process Defect and problem prevention Requirements development Risk management Technical solution Quantitative project management
Individuals		People	Collaboration characteristics	
Communication	Partnership management	Technology	Collaboration characteristics	Interoperability and Collaboration technologies
Social Capital	Partnership development	People	Collaboration characteristics	Trust management
Legal	Project initiation			Collaboration agreement, IPR
Outcome		Outcome		
Knowledge Management		Technology	Information and knowledge integration	

Table 8.3: Key Process Areas (KPAs) of UICMM in relation to KPAs of other Maturity Models

UICMM	CEMM	CollabMM	DPMM
Contextual	Field interview	Awareness	Belief and willingness
Organizational	Sustained organizational use		Belief and willingness Utilization of distributed technology infrastructure Budget and cost structure Managerial training Nurturing and leveraging core competencies Best practices management
Cultural adaptation		Coordination	Understanding cultural differences
Operation and Management	Field interview Design Transition Practitioner implementation		Setting shared business goals Tailoring business goals Devising mechanism for division of labour Product development tools and processes Consistency in project management processes Ownership and responsibilities Performance monitoring Managing complexity
Individuals			Personnel communication skills Critical mass Managing social networks
Communication		Communication	Top-management communication channels Enabling social communication
Social Capital			Managing symbiotic relationship and continuous development
Legal			Contract management and nurturing partnership Interorganizational innovation management
Outcome			
Knowledge Management		Memory	Knowledge transfer

8.3.2 The need for a new Maturity Model for UIC

As illustrated in the previous section (Section 8.3.1), various models for collaboration have been proposed in the existing literature. All of these maturity models have defined a set of maturity levels along with associated KPAs. They generally have 4 levels except for DPMM [Ramasubbu et al., 2005], which has 3 levels, as depicted in Table 8.1. Most of the models have levels indicating progress from 'ad-hoc' to 'optimized', though different terminologies have been used.

Tables 8.2 and 8.3 show the KPAs covered by the maturity models discussed in Section 8.3.1. These KPAs are grouped according to the KPAs to be used by the proposed UICMM described in Section 8.4. These UICMM KPAs are those applicable to UIC and were derived from the categorization of practices presented in Chapter 7, and KPAs common across the maturity models discussed in Section 8.3.1.

Tables 8.2 and 8.3 show that none of the existing models cover all of the KPAs applicable to UIC. Most of the KPAs in the Collaboration Maturity Grid (CMG) [Fraser et al., 2003] are relevant to UIC. However, its focus on NPI and inter-firm collaboration may restrict its generalization to UICs, which do not always involve or lead to creation of a product. The CIMAM [Boughzala et al., 2014] focuses on crowdsourcing. Crowdsourcing is open collaboration. In contrast, in a UIC, university and industry participants have to work under the guidelines or code of conduct of their organizations. Hence, crowdsourcing operates in a different professional environment compared to formal UICs. So, application of the CIMAM to UIC needs validation. The Col-MM [Boughzala and de Vreede, 2012] is limited to assessing team collaboration quality within an organization. While aspects identified in the CollabMM are relevant to UIC, the model has been designed for the intra-organisational setting, and does not consider several aspects relevant to UIC such as cultural adaptation, and organizational factors. The DPMM considers a comprehensive set of factors for distributed software development, which are also relevant to UIC. However, globally distributed development teams may be operating within a single organisation. As such, they may have fewer conflicts arising out of different operational cultures. Hence, application of the DPMM to UIC, which involves multiple organisations with different operational norms, would need to be the subject of further research.

The above analysis demonstrates the need and scope for developing a comprehensive UIC maturity model. In order to address this need, the UICMM, a comprehensive maturity model for assessing organizational collaboration maturity, is proposed based on the UIC Practices Framework (Chapter 7) and existing relevant maturity models.

8.4 UICMM: A Maturity Model for University-Industry Collaboration

In this section I describe the UICMM along with the methodology adopted to develop and evaluate it.

8.4.1 UICMM design

Because maturity models are artefacts designed to solve particular problems, Design Science, as described in Chapter 3, will be used to design and evaluate the UICMM. Specifically, Becker's [Becker et al., 2009] systematic approach for developing maturity models based on Design Science guidelines defined by Hevner et al. [Hevner et al., 2004] will be adopted.

Becker's approach comprises a set of eight requirements, which need to be addressed when designing a new Maturity Model. Each of the following sections describe the design of the UICMM in terms of these requirements.

8.4.1.1 R1 - Comparison with existing maturity models

> *'The need for the development of a new maturity model must be substantiated by a comparison with existing models. The new model may also just be an improvement of an already existing one.'*

I have reviewed the existing maturity models and compared the models related to collaboration as depicted in the Table 8.1. None of these models specifically address UIC, but they do provide guidance in identifying key process areas for the UICMM.

8.4.1.2 R2 - Iterative procedure

> *'Maturity models must be developed iteratively, i. e., step by step.'*

An iterative procedure was followed to develop the initial version of the UICMM. The first model was developed based on the UIC Practices Framework described in Chapter 7. This model was further developed using inputs from the review of existing maturity models presented in Section 8.3.1. As lessons are learned during real-world evaluation and use of the UICMM (Chapter 10), I expect to create further iterations of the model.

8.4.1.3 R3 - Evaluation

> *' All principles and premises for the development of a maturity model, as well as usefulness, quality and effectiveness of the artifact, must be evaluated iteratively.'*

The proposed maturity model has been evaluated against the general requirements of a maturity model outlined in literature [Fraser et al., 2002; Klimko, 2001] as described in Section 8.7.1. An evaluation for utility and applicability of UICMM is presented in Section 8.7.2. In addition, I have developed a strategy for real-world evaluation and improvement of the model as described in Chapter 10.

8.4.1.4 R4 - Multi-methodological procedure

> *'The development of maturity models employs a variety of research methods, the use of which needs to be well-founded and finely attuned. This requirement is based on 'Guideline 5: Research Rigor', that recommends that the selected methods need to be rigorously attuned.'*

This requirement is fulfilled by using various methods for data-collection to develop the model such as the qualitative study described in Chapter 4, the UIC Practices Framework described in Chapter 7, and review of existing maturity models as described in Sections 8.3.1 and 8.4.1.1 (R1).

8.4.1.5 R5 - Identification of problem relevance

> *'[Design Science] 'Guideline 2: Problem Relevance' [Hevner et al., 2004] states that the problem-solving artifact must not only be innovative, but the problem to be solved must also be relevant for researchers and/or practitioners. This relevance can again be established through different scientific methods, e. g. by interviewing potential users of the maturity model in question. Establishing relevance also requires the exact definition of the problem, which in turn is prerequisite for ensuing evaluations. The relevance of the problem solution proposed by the projected maturity model for researchers and/or practitioners must be demonstrated.'*

The work presented in Chapter 2 and Chapter 4 as well as the early feedback from the potential users (Section 8.7.2), establishes the relevance of the problem, and importance of this work.

8.4.1.6 R6 - Problem definition

> *'The prospective application domain of the maturity model, as well as the conditions for its application and the intended benefits, must be determined prior to design.'*

The problem has been clearly defined in Chapter 1 as 'the need to improve UIC'. The objective is identified as evaluating and improving UIC. The UICMM presents itself as a tool to assist organisations in assessing their UIC maturity. The UICMM can be applied in both inter-organisational and intra-organisational settings. The intended benefits of using the UICMM include improved UICs which will, in turn, deliver benefits to both industry and universities as discussed in Section 2.2.

8.4.1.7 R7 - Targeted presentation of results

> *'The presentation of the maturity model must be targeted with regard to the conditions of its application and the needs of its users. Documentation of the research process is of vital importance for the scientific procedure. 'Guideline 7: Communication of Research' emphasizes that the presentation of results must be targeted at the specific user groups.'*

The UICMM has been presented using KPAs relevant to UICs. The characteristics of KPAs have been described for each level of maturity to assist in assessment of the evolutionary progress of an organisation's UIC maturity. In addition, the process of application of the UICMM as well as a survey questionnaire to assist the assessment is documented in this thesis. It is expected to be useful for various stakeholders in UIC. Further, a digital tool designed to support UICMM based assessments and presentation of assessment results, is planned as part of future work (Chapter 11, Section 11.7). The research process adopted during development of the UICMM is clearly documented.

8.4.1.8 R8 - Scientific documentation

> *'The design process of the maturity model needs to be documented in detail, considering each step of the process, the parties involved, the applied methods, and the results. [Becker et al., 2009]'*

Documentation of the UICMM development is presented in this thesis. The definition of each maturity level has been clearly documented for understanding and application by its intended users. In addition, a conference paper related to this work has been published [Awasthy et al., 2018], and submission of an extended version has been requested for publication in a journal.

8.4.2 UICMM maturity levels

The proposed UICMM comprises five levels of maturity as depicted in Table 8.4 and described below. The level of 'maturity' in the UICMM refers to the maturity of organizational capabilities and processes related to supporting and managing UICs. The descriptions at each level are intended to indicate incremental development in an organization's level of UIC maturity, where some of the descriptions are derived from the reviewed literature. The five levels in UICMM were determined to adequately depict gradual improvement.

Table 8.4: Maturity Levels of UICMM

Level	Definition
5: Continuous improvement	Continual improvement. Diversity of stakeholders. Collaboration processes are reviewed, measured and improved.
4: Practised and Managed	Ensuring the quality of both the collaboration process and outcomes. Collaboration related activities are part of work-flow with commitment from leadership, and training and rewards for individuals engaging in collaboration.
3: Encouraged	Culture encourages collaboration. Value of collaboration is recognized. Awareness of various ways of interaction. Clear objectives for collaboration.
2: Initial	Awareness of value of collaboration leads to efforts to gain knowledge about various ways of collaboration. People who understand the value of collaboration may do it.
1: Non-existent	Isolated entities. There is general unwillingness to collaborate. Collaboration is not valued.

Level 1: Non-existent - At this level, organisations work as isolated entities. Collaboration is not initiated or conceptualised due to a general unwillingness to collaborate. There is lack of recognition of its value. This level recognizes that some organisations may not be currently engaging in UIC.

Level 2: Initial - Organisations are developing awareness of the collaboration system, which means they are spending time researching emerging collaborations among other organisations. At this level organisations are realizing the importance of collaboration and are initiating efforts to collaborate. They gain knowledge regarding various ways of collaboration. Motivation and benefits of collaborations are identified. Various barriers to collaboration are studied and understood. However, organisations are still thinking in isolation and are working towards their own distinct goals with independent decision-making.

Level 3: Encouraged - Organizational culture encourages collaboration as its value is recognized. At this level, stakeholders have been identified, objectives are defined and a framework to work under has been agreed upon. This level is focused on the structure and definition of processes involved in collaboration. Processes are customized in order to achieve shared objectives among stakeholders.

Level 4: Practised and managed - Value of collaboration is well-established with quality of both the collaboration process and outcomes being ensured. Goals are shared by collaborators and progress is tracked. To enhance the effectiveness of collaboration there are defined processes for collaboration. Training is provided to individuals engaging in collaboration. Systems/tools are set-up for collaboration, and performance is measured. Leadership exhibits commitment to collaboration and provides a collaboration strategy.

Level 5: Continuous improvement - This is the level of continual improvement, where collaboration is mature and operating seamlessly between a diverse set of stakeholders. It is achieving high quality outcomes and deriving benefits that have a wider socio-economic impact. Collaboration systems are widely accepted, monitored and updated accordingly. Review processes are established to assess collaboration processes and feedback into the system for continuous improvement. Past experiences are utilized to make informed decisions. Collaboration assessment guides realistic improvements by identifying improvement areas.

8.4.3 UICMM Key Process Areas

The dimensions or Key Process Areas (KPAs) in a maturity model indicate the areas where organisations should focus in order to improve the maturity of the subject domain such as quality assurance, interoperability, UIC. To be specific, the SEI defines a process area as 'a cluster of related practices in an area that, when implemented collectively, satisfies a set of goals considered important for making improvement in that area' [CMMI Product Team, 2011, pg. 13].

In the UICMM context, KPAs indicate the identified areas where organizations should focus in order to improve the effectiveness of UIC by achieving higher levels of maturity. Descriptions of practices associated with the KPAs at each level will allow organisations to assess their current level of maturity and identify the practices to be followed or improved to achieve higher levels of UIC maturity.

The following Key Process Areas (KPA) of the UICMM are derived from the UIC Practices Framework (Chapter 7) and existing maturity models (Section 8.3.1):

- **Contextual** - related practices described in Section 7.3.1.
- **Organizational** - related practices described in Section 7.3.2.
- **Cultural adaptation** - related practices described in Section 7.3.3.
- **Operation and Management** - related practices described in Section 7.3.4.
- **Personnel** - related practices described in Section 7.3.5.
- **Communication** - related practices described in Section 7.3.6.
- **Social capital** - related practices described in Section 7.3.7.
- **Legal** - related practices described in Section 7.3.8.
- **Outcome** - derived from the CIMAM [Boughzala et al., 2014] (Section 8.3). Outcomes are the results of UIC for individuals and organisations, which may be direct or indirect, tangible or intangible, and positive or negative.
- **Knowledge Management** - derived from the CIMAM [Boughzala et al., 2014], Col-MM [Boughzala and de Vreede, 2012], ColabMM [Magdaleno et al., 2009], DPMM [Ramasubbu et al., 2005], and G-KMMM [Teah et al., 2006] (Section 8.3). Knowledge management refers to the capacity of an organisation to manage its knowledge base including both tacit and explicit knowledge. It includes effective utilization of existing knowledge, and acquisition and absorption of new related and unrelated knowledge to achieve organizational goals.

The characteristics of KPAs at each level of the proposed UICMM are presented in Tables 8.5, 8.6, 8.7, 8.8, and 8.9. Descriptions of the characteristics have been derived from the UIC Practices Framework (Chapter 7) and characteristics of the maturity models reviewed in Section 8.3. These descriptions are intended to indicate incremental development in the KPAs as organizations increase their level of maturity. It is to be noted that the definition of characteristics of a KPA at each level is expected to include the characteristics at lower levels.

Table 8.5: Characteristics of Key Process Areas (KPAs) at Maturity Level 1 of UICMM

Maturity Level	**Key Process Areas**	**Description of Characteristics**
Level 1: Non-existent	Contextual (Practices in Section 7.3.1)	Undefined.
	Organizational (Practices in Section 7.3.2)	Unaware of collaboration needs.
	Cultural adaptation (Practices in Section 7.3.3)	Difference in goals and objectives.
	Operation and Management (Practices in Section 7.3.4)	No formal process to collaborate.
	Personnel (Practices in Section 7.3.5)	Working in isolation. Not aware of the need to collaborate.
	Communication (Practices in Section 7.3.6)	No communication.
	Social Capital (Practices in Section 7.3.7)	Non existent.
	Legal (Practices in Section 7.3.8)	Not applicable.
	Outcome	Unclear
	Knowledge Management	No management.

Table 8.6: Characteristics of Key Process Areas (KPAs) at Maturity Level 2 of UICMM

Maturity Level	Key Process Areas	Description of Characteristics
Level 2: Initial.	Contextual (Practices in Section 7.3.1)	Efforts to understand the variety of possible UICs types, and identify motivations. No set process or criteria for identification of stakeholders.
	Organizational (Practices in Section 7.3.2)	Understanding of the value of collaboration. No concern for Alumni relationships.
	Cultural adaptation (Practices in Section 7.3.3)	Developing understanding of difference in culture, mission and goals between partner organisations.
	Operation and Management (Practices in Section 7.3.4)	Identifying objectives and goals.
	Personnel (Practices in Section 7.3.5)	Motivated to collaborate. Identification of key individuals.
	Communication (Practices in Section 7.3.6)	Limited one way communication. Information is only provided when requested.
	Social Capital (Practices in Section 7.3.7)	There is trust regarding ethical performance of partners. Commitment specific to the collaborative effort. Trust needs to be established beyond individual UICs.
	Legal (Practices in Section 7.3.8)	Developing understanding regarding legal aspects including IP.
	Outcome	Some idea about goals.
	Knowledge Management	Limited knowledge sharing.

Table 8.7: Characteristics of Key Process Areas (KPAs) at Maturity Level 3 of UICMM

Maturity Level	**Key Process Areas**	**Description of Characteristics**
Level 3: Encouraged.	Contextual (Practices in Section 7.3.1)	Variety of UIC mechanisms explored. Clear articulation of motivation. Predefined criteria for identification of stakeholders.
	Organizational (Practices in Section 7.3.2)	Practices adopted to encourage collaboration. Short-term or lower levels of engagements. Alumni relationships encouraged.
	Cultural adaptation (Practices in Section 7.3.3)	Creation of shared goals. Awareness of time requirements.
	Operation and Management (Practices in Section 7.3.4)	Processes for collaboration formalized.
	Personnel (Practices in Section 7.3.5)	Capable people to identify collaboration opportunities, reach out and engage.
	Communication (Practices in Section 7.3.6)	Regularly scheduled communication. Two-way exchange.
	Social Capital (Practices in Section 7.3.7)	Partner is considered as trusted, generally based on past experiences. Low commitment of time or resources.
	Legal (Practices in Section 7.3.8)	Shared and enforceable guidelines established.
	Outcome	Clear definition of goals.
	Knowledge Management	Organization recognizes the importance of knowledge management. Basic knowledge management infrastructure established.

Table 8.8: Characteristics of Key Process Areas (KPAs) at Maturity Level 4 of UICMM

Maturity Level	Key Process Areas	Description of Characteristics
Level 4: Practised and Managed.	Contextual (Practices in Section 7.3.1)	A portfolio of UICs is maintained. Precisely defined and organizationally aligned motivations. Defined process for identification of stakeholders.
	Organizational (Practices in Section 7.3.2)	Collaboration is part of the organisation's strategy. Measures adopted to facilitate effective collaboration. Deeper levels of collaboration. Well-maintained alumni relationships.
	Cultural adaptation (Practices in Section 7.3.3)	Common vision. Adapting to each other's requirements.
	Operation and Management (Practices in Section 7.3.4)	Quantitative measurement of collaborations.
	Personnel (Practices in Section 7.3.5)	Individuals recognize the value of collaboration. Individuals are trained. Self-motivated to engage in various collaborative efforts.
	Communication (Practices in Section 7.3.6)	Planned as a part of collaboration. Systematic and multiple modes of communication. Balanced two-way exchange.
	Social Capital (Practices in Section 7.3.7)	Complete trust among partners due to previous experiences. High commitment in terms of time or resources.
	Legal (Practices in Section 7.3.8)	Clear and agreed IP and publication rights strategy.
	Outcome	Mutually beneficial outcomes aligned with goals. A broad spectrum of outcomes.
	Knowledge Management	Knowledge management is part of the organizational strategy.

Table 8.9: Characteristics of Key Process Areas (KPAs) at Maturity Level 5 of UICMM

Maturity Level	**Key Process Areas**	**Description of Characteristics**
Level 5: Continuous improvement.	Contextual (Practices in Section 7.3.1)	Multiple types of collaboration. Shared motivation having wide impact. Informed identification and review of stakeholders.
	Organizational (Practices in Section 7.3.2)	Collaborative efforts are measured and rewarded. Deeper and longer term collaborative engagements. Improvement measures for alumni relationships.
	Cultural adaptation (Practices in Section 7.3.3)	Working seamlessly with each other.
	Operation and Management (Practices in Section 7.3.4)	Collaboration processes are reviewed and improvement measures adopted. Existing processes can be adapted to address the requirements of changing environment.
	Personnel (Practices in Section 7.3.5)	Boundary spanners are appointed. Leadership is involved and inspires individuals to collaborate.
	Communication (Practices in Section 7.3.6)	Seamless communication. Communication of progress. Wider results dissemination methods.
	Social Capital (Practices in Section 7.3.7)	Stronger trust leading to continued engagement. High commitment demonstrated through resource engagement and leadership involvement. There is continuous mutual improvement in trust and commitment between stakeholders.
	Legal (Practices in Section 7.3.8)	Understanding of the value of partnerships beyond the IP rights. Review of strategies.
	Outcome	Collaboration is measured and reviewed based on outcomes.
	Knowledge Management	Knowledge management processes are reviewed for improvements.

8.5 Application of the UICMM

The proposed UICMM can be used in conjunction with the Cynefin sense-making framework as part of the proposed UIC Framework, or as a standalone tool as described in the following sections.

8.5.1 Using the UICMM with the Cynefin sense-making framework

The proposed UICMM can be used in conjunction with existing organizational practices or, where applicable, in conjunction with the UIC Practices Framework (Chapter 7) and the Cynefin framework as described in Chapter 9. While the UICMM could be used in any Cynefin domain to assess the maturity level of UIC within an organization, it is most applicable in the complicated and complex domains.

In the complicated domain, experts can use the maturity model to identify and apply the practices required to move to the next level of maturity. Within the complex domain, experts can design experiments aimed at identifying those practices that will be effective in moving an organization to higher levels of maturity.

The detailed process for using the UICMM within the Cynefin framework is described in Chapter 9.

8.5.2 Using the UICMM as a standalone tool

In this section, I present a process for application of the proposed UICMM as a standalone tool in real-world settings. The process includes interviewing stakeholders, a survey instrument, and a review of information available through public sources.

The steps in the process are summarised below.

1. **Identify the unit of analysis for UICMM.** The UICMM was developed with an intention to assess the UIC maturity of organisations. The unit of analysis for evaluation of the UICMM is identified as an organisation. However, the assessment of an organisation cannot be conducted in isolation from the UIC projects it is engaging in. So, in order to assess the organisational UIC maturity, it is important to identify the UICs that will be included as part of the maturity level assessment.

   It is to be noted that the UICMM can be used for self-assessment or third-party assessment. In this step, this assessment type needs to be clearly stated. The self-assessment process may introduce some bias in the assessment. In order to overcome this bias, an evidence-based approach is recommended during information gathering, where each criterion (characteristic of a KPA) is supported by evidence.

2. **Finalise information details.** This step involves identification of information to be gathered for the assessment purpose. The information includes organisational and project characteristics aligning with KPAs in the UICMM (Section 8.4.3).

3. **Identify the Participants.** This step identifies individuals to be involved in the information gathering process. The organisation will need to recommend individuals to be involved in the data-collection process based on the following criteria:

   * The individual possesses in-depth knowledge about UIC and/or maturity models.
   * The individual has experience through direct or indirect engagement in UIC within the organization.
   * The individual has access to required information within the organization
   * The individual has knowledge about the confidentiality of data being collected.
   * The individual has decision-making roles or authority to reach out to appropriate individuals within the organisation when seeking further information or clarification.

   To prevent data-collection bias, multiple individuals from diverse backgrounds representing different disciplines/sectors, such as project/department heads, researchers, and other stakeholders with involvement in UIC, should be selected.

4. **Information gathering.** In this step, the assessment team selects the instruments for information gathering, and uses them to gather the quantitative and qualitative information identified in step 2 from the participants identified in step 3. The instruments for information gathering include public sources, interviews, and surveys.

   The semi-structured interview/survey approach including open-ended questions and Likert-scale questions structured around the KPAs within UICMM seems appropriate to gather the required information in an unbiased way as open-ended questions can seek an evidence-based response. The benefits of semi-structured interviews have been described in Section 4.3.4.3. Semi-structured in-depth interviews can be conducted face-to-face or by telephone with the responses being recorded digitally as well as in writing. The survey can be conducted electronically. A sample survey questionnaire is provided in Appendix G. It includes questions to gather qualitative as well as quantitative information. The survey will be iteratively improved through use in practice.

A high-level understanding of the UIC maturity level of an organisation can be gained from public sources. Such sources can provide evidence for engagement of an organisation in UICs, the kind of UIC projects it is involved in, and the duration of such engagements. However, other required information is available only within the organisation such as organisational practices, individual practices, and legal practices. Interviews and surveys provide a means to gather such information, including access to confidential information. This specific information will be mapped to the characteristics of KPAs at various maturity levels to understand the achieved characteristics and improvements in the KPAs.

5. **Data analysis.** The data gathered in the above step is analysed in order to understand the UIC maturity level of an organisation.

   Due to the design of the survey questionnaire, responses to the questions can be mapped to the characteristics of the KPAs in the UICMM. However, there is a possibility that responses may be worded in such a way that efforts are required to interpret them. Similarly, data gathered from public sources will need analysis for mapping.

   Content analysis can be applied to analyse the gathered data. Content analysis is 'a research technique for making replicative and valid inferences from texts (or other meaningful matter) to the contexts' [Krippendorff, 2018, pg. 25]. The process of coding [Corbin and Strauss, 1990] can be applied using the deductive approach (Section 3.4) for such analysis of the gathered qualitative data so that the responses can be mapped to the KPA characteristics.

   Further, inferences drawn from analysis of data in the public domain can be validated using data gathered through interviews/surveys. In addition, analysis can be conducted by more than one expert concurrently or in multiple iterations to ensure the reliability and validity of the analysis, and reduce any potential bias arising out of the researchers' background.

6. **Assess organisation.** Based on the analysis in the previous step, an organisation is assessed by mapping the data to the UICMM KPA characteristics and determining the maturity level of the organisation. An organisation achieves a

level of maturity by satisfying all of the characteristics of KPAs at that maturity level and all lower levels. The results of the assessment also provide details of required improvements to the organisation. For example, if an organisation is at maturity level 3, the characteristics at level 4 can be used to identify required improvements.

8.6 Implications for real-world application of UICMM

The UICMM has potential application in various contexts. It can be used for assessing the current collaboration performance of organisations and identifying areas for improvement. The assessment will also indicate the collaboration capability of an organisation. Practitioners can utilise the model to assess the UIC maturity of potential future collaboration partners.

UIC provides opportunities to students to engage with industry, gain skills relevant to the market, and improve their career prospect. A university with higher UIC maturity should increase the probability for students to gain such opportunities. Students can utilise the results of UICMM assessments to help identify such universities.

Governments can use the model to assess organisations, and accordingly consider various funding-related decisions, which can lead to better return on investments.

8.7 Evaluation and improvement of the UICMM

As discussed in Section 8.4.1.3, evaluation is a key component of the Design Science Research approach used to develop the UICMM [Becker et al., 2009]. Maturity models can be evaluated in multiple ways with respect to their design process, the design itself, utility, and their practical application. Based on a systematic study of evaluation and assessment of maturity models, three types of evaluations have been suggested [Helgesson et al., 2012]: Author evaluation, Domain expert evaluation, and Practical setting evaluation.

In this section, I describe details of the evaluation process (Requirement R3 of Becker's approach) as well as preliminary results. The evaluation process aligns with the two-phase evaluation approach adopted in this thesis, as described in Chapter 3. Phase one, involves descriptive evaluation, including illustrative scenarios and expert evaluation. Phase two, involving real-world evaluation and improvement of the UICMM, is part of future work, as detailed in Chapter 10.

By combining the Helgesson's [Helgesson et al., 2012] suggestions and the two-phase evaluation, the following approaches have been adopted for evaluation of the

UICMM.

- **Author evaluation:** This is an assessment of the UICMM design and design process without involving outside experts. It was conducted by the researcher, and is presented in Section 8.7.1.

- **Domain expert evaluation:** This is an assessment of the utility and applicability of the UICMM. It was conducted by involving practitioners, who are potential users of the maturity model or expert in UIC, and is presented in Section 8.7.2.

- **Illustrative scenarios:** This is a demonstration of the utility and applicability of the UICMM by applying it in synthetic situations. It was conducted by the researcher. Section 9.3 in Chapter 9 presents the scenarios that demonstrate use of the UICMM in synthetic situations.

- **Practical setting evaluation:** This is an evaluation of the UICMM through application in real-world settings. I propose a strategy for such an evaluation in Chapter 10.

8.7.1 Author evaluation: Evaluation of the UICMM design

Becker [Becker et al., 2009] describes a set of requirements that need to be satisfied by the process used to design a maturity model. Section 8.4.1 shows that these requirements were met during the design of the UICMM.

Reviewed literature describes the required properties of a well-designed maturity model [Fraser et al., 2002; Klimko, 2001]. The UICMM design was evaluated against these properties. The result of this evaluation was that the UICMM has all of the required properties as summarized in Table 8.10.

8.7.2 Domain expert evaluation: Evaluation of UICMM utility and applicability

In order to assess the utility and applicability of UICMM, the researcher decided to engage and conduct discussions with professionals from organisations interested in UIC. The organisations were selected on the basis of the following criteria:

- The organisation is interested in encouraging UIC.

- The organisation is actively taking measures to improve UIC.

- The participant(s) from the organisation possesses knowledge of UIC and/or maturity models.

Table 8.10: Evaluation of the UICMM Design

Required Properties	UICMM Properties
i) The way in which maturity of a single domain develops is described in terms of maturity levels (usually four to six).	The domain of interest is UIC. The UICMM comprises five maturity levels to describe the way in which UIC maturity develops.
ii) Levels are characterized by certain requirements	Collaboration levels are characterized with requirements based on Key Process Areas (Section 8.4.3).
iii) Levels are cumulative where higher levels are built on top of the requirements of lower ones	To achieve a level, the UICMM expects that the requirements of the level and all the lower levels have been satisfied.
iv) The number of levels may vary, but they are distinct, well-defined, and sequentially ordered, from an initial up to an ending level	UICMM has five distinct and ordered maturity levels, from level 1 to level 5.
v) There is a logical progression through levels and no levels can be skipped	Organisations are expected to progress through levels 1 to 5 of the UICMM. None of the levels can be skipped.
vi) Levels should be named with short labels that give a clear indication of the intent of the level	Each collaboration maturity level has a label (Non-existent, Initial, Encouraged, Practised and Managed, and Continuous Improvement) that indicates the intent of the level.
vii) Level definitions should be developed to expand their names and provide a summary of the major requirements and measures	Levels definitions are in a clear state (Table 8.4) and the requirements of each level are defined (Tables 8.5, 8.6, 8.7, 8.8, and 8.9).

- The organisation is interested in practical application of UICMM.

The following organisations were identified as domain experts for this evaluation. These organisations satisfy the above criteria and were selected when they expressed an interest in the UICMM after reading a published paper on the work [Awasthy et al., 2018].

- The Australian Academy of Technology and Engineering (ATSE) [ATSE], and
- Coalfacer [Coalfacer, 2019].

Multiple discussions were held with participants from both the organisations by telephone and video conferencing. Both organisations have shown interest in application of the UICMM, and have provided valuable feedback during discussions. They have expressed satisfaction with the KPAs included within the UICMM. In terms of utility and applicability, the UICMM has been rated highly by the organisations as indicated in correspondence reproduced in Appendix F.

8.7.3 Methodological approach for domain expert evaluation

The above evaluation is preliminary, and a more robust evaluation would need to be conducted in future work. This could be undertaken as follows:

- **Preparation.** The researcher develops the context, suitable scenarios for application of the framework and tools, required presentation material, and documentation for the panel of experts involved in the evaluation. The scenarios presented in Chapter 9 are examples of valid scenarios. The documentation includes the process of application of the framework or individual tools, and criteria for evaluation. Some material to take notes can also be provided to the evaluators.

- **Identify and recruit experts for evaluation.** The experts for the panel of evaluators are identified, approached, and recruited. The sampling process described in Section 4.3.4.2 is useful for recruiting experts. The main criterion for the selection of experts is that they are individuals and/or organisations with high interest and/or experience in UIC. A combination of criteria listed in Section 4.3.4.2 and Section 8.7.2 is valid for the identification and recruitment of experts.

  In order to ensure the robustness of the process, it will be useful to include experts from diverse fields and experience. In addition, multiple expert-evaluation sessions can be conducted, and their results compared to increase the validity of the evaluation further.

- **Schedule the evaluation.** Depending on the availability of the experts, the researcher decides the day for conducting the evaluation. The evaluation may range from a 2-hour session to a day-long workshop depending on the extent of the UIC Framework being evaluated. For example, assessing the utility of only one tool within the proposed UIC Framework may require a 2-hour session, while assessing the entire framework may require a day-long workshop.

- **Conduct the evaluation.** The researcher presents the context, tools for evaluation, and associated scenarios. Evaluation criteria and related material, such as a questionnaire (Appendix G) or an assessment matrix (Appendix H), are explained to the panel of experts.

  During the evaluation process, the experts review the framework and/or tool against each of the evaluation criteria with relevance to the provided scenarios or other scenarios familiar to them. The evaluators also note any identified concern or valuable enhancement in the tool under evaluation. After each of the experts has completed their assessment, the panel reports and discusses the issues and enhancements identified during the individual assessment.

- **Generate evaluation report.** An evaluation report is created with a list of issues and enhancements identified during the panel discussion. The items in the list can be classified according to severity. The severity is decided through discussion among the experts.

- **Analyse evaluation report.** The researcher analyses the generated evaluation report to establish the utility and applicability of the proposed framework and specific tools. The researcher also gains an understanding of the issues to be addressed, and required enhancements to be implemented from the report.

8.8 Conclusion

In this chapter, the UICMM, a maturity model for University-Industry Collaboration, is presented. It is a comprehensive model for assessing and guiding improvement in UIC capability at the organisational level.

The UICMM was developed by following the maturity model design process proposed by Becker et al. [Becker et al., 2009] and based on design science guidelines [Hevner et al., 2004]. As part of the design, several Key Process Areas, and five levels of maturity were identified. In developing the content of the maturity model, I utilized the UIC Practices Framework presented in Chapter 7, and insights from existing relevant maturity models.

The chapter provides details of the process of application of the UICMM so that it can be used effectively.

The UICMM has been assessed for its utility and applicability using a descriptive evaluation comprising both author and domain expert evaluation. Demonstration using illustrative scenarios is presented in Chapter 9. Future work will include ongoing real-world evaluation and improvement of the UICMM in the context of various organisations involved in different types of collaborations as outlined in Chapter 10.

Chapter 9

Application of the UIC Framework

The aim of this chapter is to provide guidelines regarding the practical application of the UIC Framework described in Chapters 5, 6, 7, and 8. This will be achieved by presenting a process that can be followed along with example scenarios in a range of different UIC contexts. Section 9.2 provides details of the proposed process with steps. It is followed by examples of application of this process in Section 9.3. These examples illustrate the potential of the developed framework as a tool for practical application by universities and industry. After reading this chapter, the reader will gain a fundamental understanding of the proposed framework, including when, where and how to apply the framework.

The scenarios presented in this chapter also serve as descriptive evaluations (Chapter 3, Section 3.2) of the UIC Framework (Section 5.5), the UIC Systems Model (Section 6.7), the UIC Practices Framework (Section 7.5), and the UICMM (Section 8.7).

9.1 Introduction

Because of the context-specific nature of UICs, the range of stakeholders involved, and the role played by various factors, effectively managing UICs can be a complex and challenging task in many cases, as established in earlier chapters (Chapters 4 and 5). However, it is proposed in this research that this can be managed effectively by using the Cynefin framework [Snowden and Boone, 2007] to guide the selection and application of the tools described in this thesis. This means that the proposed UIC Framework facilitates context-specific decision-making rather than a uniform approach across different scenarios.

In order to help readers apply the work presented in this thesis effectively, it is important to clearly document a process they can follow. In this chapter, such a process is presented using a flowchart and detailed descriptions of each step. The practical application of the process is then demonstrated using example scenarios. These examples will increase understanding of the application of the framework in practice, and enable its users to replicate the application in similar scenarios or adapt them to their specific context.

9.2 Proposed UIC Framework application process

In this section, details of the process to be followed for application of the proposed UIC Framework are provided. The process comprises the steps depicted in Figure 9.1 and detailed below.

Note that while this process is about using the proposed UIC Framework, it is also a ***process*** as defined in the UIC Systems Model (Chapter 6). That is, it is a ***process*** that can, itself, be followed to complete UIC Activities. Scenario 2 (Section 9.3.2) and Scenario 5 (Section 9.3.5) demonstrate this idea.

9.2.1 Step 1 - Initiation

As depicted in Figure 9.1, the first step is initiation. The process is initiated by any individual or group that wants to undertake a project to conduct, evaluate and/or improve UIC. After initiation, an individual or group will be identified as participants in the project. The participants may be internal to the subject organization, external to the organization, or a combination of internal and external people. They should all have an understanding of the context, and the expected outcomes from the process.

9.2.2 Step 2 - Describe scenario

In Step 2 of the ***process*** in Figure 9.1, participants develop a description of the UIC scenario under consideration. They use the UIC Systems Model (Chapter 6) to describe[1] the elements involved in the scenario and their interrelationships. The scenario can be described by considering a combination of the following:

(i) Identify the ***stakeholders***.

(ii) Identify and clearly describe the motivation and requirements of the ***stakeholders*** at various organisational levels (e.g. individual, project, or department), disciplines, and teams.

(iii) Clearly describe areas of conflict and agreement between ***stakeholders***.

[1]When referring to the language of the UIC Systems Model, classes are formatted as ***practice***, ***stakeholder***, and ***success factor*** etc. Associations are formatted as *motivates*, *seeks to influence*, and *provide* etc.

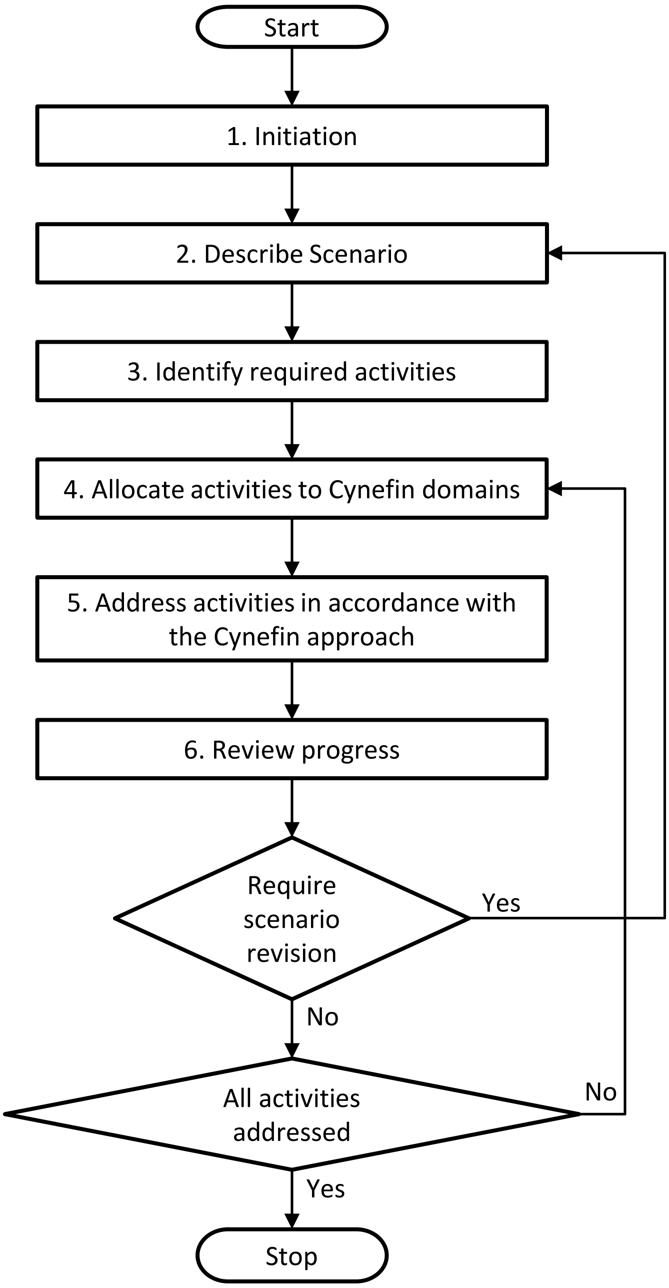

Figure 9.1: Process for Application of the proposed UIC Framework

(iv) Clearly describe areas of certainty and uncertainty.

(v) Identify applicable assumptions and constraints.

(vi) Identify the ***barriers*** (see Section 4.2) and ***success factors*** (Table 7.1) that play a role in the scenario and how they relate/interact with ***stakeholder*** perspectives.

9.2.3 Step 3 - Identify required activities

During Step 3 of the process in Figure 9.1, the participants identify the activities required to deal with the scenario. A ***UIC activity***, here, refers to a task that needs to be completed as part of the UIC scenario. For example, agree on IP, order equipment, recruit a post-doctoral fellow, exchange information, report progress, evaluate a technology, develop some software, run an evaluation, organise working spaces and equipment, learn something, develop a theory, etc.

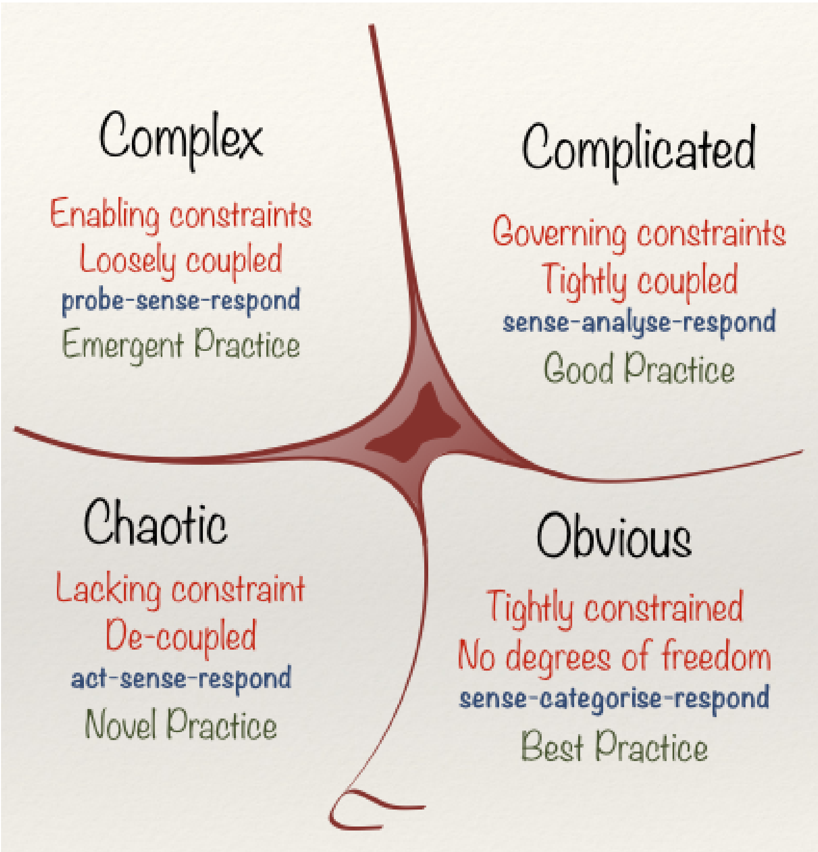

Figure 9.2: Domains of the Cynefin framework; the dark domain in the centre is disorder. [Snowden and Boone, 2007]

9.2.4 Step 4 - Allocate activities to Cynefin domains

The next step in Figure 9.1 is to assign the activities identified in the above step to appropriate domains within the Cynefin framework (Figure 9.2). This will help us later to select an appropriate approach to deal with our scenario.

Participants should allocate the identified activities to appropriate domains within the Cynefin framework using the following guidelines.

- If an ***activity*** is well-understood, doesn't involve conflicts, and is covered by known established ***practices***, then allocate it to the 'Simple' domain.
- If expertise is required to select an appropriate approach to deal with a ***UIC activity***, then allocate it to the 'Complicated' domain.
- If it is not possible to determine a way ahead, and effect of actions can be understood only in retrospect, then allocate it to the 'Complex' domain.
- If none of the above are applicable and immediate action is required to contain the situation, then allocate it to the 'Chaotic' domain.
- If agreement cannot be reached to allocate an ***activity*** to one of the above domains, then allocate it to the central 'Disorder' domain.
- Note that some ***UIC Activities*** may lie at the boundary between two domains when it is not clear which of the two domains is appropriate.
- The iterative nature of the ***process*** means that it is not necessary to allocate all ***activities*** to a domain at the same time. For example, ***activities*** conducted towards the end of a UIC, may not need to be considered at the start of the UIC. It is also possible that various types of ***activity*** such as legal, facilities or research planning, will be considered by different groups of participants and at different stages of the UIC. In summary, ***activities*** can be allocated to Cynefin domains at any appropriate time during the UIC.

The result of this step is a contextualised Cynefin framework that will be utilised for further detailed discussion and planning in the next step.

9.2.5 Step 5 - Address activities in accordance with the Cynefin approach

Step 5 in Figure 9.1 involves the identification of a suitable approach to deal with each of the ***activities*** identified in the previous step. The approach is selected as per the recommendations of the Cynefin framework depicted in Figure 9.2 and described in Section 5.4.

Pick an ***activity*** from the contextualised Cynefin framework that resulted from the previous step, and depending on the domain of the ***activity***, respond as detailed below.

1. **Obvious/Simple Domain.** Apply the following approach in this domain as per the Cynefin framework:

   (a) **Sense.** Collect data to fully describe the ***activity*** and its context.

   (b) **Categorise.** Identify an existing ***process*** that *implements* best ***practices*** and can be followed to complete the ***activity***.

   (c) **Respond.** Follow the selected ***process*** to complete the ***activity***.

2. **Complicated Domain.** This is the domain of experts. Apply the following approach in this domain as per the Cynefin framework:

   (a) **Sense.** Collect data to fully describe the ***activity*** and its context.

   (b) **Analyse.** Identify the experts who need to be engaged to analyse the ***activity*** using the following criterion.

      - They have understanding of UICs, and capability to provided guidance for the ***activity***.

      In addition, knowledgeable people from other related areas, who can add value, can be included in the cohort of selected experts. Such acknowledged experts from different areas will increase diversity.

      The identified experts use their knowledge to analyse the data collected above in order to develop and/or recommend the use of ***processes*** that implement 'good' ***practices*** and can be followed to complete the ***activity***. They can use the Practices Framework (Chapter 7) to analyse and identify the applicable ***practices***.

   (c) **Respond.** Follow the experts' recommended ***processes*** to complete the ***activity***.

3. **Complex Domain.** The Complex domain requires experimentation to gain more understanding, and discover what ***processes*** work and what ***processes*** don't work when attempting to complete the ***activity***. Apply the following approach in this domain as per the Cynefin framework:

   (a) **Probe.** Select or develop ***processes*** that implement ***practices*** that might *overcome* ***barriers*** to completing the ***activity*** and/or *enable* applicable ***success factors*** for completing the ***activity***. Then design experiments to evaluate the effectiveness of these ***processes***. Conduct the experiments.

   (b) **Sense.** Assess the results of the experiments, and identify the ***processes*** that work and the ***processes*** that don't work.

(c) **Respond.** Identify and document ways to encourage use of the ***processes*** that work and discourage use of the ***processes*** that don't work. This may require modification and/or development of new ***processes*** and ***practices*** followed by further iterations of 'probe-sense-respond'.

4. **Chaotic Domain.** The priority in this domain is to contain a chaotic situation by taking charge and immediately acting with the goal of moving the situation to another domain. Apply the following approach to deal with situations in this domain:

   (a) **Act.** Identify an individual/group to take charge and act immediately. Identify the actions to be taken. Act upon or delegate the actions to contain the situation.

   (b) **Sense.** Assess the effect of the actions taken in the above step.

   (c) **Respond.** Identify the domain to which the resulting situation can be allocated. Treat the newly developed situation as per the Simple, Complicated, or Complex domain approaches described above.

9.2.6 Step 6 - Review progress

The ***activities*** addressed during the previous step need to be reviewed. All identified ***activities***, their domain identification, and results can be reviewed regularly throughout the ***process*** as indicated by the iteration depicted in Figure 9.1. The aim of the reviews is to improve the ways ***activities*** are addressed and to adapt to changing scenarios.

Reviews should be conducted as follows:

- **Identify the scope of the review.** The participants define the scope of review based on time, or completion of an ***activity*** or group of ***activities***.

- **Identify the reviewers.** Identify the individuals who will be part of the reviewing team.

  It is expected that each ***activity*** will be reviewed by the individual or group involved in the ***activity***. However, in the interest of a larger project the ***activities*** may be reviewed by a team of reviewers from diverse groups.

- **Review outcomes.** The review will indicate if ***activities*** are progressing and delivering outcomes as per expectations, if the ***activities*** are complete, or if the scenario or ***activities*** need to be revised.

9.3 Demonstration of the UIC Framework application process

In this section, a set of scenarios is described to demonstrate how the ***process*** presented in Section 9.2 can be used. These scenarios were selected to demonstrate application of tools in the proposed UIC Framework across different Cynefin domains and at different organisational levels (individual / team / organisation) as summarized in Table 9.1.

Note that the Cynefin Chaotic domain is not covered by these scenarios because the actions required to contain a chaotic situation (Step 5, Section 9.2) will move the situation into the Complex or Complicated domains, which are covered by scenarios presented in this section.

Table 9.1: Scenario coverage of UIC Framework Features

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Simple Domain	X				
Complicated Domain		X	X	X	
Complex Domain				X	X
Individual	X				
Team		X	X		
Organization				X	X
UIC Systems Model	X	X	X	X	X
UIC Practices Framework	X	X	X	X	X
UICMM				X	
Recursive application of the UIC Framework		X			X

9.3.1 Scenario 1 - Organising a guest lecture by an industry expert.

9.3.1.1 Step 1 - Initiation

An academic initiates the process to organise a guest lecture.

9.3.1.2 Step 2 - Describe scenario

The scenario is described as 'An academic would like to invite an industry expert to deliver a guest lecture in a university'. This scenario can be described using the language of the UIC Systems Model (Chapter 6) as follows.

- ***Stakeholders*** comprising an individual academic *seeks to influence* an industry practitioner, students, and administration team ***stakeholders*** to collaborate in a

UIC to deliver a guest lecture.

- Networking, knowledge sharing, and improving student's knowledge about the practical application and relevance of their learning are ***benefits*** that *motivate* students and individual academic ***stakeholders***. The ***benefit*** of early access to bright students *motivates* the industry practitioner ***stakeholders***.

- ***practices*** will be used to *enable* ***success factors*** relevant in the scenario, including motivation, partner selection, and quality of communication (Table 7.2).

- There are no conflicts between ***stakeholders***.

- The university *places requirement on* the guest lecture that are clearly understood leading to high certainty about the outcome of the guest lecture.

- The university has established ***processes*** for selecting guest lecturers, timetabling, and making travel arrangements.

9.3.1.3 Step 3 - Identify required activities

The following activities are required in this scenario:

1. Select the guest lecturer.

2. Finalise schedule and venue for the lecture.

3. Organize travel and accommodation for the guest lecturer.

9.3.1.4 Step 4 - Allocate activities to Cynefin domains

All the activities in this scenario are clearly understood and are covered by established ***processes***. Hence, they are allocated to the Simple domain.

The result of this step is the contextualised Cynefin Framework depicted in Figure 9.3.

9.3.1.5 Step 5 - Address activities in accordance with the Cynefin approach

Use the contextualised Cynefin Framework resulting from Step 4 to select appropriate Cynefin approaches to complete each ***activity***.

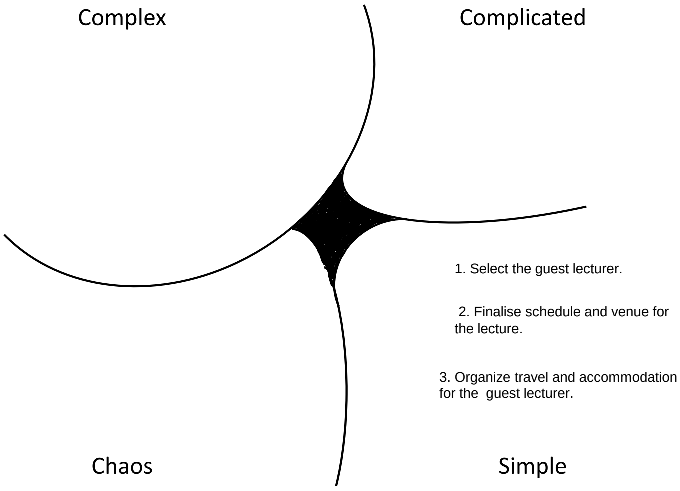

Figure 9.3: Contextualised Cynefin Framework for Scenario 1.

Activity 1: Select the guest lecturer (Simple).

(a) **Sense.** The academic collects details regarding potential guest lecturers.

(b) **Categorize.** The university has an existing ***process***, which implements the 'Evaluate and select an appropriate partner' ***practice***. This ***process*** is selected as applicable to this ***activity***.

(c) **Respond.** The academic identifies the guest lecturer by following the ***process*** identified above.

Activity 2: Finalise schedule and venue for the lecture (Simple).

(a) **Sense** The academic collects details regarding the possible schedule and venue for the lecture.

(b) **Categorize** The university has an existing ***process*** for timetabling, which deals with scheduling the use of venues. This ***process*** is selected as suitable for this ***activity***.

(c) **Respond.** The academic follows the ***process*** to finalise and publish the lecture schedule and venue.

Activity 3: Organize the travel and accommodation (Simple).

(a) **Sense.** The academic collects details regarding the required travel and accommodation.

(b) **Categorise.** The university has an established ***process*** for organising travel and accommodation. The ***process*** is selected as applicable for this ***activity***.

(c) **Respond.** The academic follows the ***process*** to book the travel and accommodation.

9.3.1.6 Step 6 - Review progress

In this scenario, the academic will review each of the activities. The academic may decide to review progress after ***activity*** 2 and 3 separately. The review at the end of ***activity*** 3 will indicate that the guest lecture has been organized. When all of the ***activities*** related to the scenario have been completed, the scenario is complete.

9.3.2 Scenario 2 - Selecting the right type of UIC.

9.3.2.1 Step 1 - Initiation

The university's Technology Transfer Office (TTO) will initiate the process.

9.3.2.2 Step 2 - Describe scenario

In this scenario, a key university researcher working in the area of cyber security has a strong working relationship with a senior level executive in Company X. The research has resulted in intellectual property which has potential for exploitation by the industry partner through further development. The university has adopted a strategy to build long-term relationships at multiple levels with various businesses. They have identified Company X as a potential partner. The university directs the Technology Transfer Office (TTO) to explore commercialisation possibilities through a deeper level of engagement with the company. The TTO needs to identify a suitable type of UIC to achieve the intended objective.

The TTO describes the scenario as follows using the language of the UIC Systems Model (Chapter 6).

- ***Stakeholders*** comprising an individual researcher, the TTO, and the university *seek to influence* ***Stakeholder*** Company X to collaborate in order to develop a long-term relationship and commercialize the subject research.

- The ***benefits*** of gaining peer recognition and publication out of the research *motivate* the academic. The ***benefits*** of additional funding and building long-term relationships *motivate* the university and the TTO. The ***benefit*** of gaining a competitive edge through commercialisation *motivates* the Company X.
- Cultural ***barriers*** associated with difference in motivations and goals of the ***stakeholders***, and legal ***barriers*** may *restrict collaboration between* the ***stakeholders***.
- Cultural adaptation and legal ***practices*** will be *adopted* to *overcome* cultural and legal ***barriers***.
- Contextual, social capital and communication ***practices*** will *enable* motivation, social capital, and communication ***success factors***.
- ***Stakeholders*** may *place requirements on* each other that will introduce some uncertainty about the desired outcome of the UIC.
- Research results produced by the individual researcher ***stakeholder*** are ready for commercialisation.

9.3.2.3 Step 3 - Identify required activities

The following activity is required in this scenario:

1. Analyse the different types of UIC relevant to the scenario and recommend a process for applying one that is suitable.

9.3.2.4 Step 4 - Allocate activities to Cynefin domains

Expertise is required to complete the ***activity*** 'Analyse the different types of UIC relevant to the scenario and recommend a process for applying one that is suitable'. Hence, it is allocated to the Complicated domain.

The result of this step is the contextualised Cynefin Framework depicted in Figure 9.4.

9.3.2.5 Step 5 - Address activities in accordance with the Cynefin approach

Use the contextualised Cynefin framework resulting from Step 4 to select the appropriate Cynefin approach to complete each of the activities.

Note that the experts involved in ***activities*** in the Complicated domain are individuals with deep knowledge about UIC and various types of UICs, individuals

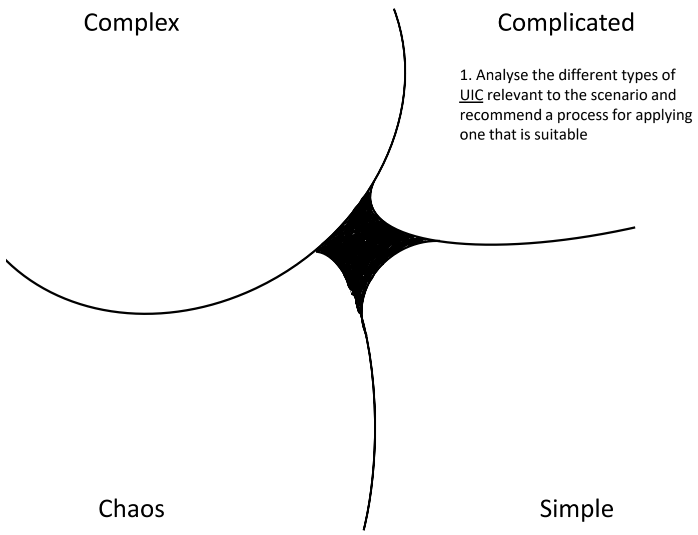

Figure 9.4: Contextualised Cynefin Framework for Scenario 2.

from administration teams with knowledge about the organization's strategy, and individuals with business acumen.

Activity 1: Analyse the different types of UIC relevant to the scenario and recommend a process for applying one that is suitable (Complicated).

(a) **Sense.** The stakeholders collect required information related to the motivation for collaboration and various types of UIC available.

As noted earlier (Section 2.3.1), there are various types of UICs, and each stakeholder may suggest a UIC type to suit their own objectives. For example, the researcher may be in favour of a consultancy, the TTO may want to exploit an opportunity for patenting and licensing, and the contract team from Company X may prefer to adopt contract research as a suitable UIC type. The academic may be under pressure to publish research results. Selecting a patent sale may result in immediate financial gains, however if no further development is conducted, both parties may later feel that there was potential for greater success in adopting another UIC type.

(b) **Analyse.** In this scenario, experts are involved to help with decision-making after considering the various stakeholder perspectives. The goal for experts is to recommend a suitable type of UIC for the scenario after analysis and assessment of possible alternatives.

The experts analyse various options for UIC in order to identify one that is suitable for the current scenario. Since the university's strategy at this time is to develop long-term relationships, contract research is not suitable. Contract research is better suited to scenarios aimed at short-term problem-solving. Considering the strategy to develop long-term relationships, the experts identify collaborative research as a suitable UIC type.

After identifying a suitable UIC type, the experts recommend use of the ***process*** described in this Chapter (Section 9.2) to implement the selected UIC type. The experts may modify the ***process*** to better align with stakeholder needs, complete steps of the ***process*** including Scenario description (Step 2), ***activity*** identification (Step 3), allocation to Cynefin domains (Step 4), and assist stakeholders during implementation (Step 5) and review (Step 6) of the ***process***.

(c) **Respond.** The stakeholders proceed by following the ***process*** elaborated and recommended by the experts with their assistance.

9.3.2.6 Step 6 - Review progress

In this scenario, the stakeholders and experts will review the completed activity. When all of the activities related to the scenario have been completed, the scenario is complete.

9.3.3 Scenario 3 - Dealing with IP rights in UIC.

9.3.3.1 Step 1 - Initiation

A research team may initiate the process.

9.3.3.2 Step 2 - Describe scenario

In this scenario, a university wants to enter into a UIC with an industry partner. However, the university and industry are not sure how Intellectual Property (IP) rights should be managed. Surprisingly, neither organisation has a policy or ***process*** for managing IP.

Participants use the language of the UIC Systems Model (Chapter 6) to describe the scenario as follows.

- ***Stakeholders*** comprising university, academic researchers and a company *seek to influence* each other to collaborate in a UIC, but are not sure how IP rights should be managed.

- None of the ***stakeholders*** have a ***process*** for managing IP rights.

- The ***benefit*** of publishing research results *motivates* the individual academic ***stakeholder***. The ***benefit*** of research commercialization *motivates* the university ***stakeholder***. The ***benefit*** of commercialization and protection of IP to maintain a competitive edge *motivates* the company ***stakeholder***.
- UIC ***barriers*** associated with IP rights, differences in motivations and goals of the stakeholders *restrict collaboration* between the ***stakeholders***.
- Motivation, social capital, and communication ***success factors*** *influence the success* of activities involved in the proposed UIC.
- Legal, communication, contextual, and social capital ***practices*** will be adopted to enable the ***success factors*** and *overcome* ***barriers***.
- It is possible that conflicts and differences in goals between ***stakeholders*** may introduce an element of uncertainty regarding the ***outcome*** *delivered* by the UIC.

9.3.3.3 Step 3 - Identify required activities

The following activities are required in this scenario:

1. Identify IP ***barriers*** associated with the UIC and ways to overcome them.

9.3.3.4 Step 4 - Allocate activities to Cynefin domains

The ***activity*** 'Identify IP barriers associated with the UIC and ways to overcome them' requires experts to select an appropriate approach. Hence, it is allocated to the Complicated domain.

The result of this step is the contextualised Cynefin Framework depicted in Figure 9.5.

9.3.3.5 Step 5 - Address activities in accordance with the Cynefin approach

Use the contextualised Cynefin framework resulting from Step 4 to select appropriate Cynefin approaches to complete each ***activity***.

Activity 1: Identify IP barriers associated with the UIC and ways to overcome them (Complicated).

(a) **Sense.** The team collects data to fully describe the ***barriers*** related to IP applicable to the UIC.

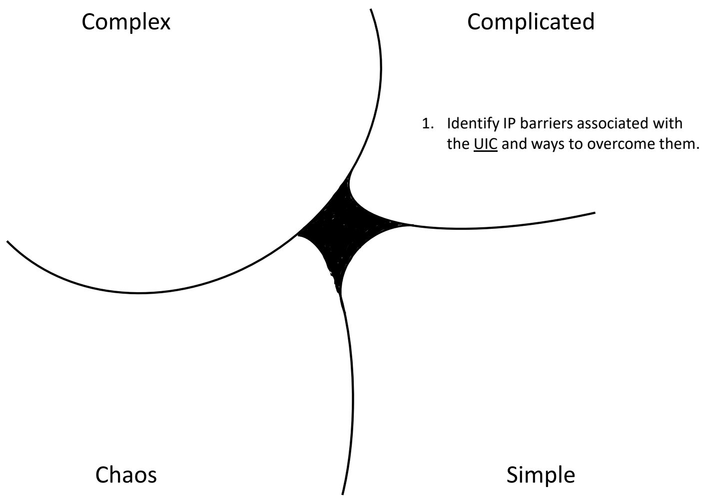

Figure 9.5: Contextualised Cynefin Framework for Scenario 3.

(b) **Analyze.** Identify the legal and administrative experts, who offer the required expertise to deal with the IP issues. Various organizational policies and their implications are known to these legal and administration experts. The experts will analyse available approaches to managing the IP related issues, and will develop and recommend the use of new ***processes*** that implement the following ***practices*** from the UIC Practices Framework:

- 'Develop a common understanding of IP'.
- 'Negotiate and clearly articulate intellectual property rights'.

These ***processes*** may include workshops to help develop a common understanding of IP among the stakeholders, and a document or framework to manage IP rights.

(c) **Respond.** The ***stakeholders*** follow the recommended ***processes***. Experts may also be involved in the application of recommended ***processes***.

9.3.3.6 Step 6 - Review progress

In this scenario, the stakeholders and experts will review the completed ***activity***. If the ***activity*** has not been completed satisfactorily, the review team may recommend modifications, and repeat the above sense-analyse-respond steps.

9.3.4 Scenario 4 - A university wants to assess and improve its UIC maturity.

9.3.4.1 Step 1 - Initiation

A team within university management will initiate the process.

9.3.4.2 Step 2 - Describe scenario

In this scenario, a university wants to assess its UIC maturity and develop a strategy for its improvement.

Participants use the language of the UIC Systems Model (Chapter 6) to describe the scenario as follows.

- ***Stakeholders*** comprising university management, business development teams, research project teams and individual researchers in the university *seek to influence* each other to assess and improve UIC maturity.
- The ***benefits*** of improving UIC maturity, including more effective collaborations with industry, *motivates* the university ***stakeholder***.
- Strategies to improve UIC maturity may introduce conflicts between ***stakeholders***.
- Information required to complete an assessment of UIC maturity is readily available.
- Conflicts between ***stakeholders*** will be resolved by university management.

9.3.4.3 Step 3 - Identify required activities

The following activities are required in this scenario:

1. Identify assessment scope.

   In this activity, the organisation identifies the unit of analysis for evaluation, the UICs that will be included as part of the UIC maturity assessment, and details of the information to be gathered.

2. Identify the participants.

   This activity identifies individuals to be involved in the information gathering ***process***.

3. Gather the required information.

   In this activity, the assessment team selects the instruments for quantitative and qualitative information gathering, and uses them to gather the information identified in activity 1 from the participants identified in activity 2.

4. Analyse the gathered information to assess and report the UIC maturity of the university.

   The data gathered in the previous activity is analysed in order to understand the UIC maturity of an organisation.

   Based on the analysis, an organisation is assessed by mapping the gathered data to the UICMM KPA characteristics and determining the maturity level of the organisation. An organisation achieves a level of maturity by satisfying all of the characteristics of KPAs at that maturity level and all lower levels.

5. Identify areas for improvement.

   The reported assessment results will be discussed and the assessment team will identify issues or areas for improvement.

6. Design and implement improvements.

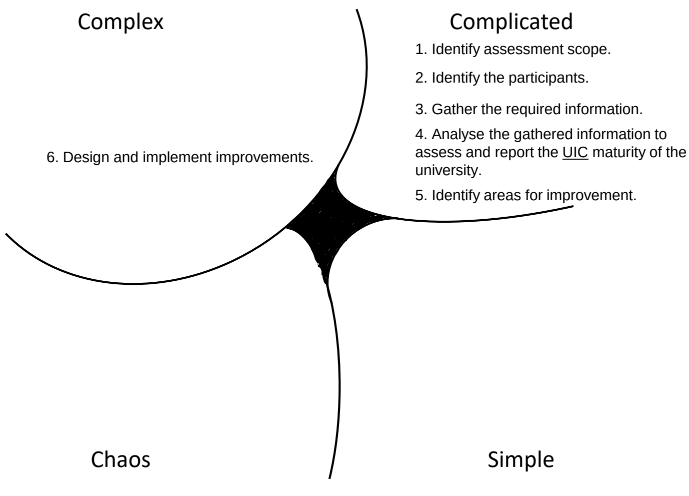

Figure 9.6: Contextualised Cynefin Framework for Scenario 4.

9.3.4.4 Step 4 - Allocate activities to Cynefin domains

Activities that require experts to identify and/or develop appropriate ***process*** are allocated to the Complicated domain. If the ***activity*** requires experimentation to identify and/or develop effective ***processes***, it is allocated to the Complex domain.

The result of this step is the contextualised Cynefin Framework depicted in Figure 9.6.

9.3.4.5 Step 5 - Address activities in accordance with the Cynefin approach

Use the contextualised Cynefin framework resulting from Step 4 to select appropriate Cynefin approaches to complete each ***activity***.

Note that all experts involved in complicated ***activities*** are expected to have deep knowledge of UICs, a sound understanding of ***practices*** used to improve the effectiveness of UICs, and experience in the use of maturity models.

Activity 1: Identify assessment scope (Complicated).

(a) **Sense.** Collect details to fully describe the ***activity*** and its context.

(b) **Analyse.** Experts will recommend ***processes*** to be followed to identify the unit of evaluation, the UICs to be included in the assessment, and details of the data required for the assessment.

(c) **Respond.** Follow the ***processes*** recommended by experts to identify the scope of the UIC maturity assessment.

Activity 2: Identify the participants (Complicated).

(a) **Sense.** Collect details to fully describe the ***activity*** and its context.

(b) **Analyse.** Experts will recommend a ***process***, which can be followed to identify participants based on specific selection criteria.

(c) **Respond.** Follow the ***process*** recommended by experts to identify the participants.

Activity 3: Gather the required information (Complicated).

(a) **Sense.** Collect details to fully describe the information to be gathered.

(b) **Analyse.** Experts will identify or develop a ***process*** that can be used to gather the information required to complete the UIC maturity assessment. The required information can be gathered through diverse means such as focus group meetings, surveys, or interviews.

(c) **Respond.** Follow the ***process*** recommended by experts to gather the required information.

Activity 4: Analyse the gathered information to assess and report the UIC maturity of the university (Complicated).

(a) **Sense.** Collect the data gathered during ***activity*** 3.

(b) **Analyse.** Experts will recommend a ***process*** that can be followed to analyse the information gathered in the previous steps, to assess and report the UIC maturity of the university.

This ***process*** may create a bar graph with maturity level for each KPA within the UICMM and infer the overall UIC maturity of the university. In order for an organisation to achieve a particular maturity level, all the KPAs should have achieved that level. For example, if all the KPAs have a maturity level of 3, except one of them, which has maturity level 2, the overall maturity will be 2. If all the KPAs have a maturity level of 3, the overall UIC maturity of the organisation will be 3.

(c) **Respond.** Follow the ***process*** recommended by the experts to assess and report the UIC maturity of the university.

Activity 5: Identify areas for improvement (Complicated).

(a) **Sense.** Collect the UIC maturity assessment results reported in Activity 4.

(b) **Analyze.** Experts will discuss the results of the UIC maturity assessment with university ***stakeholders***, and will identify areas for improvement.

For the purposes of this scenario, they recommend that improvements be made in the following areas:

- industry-relevance of graduate skills,
- demonstrating the relevance of research, and
- communication of research results.

(c) **Respond.** The team accepts the improvement areas recommended by the experts to be addressed.

Activity 6: Design and implement improvements (Complex).

(a) **Probe.** Design experiments to explore the areas of improvement identified during Activity 5.

- **Industry-relevance of graduate skills.** In order to address this issue, a new ***process*** could be proposed to bridge the graduate skills gap by providing students with an authentic project experience in collaboration with industry or as a startup group project. Such a ***process*** could be designed to *overcome* cultural, communication, and relevance ***barriers***, and to *enable* technological relatedness, project selection, communication, and social capital ***success factors***. Experiments could then be designed and run to evaluate the new ***process***.

An example of such collaborative education, is the Australian National University's TechLauncher initiative, a capstone group project course that aims to better prepare graduates for the workforce. A case study of this initiative [Awasthy et al., 2017a] was conducted and is reproduced in Appendix C.

- **Demonstrating the relevance of research.** In order to address this issue, the team may develop a ***process*** to demonstrate the real-world value of research. Such a ***process*** would be designed to *overcome* communication and relevance ***barriers***, and to *enable* technological relatedness, and information dissemination ***success factors***. Experiments could then be designed and run to evaluate the new ***process***.

  As a demonstration of this idea, a ***process*** was developed to increase adoption of university research in industry as elaborated in [Awasthy et al., 2016] and reproduced in Appendix A.

- **Communication of research results.** In order to address this issue, a new ***process*** could be proposed to improve dissemination of research. Such a ***process*** would be designed to *overcome* communication, relevance, and contextual ***barriers***, and to *enable* information dissemination ***success factors***. Experiments could then be designed and run to evaluate the new ***process***.

  As an experiment, a ***process*** to enhance existing digital platforms or create an entirely new platform could be developed to ensure efficient information communication, as discussed in Appendix I.

(b) **Sense.** Assess the results of the above experiments to identify the ***processes*** that work well and the ***processes*** that don't work so well.

(c) **Respond.** Identify and document ways to encourage use of the ***processes*** that work and discourage use of the ***processes*** that do not work. This may require modification and/or development of new ***processes*** followed by further iterations of 'probe-sense-respond'.

9.3.4.6 Step 6 - Review progress

In this scenario, the experts and stakeholders will review each of the completed activities. If the ***activity*** has not been completed satisfactorily, the review team may recommend modifications, and repeat the above sense-analyse-respond or probe-sense-respond steps.

9.3.5 Scenario 5 - A university and a company want to explore how they might collaborate.

9.3.5.1 Step 1 - Initiation

University and company management will initiate the process.

9.3.5.2 Step 2 - Describe scenario

In this scenario, a university has made a discovery that could be commercialized by Company X. Because the company has no UIC experience and is culturally very different to the university, the university wants to explore how, and if, it can collaborate effectively with Company X.

Participants use the language of the UIC Systems Model (Chapter 6) to describe the scenario as follows.

- ***Stakeholders*** comprising a university and an industry partner *seeks to influence* each other to explore how they might collaborate.

- The industry partner ***Stakeholder*** has no experience of UIC.

- UIC ***benefits*** such as access to sources of research funding, increased relevance, application and commercialization, and learning impact *motivate* the university ***Stakeholder***.

  UIC ***benefits*** such as access to base scientific competence, access to knowledge, and acquire capability to build competitive advantage *motivate* the industry ***Stakeholders***.

- Cultural ***barriers*** including differences in motivation, goals and operations of the ***stakeholders*** may *restrict collaboration* between the ***stakeholders***.

9.3.5.3 Step 3 - Identify required activities

The following activities are required in this scenario:

1. Develop an effective approach to UIC.

9.3.5.4 Step 4 - Allocate activities to Cynefin domains

The ***activity*** 'Develop an effective approach to UIC' requires experimentation to learn what ***barriers*** exist and what ***processes*** and associated ***practices*** can be used to overcome them. Hence, it is allocated to the Complex domain.

The result of this step is the contextualised Cynefin Framework depicted in Figure 9.7.

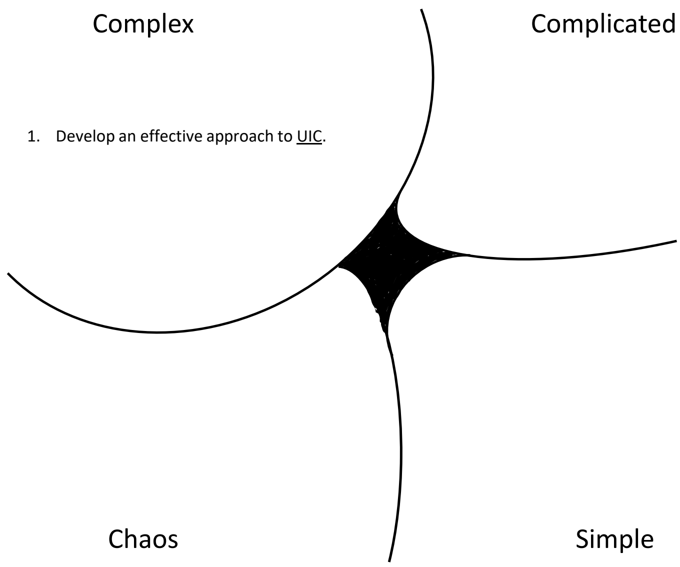

Figure 9.7: Contextualised Cynefin Framework for Scenario 5.

9.3.5.5 Step 5 - Address activities in accordance with the Cynefin approach

Use the contextualised Cynefin framework resulting from Step 4 to select appropriate Cynefin approaches to complete each ***activity***.

Activity 1: Develop an effective approach to UIC (Complex).

(a) **Probe.** The organizations decide to undertake one or more small pilot UICs to explore how they might work together. They began by identifying ***barriers*** that may *restrict collaboration between* them, and the ***success factors*** that may *influence the success* of their UIC. The university then selects existing ***processes*** that implement ***practices*** intended to *overcome* these ***barriers*** and/or *enable* these ***success factors***. To test these ***processes*** the university and company design and execute a small pilot UIC by (recursively) applying the UIC Framework application ***process*** presented in this chapter.

(b) **Sense.** Assess the results of the small pilot UICs to identify the ***processes*** that work and the ***processes*** that don't work.

(c) **Respond.** Identify and document ways to encourage use of the ***processes*** that worked and discourage use of the ***processes*** that didn't work. This may require modification and/or development of new ***processes*** and ***practices*** followed by further iterations of 'probe-sense-respond'.

9.3.5.6 Step 6 - Review progress

A review team comprising representatives from both the organisations will review progress at the end of each pilot UIC to determine if further experimentation (i.e. Pilot UICs) is required, or if more significant UICs are possible or not.

9.4 Discussion

Evaluation is the process of assessing a product or an artefact against various criteria such as utility, quality, impact, and value. There are various ways to evaluate an artefact resulting from Design Science Research. Various authors have formalized the design science research process with dedicated activities for evaluation termed as 'demonstration' and 'evaluation' of artefacts.

Descriptive evaluation uses 'Descriptive Informed Argument' and/or 'Scenarios'. The examples presented in this chapter align with expectations of Hevner's [Hevner et al., 2004] definition of descriptive evaluation using 'Scenarios'. Demonstration using the scenarios here can be considered as a weak form of evaluation. The example scenarios indicate that following the guidelines for the proposed UIC Framework has some promising value for dealing with UIC. It validates the utility and applicability of the developed UIC framework.

In order to provide a more robust evaluation of the proposed UIC Framework, I recommend a strategy based on real-world deployment as detailed in Chapter 10.

However, empirical evidence may also be provided by studying historical UICs. Such case studies would involve analysis of successful UICs to understand the extent to which the processes and practices followed align with the purpose of the tools within the developed UIC Framework, and the scope for improvement by using the framework. Analysis of failed cases will help point out how the proposed UIC Framework might have helped to avoid failure. The results of such case studies would help in building a more convincing argument regarding the utility and effectiveness of the developed UIC Framework.

9.5 Conclusion

This chapter explained how the proposed UIC Framework can be applied to evaluate and improve UIC. This was achieved by presenting a ***process*** and example scenarios that demonstrate how key aspects of the UIC Framework can be used to deal with ***UIC Activities*** in various domains of the Cynefin framework. These scenarios are intended to increase understanding of the proposed UIC Framework in order to support better decision-making for effective UICs. The examples in the chapter indicate that following the guidelines for the proposed UIC Framework has some promising value for dealing with UIC. They validate the utility and applicability of the framework.

The demonstrations in this chapter also serve as descriptive evaluations (Section 3.2) of the proposed UIC Framework (Section 5.5), and the comprising tools - the UIC Systems Model, the UIC Practices Framework, and the UICMM.

The next chapter presents a strategy for ongoing evaluation and improvement of the UIC framework in real-world UICs.

Chapter 10

Evaluation and Improvement Strategy

Previous chapters presented Design Science Research resulting in the UIC Framework, a design artefact for evaluating and improving UIC. According to Hevner et al. [Hevner et al., 2004, pg. 85], 'the utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.' As described in Chapter 3, a two-phase evaluation approach is adopted in this thesis. Phase one, including descriptive evaluation of the developed framework and associated tools, has been presented earlier in the thesis. This chapter presents a strategy for phase two, involving evaluation and improvement of the framework through its application in real-world settings.

The chapter begins with an argument that, like UIC itself, evaluation and improvement of the proposed approach to UIC will often be complex and best achieved through iterative ongoing experimentation and learning within the context of real-world UIC. It is further argued that such experimentation is beyond the scope of this thesis, and that an appropriate contribution at this stage of the research would be a detailed strategy for experimentation as part of future work. The remainder of this chapter presents such a strategy, examples of how it might be applied, and a summary of preliminary real-world experimentation currently under way.

10.1 Introduction

Evaluation is a central and crucial activity in conducting rigorous Design Science Research (DSR). The DSR approach recommends that artefacts are evaluated in real-world settings [Venable et al., 2016]. Therefore, for evaluation, the UIC Framework needs to be used in a variety of real-world UICs according to the process presented in Chapter 9.

It was established in Chapter 6 that a systems approach needs to be adopted to deal with UICs. In accordance with that approach, UICs must be evaluated and improved as a whole system. It is not appropriate to evaluate a small part of the UIC process, and because real-world UICs involve people and associated costs, time and risks, it is not possible to conduct a UIC just for evaluation purposes. In addition, many such UICs would be required in order to cover the broad applicability of the UIC Framework presented in this thesis. Hence, an ongoing process of 'evaluation' and 'learning' is appropriate. That is an ongoing 'iterative' process of research and practice aimed at learning how to use the proposed framework in different contexts (eg. where it works and doesn't work), and how the framework might be improved over time is considered appropriate. This process adheres to the DSR practice of conducting iterative development and evaluation.

10.2 The need for iterative real-world evaluation

The purpose of UIC Framework evaluation is to learn about the impact of the framework on UICs. As such, we don't know what this impact will be ahead of time. We will only know in retrospect. In addition, the involvement of multiple stakeholders and their diversity of perspectives in UICs adds to the difficulty in understanding the potential impact of the proposed UIC Framework.

Such characteristics indicate that UIC evaluation falls into the complex domain of the Cynefin framework (Section 5.4) and, therefore, requires an experimental approach.

10.2.1 The role of experimentation

Having established that evaluation of the proposed framework is complex, an experimental approach to UIC evaluation and improvement is adopted in accordance with the Cynefin framework. Such experimentation will help us understand what works and what does not work. While 'what works' establishes the utility of the framework, 'what does not work' allows us to learn and gain a better understanding of the aspects of the framework that need improvement. Experimentation is an iterative path to improvement, which can be followed until no further improvements are required.

10.2.2 Experimentation scope

Chapters 5 and 6 argued that UIC should be considered using a systems approach. A key aspect of such approaches is that parts of a system cannot be easily treated in isolation. So, any evaluation and improvement of the proposed UIC Framework will need to consider its impact on UICs as whole systems. Therefore, the scope of any experimentation to evaluate and improve the proposed UIC Framework will need to be UICs as whole systems.

10.2.3 Experimentation context

Chapters 5 and 6 showed that UICs operate as a system, and as part of an enclosing system, comprising a diverse range of stakeholders, resources, needs and constraints. It is also known that UICs often run for many months or even years. As such, it would be infeasible to run a UIC solely for the purposes of evaluating the framework proposed in this thesis. Therefore, the context of any experimentation to evaluate and improve the proposed framework will need to be real-world UICs.

10.2.4 Feasibility of real-world experimentation

As discussed in the previous sections, real-world evaluation of the proposed UIC Framework will involve iterative experimentation over many UICs and over extended time periods. This means that such evaluation is beyond the scope of a typical Ph.D and, hence, this thesis. However, a strategy for evaluating the UIC Framework has been developed and is presented in the next section.

10.3 Proposed strategy

In this section, I present a strategy for evaluating the proposed UIC Framework in real-world UIC projects. The strategy includes evaluation of the overall framework as well as the individual tools.

10.3.1 Evaluation objectives

Evaluation will provide evidence that the proposed UIC Framework is achieving the purpose for which it was developed. In this section, I outline the objectives of evaluation of the framework and individual tools.

10.3.1.1 Evaluation of the proposed UIC Framework

It is of interest to investigate the extent to which the proposed UIC Framework can help UIC stakeholders adopt appropriate approaches to dealing with UICs so that they can establish successful UICs.

Evaluation experiments should help answer the following questions:

- Following the UIC Framework application process presented in Chapter 9, does the UIC Framework have **utility, applicability**, and **effectiveness** in helping stakeholders:
  - understand and describe UIC scenarios (Figure 9.1, Step 2)
  - identify UIC activities required to complete a UIC (Figure 9.1, Step 3)
  - allocate UIC activities to Cynefin domains (Figure 9.1, Step 4)
  - complete UIC activities (Figure 9.1, Step 5)
  - review UIC progress (Figure 9.1, Step 6)
- Does the proposed UIC Framework have **utility, and applicability** in real-world UICs?
- Is the UIC Framework **effective** in helping stakeholders establish effective UICs?
- Does the UIC Framework have **ease of use**?
- Are there any improvements possible to the UIC Framework in terms of utility, applicability, and effectiveness?

10.3.1.2 Evaluation of the UIC Systems Model

It is of interest to investigate to what extent the UIC Systems Model can help UIC stakeholders to better understand UICs and make informed decisions regarding the applicable types of UIC, and the UIC barriers, success factors and practices relevant to the UIC application context.

Evaluation experiments should help answer the following questions:

- As a key tool in the UIC Framework application process presented in Chapter 9, does the UIC Systems Model have **utility, applicability,** and **effectiveness** in helping stakeholders:
  - understand and describe UIC scenarios (Figure 9.1, Step 2)
  - identify UIC activities required to complete a UIC (Figure 9.1, Step 3)
  - allocate UIC activities to Cynefin domains (Figure 9.1, Step 4)
  - complete UIC activities (Figure 9.1, Step 5)
  - review UIC progress (Figure 9.1, Step 6)
- Does the UIC Systems Model have **ease of use**?
- Are there any improvements possible to the UIC Systems Model in terms of utility, applicability, and effectiveness?

10.3.1.3 Evaluation of the UIC Practices Framework

It is of interest to investigate to what extent the UIC Practices Framework can help UIC stakeholders improve the effectiveness of UICs and establish successful UICs.

Evaluation experiments should help answer the following questions:

- As a key tool in the UIC Framework application process presented in Chapter 9, does the UIC Practices Framework have **utility, applicability,** and **effectiveness** in helping stakeholders:
  - understand and describe UIC scenarios (Figure 9.1, Step 2)
  - identify UIC activities required to complete a UIC (Figure 9.1, Step 3)
  - allocate UIC activities to Cynefin domains (Figure 9.1, Step 4)
  - complete UIC activities (Figure 9.1, Step 5)
  - review UIC progress (Figure 9.1, Step 6)
- Does the UIC Practices Framework have **utility, applicability and effectiveness** in improving an organisation's ability to overcome barriers to UIC?
- Does the UIC Practices Framework have **utility, applicability and effectiveness** in improving an organisation's ability to enable UIC success factors?
- Can the UIC Practices Framework improve the ability of an organization to establish effective UICs?
- Does the UIC Practices Framework have **ease of use**?
- Are there any improvements possible to the UIC Practices Framework in terms of utility, applicability, or effectiveness?

10.3.1.4 Evaluation of the UICMM

It is of interest to investigate to what extent the UICMM can help UIC stakeholders assess their UIC maturity level and identify required improvements.

Evaluation experiments should help answer the following questions:

- Does the UICMM have **utility, applicability and effectiveness** in helping organisations assess their current level of UIC maturity?
- Does the UICMM have **utility, applicability and effectiveness** in helping organisations identify practices to improve their current level of UIC maturity?
- Do organisations have **confidence** in the UICMM assessment results?

- Does the UICMM have **ease of use**?
- Are there any improvements possible to the UICMM in terms of utility, applicability, or effectiveness?

10.3.2 General approach

Evaluation will be based on a strategy of experimentation in real-world UICs. The proposed evaluation strategy comprises the following steps:

1. Identify an organization that is intending to engage in a UIC. Select the organization if the UIC team is interested and willing to investigate the potential value of the proposed UIC Framework by applying it in their UIC.

2. Action research (Section 3.3.3), specifically participatory action research [McTaggart, 1991], can be used as a methodology to carry out the investigation through experimentation. Action research is one of the recommended and widely used approaches to real-world DSR evaluation [Venable et al., 2016]. The researcher gets involved in the participatory action research with the UIC team and helps them in understanding the process for applying the UIC Framework as outlined in Chapter 9.

3. Through application of the framework, the team identifies the applicable tool(s) within the evaluation context. As described in Chapter 9, different tools will be applicable in different scenarios. It may be one tool or a combination of tools within the proposed UIC Framework. Based on the applicable tools, the objectives of evaluation are defined and agreed upon.

4. The researcher is involved throughout the life-cycle of the UIC, and learns about the value of the UIC Framework and required improvements through observation and experience during the participatory action research.

5. The researcher gathers insights from the team's experience by conducting surveys, interviews, and/or focus groups regularly during the UICs to assess the overall utility, applicability and effectiveness of the framework and the specific tools.

   The questions asked during such information gathering are phrased to understand if the framework proved to be useful for the team, if they have any suggestions for improvement, and if they will continue using the framework during the current UIC and in future UICs. A sample questionnaire that can be used for information gathering is provided in Appendix H.

6. The researcher analyses the results to establish if application of the UIC Framework helped the UIC team achieve their objectives. This will indicate the effectiveness of the framework. Analysis of experience of the UIC team in using the framework will indicate the utility and applicability of proposed framework and specific tools. Regular analysis during the UIC will allow appropriate improvements to be made and evaluated during the UIC and passed on to other UICs.

10.4 Example evaluation scenarios

In this section, I illustrate the evaluation strategy detailed in Section 10.3 using some of the scenarios described in Chapter 9.

10.4.1 Example 1 - Evaluation of the UIC Systems Model

University research has resulted in intellectual property which has the potential for exploitation by industry through further development. The university wants to explore commercialisation possibilities through a suitable UIC engagement with an industry partner as described in the scenario presented in Section 9.3.2.

Using the proposed evaluation strategy (Section 10.3.2), the evaluation in this scenario comprises the following steps:

1. The researcher selects and engages with the university for evaluation purpose.

2. The researcher decides that the appropriate methods of evaluation are action research and the use of focus groups. The researcher engages with the UIC team in participatory action research followed by data collection using a focus group.

3. By applying the process for using the UIC Framework, detailed in Chapter 9, the UIC team decided to use the UIC Systems Model as described in Section 9.3.2. Hence, the objectives of the evaluation are to evaluate the UIC Framework and the UIC Systems Model by answering the questions presented in Sections 10.3.1.1 and 10.3.1.2.

4. The researcher works with the team and provides any help required during application of the UIC Framework as described in the scenario presented in Section 9.3.2.

5. Organise a focus group to gather answers to questions related to the objectives identified in Step 3.

6. Review the results of the focus group. The results will indicate the validity of the UIC Framework and the UIC Systems Model in terms of utility, applicability, and effectiveness. They will also indicate any required improvements to the UIC Framework, and the UIC Systems Model.

10.4.2 Example 2 - Evaluation of the UIC Practices Framework

A university wants to enter into a UIC involving IP rights. The stakeholders would like to identify effective approaches to deal with IP rights as described in the scenario presented in Section 9.3.3.

Using the proposed evaluation strategy (Section 10.3.2), the evaluation in this scenario comprises the following steps:

1. The researcher selects and engages with the university for evaluation purpose.

2. The researcher decides that the appropriate methods of evaluation are action research and the use of focus groups. The researcher engages with the UIC team in participatory action research followed by data collection using a focus group.

3. By applying the process for using the UIC Framework, detailed in Chapter 9, the UIC team decided to use the UIC Systems Model, and the UIC Practices Framework as described in Section 9.3.3. Hence, the objectives of evaluation are to evaluate the UIC Framework, the UIC Systems Model, and the UIC Practices Framework by answering the questions presented in Sections 10.3.1.1, 10.3.1.2, and 10.3.1.3.

4. The researcher works with the team and provides any help required during application of the UIC Framework as described in the scenario presented in Section 9.3.3

5. Organise a focus group to gather answers to questions related to the objectives identified in Step 3.

6. Review the results of the focus group. The results will indicate the validity of the UIC Framework, the UIC Systems Model, and the UIC Practices Framework in terms of their utility, applicability, and effectiveness. They will also indicate any required improvements to the UIC Framework, the UIC Systems Model, and the UIC Practices Framework.

10.4.3 Example 3 - Evaluation of the UICMM

A university would like to assess its current level of UIC maturity and identify the improvements required to increase its UIC maturity level as described in the scenario presented in Section 9.3.4. Using the proposed evaluation strategy (Section 10.3.2), the evaluation in this scenario comprises the following steps:

1. The researcher selects and engages with the university for evaluation purpose.

2. The researcher decides that the appropriate methods of evaluation are action research and the use of focus groups. The researcher engages with the UIC team in participatory action research followed by data collection using a focus group.

3. By applying the process for using the UIC Framework, detailed in Chapter 9, the university decided to use the UICMM as described in Section 9.3.4. Hence, the objectives of evaluation are to evaluate the UIC Framework, and the UICMM by answering the questions presented in Sections 10.3.1.1, and 10.3.1.4.

4. The researcher works with the team and provides any help required during application of the UIC Framework as described in the scenario presented in Section 9.3.4.

5. Organise a focus group to gather answers to questions related to the objectives identified in Step 3.

6. Review the results of the focus group. The results will indicate the validity of the UIC Framework, and the UICMM in terms of their utility, applicability, and effectiveness. They will also indicate any required improvements to the UIC Framework and the UICMM.

10.5 Preliminary real-world application of the strategy

This section describes initial deployment of the proposed evaluation strategy in real-world pilot projects with the following organisations:

- The Australian Academy of Technology and Engineering (ATSE) [ATSE], and

- Coalfacer [Coalfacer, 2019].

As mentioned in Section 8.7.2, these organisations had approached the researcher to discuss the potential value of utilising elements of the UIC Framework for their real-world projects. Since then, the researcher has been involved with practitioners from the two organisations to further their project by applying the results of the research presented in this thesis. This engagement demonstrates real-world interest in the research presented in this thesis and provides the researcher with an opportunity to develop and validate the strategy presented in this chapter with industry partners. It will allow testing of the utility, applicability, and effectiveness of the tools within two real-world contexts. Experience through such participative action will enable the researcher to understand possible improvements to the proposed UIC Framework and individual tools.

10.5.1 Pilot project with ATSE

10.5.1.1 Project description

The Australian Academy of Technology and Engineering (ATSE) [ATSE] intends to develop a tool to assess the collaboration maturity level of Australian organisations engaging in UIC.

10.5.1.2 Evaluation method

Using the proposed evaluation strategy (Section 10.3.2), the evaluation in this scenario comprises the following steps:

1. The researcher engages with the ATSE for evaluation purpose.
2. The researcher decides that the appropriate methods of evaluation are action research and the use of focus groups. The researcher engages with the ATSE team in participatory action research followed by data collection using a focus group at the end.
3. When ATSE first contacted the researcher, they advised that the UICMM (described in Chapter 8) was a potentially useful tool for their project. Hence, the objectives of evaluation in this case are to evaluate the UICMM by answering the questions presented in Section 10.3.1.4.
4. ATSE is exploring the development of a digital tool informed by the UICMM to assess UIC maturity of organisations. The researcher is working with the team and providing any help required during the progress of the project. The researcher, in collaboration with the practitioners, will analyse project outcomes

in order to understand which aspects of the UICMM work, don't work, or can be improved. Regular analysis during the project will allow appropriate improvements to be made and evaluated during the project.

5. While participative action research allows learning throughout the life-cycle of the above projects, the researcher will also conduct focus group meetings with the practitioners to gather answers to questions related to the objectives identified in Step 3.

6. The results of the focus group meetings will be reviewed to determine the validity of the UICMM in terms of utility, applicability, effectiveness, and confidence. The review will also identify any required improvements to the UICMM.

10.5.1.3 Preliminary results

The interest of ATSE practitioners in application of the UICMM provides evidence of the utility and applicability of the tool. In addition, validity regarding the utility and applicability of the tool is supported through the practitioner's feedback presented in Appendix F.

10.5.2 Pilot project with Coalfacer

10.5.2.1 Project description

Coalfacer [Coalfacer, 2019] intends to develop a digital tool for matchmaking between organisations planning to engage in UICs. The aim of the tool is to help organisations identify suitable partners and establish effective UICs.

10.5.2.2 Evaluation method

Using the proposed evaluation strategy (Section 10.3.2), the evaluation in this scenario comprises the following steps:

1. The researcher engages with the Coalfacer for evaluation purpose.

2. The researcher decides that the appropriate methods of evaluation are action research and the use of focus groups. The researcher engages with the Coalfacer team in participatory action research followed by data collection using a focus group at the end.

3. When Coalfacer first contacted the researcher, they advised that the UIC Practices Framework (Chapter 7) and the UICMM (Chapter 8) were potentially useful tools for their project. Hence, the objectives of evaluation in this case are

to evaluate the UIC Practices Framework and the UICMM by answering the questions presented in Sections 10.3.1.3 and 10.3.1.4.

4. Like the ATSE project described above, this project is also exploratory in nature. Coalfacer is exploring the development of a digital tool informed by the UIC Practices Framework presented in Chapter 7 and the UICMM described in Chapter 8. The researcher, in collaboration with the practitioners, will analyse project outcomes in order to understand which aspects of the UIC Practices Framework and UICMM work, don't work, and can be improved. Regular analysis during the project will allow appropriate improvements to be made and evaluated during the project.

5. While participative action research allows learning throughout the life-cycle of the above projects, the researcher will also conduct focus group meetings with the practitioners to gather answers to questions related to the objectives identified in Step 3.

6. The results of the focus group meetings will be reviewed to determine the validity of the UIC Practices Framework, and the UICMM in terms of utility, applicability, effectiveness, and confidence. The review will also identify any required improvements to the UIC Practices Framework and UICMM.

10.5.2.3 Preliminary results

The interest of Coalfacer practitioners in application of the UIC Practices Framework, and the UICMM provides evidence of the utility and applicability of the tools. In addition, the utility and applicability of the tools is supported through the practitioner's feedback presented in Appendix F.

10.6 Conclusions

Evaluation is a crucial activity in research and central to DSR. This chapter presented a strategy for real-world evaluation and improvement of the proposed UIC Framework. The primary aim of the strategy is to guide the design of real-world experiments to evaluate and improve the UIC Framework. As described in this chapter, an iterative approach to learning, development, and evaluation in real-world settings is considered appropriate for evaluation of the UIC Framework.

Part III
Conclusions

Chapter 11

Conclusions

The aim of this thesis was 'to develop a framework that can be used to evaluate and improve the effectiveness of University-Industry Collaboration (UIC)' (Section 1.3). The thesis adopted the Design Science Research (DSR) approach to achieve this aim by proposing a UIC Framework (Chapter 5). In this chapter, I present a summary of the research completed to achieve this aim. I briefly revisit the research objectives associated with the research aim identified in Chapter 1. The contributions made by this thesis are then summarised, followed by limitations of the research, and discussion of directions for future research.

11.1 Introduction

UIC is important due to the many benefits it provides to both industry and universities (Chapter 2). It has gained increased attention as a result of the need for fast-paced innovations in highly competitive global markets. This is forcing businesses to seek external sources of knowledge and resources for innovation.

Despite its many benefits and existing approaches, UIC is challenging, and the benefits are often not derived effectively in practice. Hence, there is a need to develop new approaches to dealing with UIC. This research has addressed this need by developing a UIC Framework to evaluate and improve UICs.

Thus, the research focuses on a problem with real-world relevance, adhering to the guidelines of Design Science Research (DSR).

11.2 Research summary

This thesis adopted a Design Science Research (DSR) approach to address the stated research aim. Aligning with the most important characteristic of DSR, 'creation of purposeful artefacts', this research developed a novel UIC Framework to evaluate and improve UIC, comprising three tools (described in Chapter 6, Chapter 7, and

Chapter 8), which can be used on their own or in conjunction with the Cynefin framework.

The developed UIC Systems Model (Chapter 6) provides a language for describing and discussing UICs by defining the elements of UIC and how they interact to form a system. It can be used as a standalone tool or in conjunction with the Cynefin sense-making framework to gain a holistic view of UIC for better understanding and decision-making.

There are practices that have been recommended in the literature to overcome potential barriers to or enable success factors for UIC. A UIC Practices Framework (Chapter 7) for effective collaboration has been created from a comprehensive review of these published practices, and improvement approaches proposed during qualitative research (Chapter 4). This framework can be used as a standalone tool or in conjunction with the Cynefin framework to analyse various practices to be applied in specific collaboration contexts.

Maturity models have been used to successfully evaluate and improve the capability of organizations in areas such as software engineering, and knowledge management. Based on a review of these existing models, I have proposed a UIC Maturity Model (Chapter 8), which can be used as a standalone tool or in conjunction with the Cynefin framework to assess and improve the UIC maturity of an organisation.

Evaluation is a key activity in DSR. A two-phase evaluation approach was adopted during this research. In phase one, in line with DSR guidelines for demonstrating the utility of the developed artefact, a descriptive evaluation using example illustrative scenarios was conducted (Chapter 9). In phase two, the UIC Framework will be evaluated and improved in real-world settings. A strategy for conducting this future work is elaborated in Chapter 10.

11.3 Review of research objectives

In this section, each of the research objectives associated with the research aim defined in Chapter 1 is briefly reviewed.

- **Investigate the current state of UIC to understand how collaboration is currently pursued.**

  As described in Chapter 2, there are diverse types of UIC identified in the literature. In addition to the various types of UIC, literature also shows that in order to improve the effectiveness of UICs, a number of models for specific types of collaboration have been developed as depicted in Table 2.2.

However, analysis of these existing models indicated the need for new approaches to deal with UIC of diverse types. This thesis contributes to addressing this need by developing a framework to not only improve the theoretical understanding of UIC, but also for practical evaluation and improvement of all types of UIC.

- **Investigate existing barriers to establishing successful UICs.**

  As detailed in Chapter 4, various barriers to UIC are identified in the reviewed literature and qualitative research involving industry practitioners and researchers within the Australian Capital Territory (ACT). The literature review led to development of a new classification scheme for barriers as depicted in Table 4.1. The barriers identified in the qualitative study are consistent with the barriers identified in the investigated literature as shown in Table 4.4, though they are referred to using different terminology.

- **Investigate the factors that enable the success of UIC.**

  Success factors for UIC and practices recommended to address them have been identified in the reviewed literature (Chapter 7). However, the review found that the discussion around success factors and best practices was fragmented. To address this fragmentation, a new classification scheme for success factors has been developed by following an iterative process of data analysis that included a combination of inductive and deductive approaches.

- **Integrate the results of the above investigations to develop a general framework for evaluating and improving the effectiveness of UIC.**

  A novel UIC Framework (Chapter 5) is proposed consisting of the following three newly developed tools:

  - UIC Systems Model (Chapter 6)
  - UIC Practices Framework (Chapter 7)
  - UIC Maturity Model (Chapter 8).

  These tools can be used on their own or in conjunction with the Cynefin sensemaking framework to analyse, improve, and evaluate the effectiveness of UICs.

  A process for applying the proposed UIC Framework (Chapter 9) and a strategy for evaluating and improving the UIC Framework in real-world settings (Chapter 10) are presented.

11.4 Summary of research contribution

The research presented in this thesis extends the existing body of knowledge regarding UIC. The contributions of this work in improving the situation around UIC for the benefit of society and the economy are listed below:

- **Comprehensive review related to UICs.** The state of research related to various aspects of UIC indicates that it is dispersed [de Wit-de Vries et al., 2019] and presents a fragmented view [Perkmann et al., 2013]. There exist very limited studies that consider all the aspects of UIC. In this thesis, a comprehensive review of aspects related to UIC is presented. This review contributes to the theoretical UIC body of knowledge by bringing various aspects together and proposing classification schemes for barriers, success factors, and practices. The novel classification scheme provides a structure that connects these aspects and improves our understanding of the relationships between them.

  In Chapter 2, I elaborated the multi-faceted substantial benefits of UICs from both university and industry perspectives, and showed that this wide range of potential benefits cannot be derived from any single type of collaboration. A review of existing approaches to organising different types of UICs identified the need for new approaches to dealing with UICs.

- **Qualitative Research to understand the state of UICs.** A qualitative research project involving university researchers and industry practitioners within the Australian Capital Territory (ACT) region was conducted. It is to be noted that most existing studies have focused on the US, Europe, and the UK indicating a lack of knowledge from other regions [Galan-Muros and Davey, 2017; Perkmann et al., 2013]. This work contributes to efforts to bridge that gap regarding availability of studies from other geographic regions. The intent of conducting this qualitative research was to gather primary data to understand the status of UIC within the ACT region. The major conclusions drawn from this research are that: i) the lack of UIC is a concern; ii) certain barriers to collaboration are identified that substantiate the barriers identified in the reviewed literature. However, there is no ACT region-specific barrier to UIC; and iii) confirmation that there are approaches that can be adopted to improve the effectiveness of UIC.

  The results of this study also informed development of the UIC Practices Framework (Chapter 7).

- **A holistic approach to UIC.** In Chapter 5, a novel UIC Framework has been proposed for dealing with UICs of varying complexity. The framework makes use of the Cynefin sense-making framework along with three newly developed tools (described below) to evaluate and improve UICs of varying complexity. Chapter 9 presents a process for applying the proposed UIC Framework and Chapter 10 presents a strategy for evaluating and improving the UIC Framework in real-world settings.

- **A UIC Systems Model.** It is argued in this thesis that a systems approach is required to deal with UICs. A UIC Systems Model (Chapter 6) is developed that provides a language for describing and discussing UICs as systems. The model defines the elements of UIC and how they interact to form a system. The model aims to help stakeholders improve understanding of UICs.

- **A UIC Practices Framework.** A UIC Practices Framework for improving the effectiveness of UIC is developed as described in Chapter 7. The framework is based on a review of practices discussed in the existing literature, and inputs from qualitative research involving university researchers and industry practitioners (Chapter 4). The practices were categorized into: contextual, organizational, cultural adaptation, operation and management, personnel, communication, social capital, and legal practices. The framework can be used on its own or, where applicable, in conjunction with the Cynefin framework.

  While the framework focuses on universities and industry, it is expected to find wider applicability as the practices covered in the framework are based on general success factors and barriers to collaboration.

- **A UIC Maturity Model (UICMM).** A UIC Maturity Model (Chapter 8) is developed. The model can be used to assess an organization's current level of UIC maturity and to identify potential improvements. The UICMM is based on a comprehensive set of practices described in the UIC Practices Framework (Chapter 7), and relevant maturity models described in the existing literature. The UICMM can be used as a standalone tool or in conjunction with the Cynefin framework as described in Chapter 5.

- **Contribution to DSR literature.** This thesis makes a contribution to the DSR literature by demonstrating the use of DSR methodology for developing artefacts for improving and evaluating UIC.

- **Proof of Concept of application of DSR and Systems Thinking to UIC.** This thesis presented a case for the value of applying systems thinking and DSR methodologies to the domain of UIC.

I believe that this work has made an important contribution to field of UIC, and provides a useful resource for future researchers and practitioners interested in this area. Implementation of the proposed UIC Framework and associated tools has potential to offer various benefits to UIC stakeholders, including:

- An increased probability of successful UICs due to informed decision-making.
- Improved effectiveness of UICs in terms of achieving objectives for both universities and industry.
- Encouragement of UIC maturity assessment and improvement leading to more effective UICs.

One of the conclusions to be drawn from this research is that universities have an important role to play as a connecting link between society and the economy. While universities need to apply ways to foster entrepreneurship, they need to equip our graduates to face the future, which requires a diversity of skills. Universities also need to leverage digital platform more effectively to improve the visibility of their work and resources for their effective utilization leading to greater benefits for society (Section 4.3.5).

A major contribution expected of this research is to encourage university researchers and industry practitioners to engage in further discussions regarding UICs and improving their effectiveness.

11.5 Application of the research

The research presented in this thesis has strong practical implications as well as a strong theoretical contribution.

The proposed UIC Framework is flexible and can be applied in a broad range of real-world contexts and across disciplines. It can be used by universities, business and governments, as well as organisational units, teams and individuals within these organisations, to understand, design, and operate UICs of all types and levels of complexity. A clear strategy for ongoing real-world evaluation and improvement of the framework has also been developed and demonstrated in this thesis.

11.6 Limitations

Limitations of the work presented in this thesis have been discussed in relevant chapters and are summarized below.

- **Coverage of the literature.** It is possible that some of the relevant literature was not covered in this thesis. However, I am confident that the literature covered is representative of the field and, therefore, serves the purpose of this thesis.

- **Validity of the Qualitative Study (Chapter 4).** The qualitative study may have external validity issues. For example, the research results may not be generalizable to other settings due to geographic and industry differences.

- **Real-world Evaluation.** The proposed UIC Framework could not be evaluated in a real-world setting. However, this thesis presents a strategy (Chapter 10) for future evaluation and improvement of the approach in real-world settings. At the time of this thesis, this strategy was being applied in early collaborations with two industry partners.

11.7 Future work

The following research should be considered as part of future work:

- **Best practices from an Academic Perspective.** Results of the qualitative research are focused on industry's perspective regarding actions to be taken by universities in order to improve the effectiveness of collaboration. Similar research can be conducted in future to identify the best practices to be adopted by industry, and do a comparative analysis. There is a possibility of some overlap between the best practices for universities and industry (as shown in Chapter 7), and identifying practices that apply exclusively to industry such as those relating to absorptive capacity.

- **Improvement of the UIC Framework.** Although, the proposed UIC Framework and associated tools have been evaluated using descriptive evaluation in Chapter 9, I expect that the framework and tools will evolve through their practical use as per the evaluation and improvement strategy described in Chapter 10.

- **Developing a tool for ease of use of the UICMM.** A digital tool to gather data required for assessing UIC maturity and presentation of results will likely increase the ease of use of the UICMM. Such a tool will provide a medium to present the results of application of the UIC Framework and the UICMM. As noted in Section 10.5, I am working with external organizations to develop tools to support practical application of the UICMM.

- **Developing a tool for the UIC Practices Framework.** The researcher is working with an industry partner to develop a digital tool to curate practices used for successful UICs, as noted in Section 10.5. The partner is interested in using such curated data, along with the UICMM, for matchmaking of collaborators based on their collaboration capability. This will help in overcoming challenges associated with identifying potential collaborators and is expected to result in successful collaborations.

- **Refinement of the UICMM.** Initially, the UICMM was designed to provide a tool for self-assessment or third-party assessment of an organisation's UIC maturity. However, discussions with researchers and practitioners have led to the conclusion that the UICMM might also be applicable at the faculty or division level. It could even be used to assess the maturity of a UIC project. However, some of the KPAs may not be valid for the division or individual project level. For example, while strategy and policy initiatives adopted at the university level will flow down to the faculty or project level, they are not applicable to maturity models at these levels because stakeholders at these levels have no role in their development. This indicates that we should identify the KPAs that are valid for a given scenario and, during application of the model, conduct an evidence-based assessment of those KPAs. The survey questionnaire (Appendix G) provides a tentative indication of the level (project/organisation) at which the KPAs are applicable.

  Refinement of the UICMM for use at the project level is a candidate for future research.

- **Influence of additional factors.** Understanding the dynamics of the UIC system and the influence of aspects such as alumni relationships, perceptions of individuals not engaging in UIC, location of the university, legislative frameworks and changes in them can be explored as part of future research.

- **External validation.** The qualitative study in this thesis presented the perspective within the ACT. Similar studies can be conducted in other parts of Australia and the world to establish external validity.

- **'Open Innovation'.** There is a movement towards open research and innovation. Open innovation is not explored in detail in this thesis. However, it is an interesting topic of discussion and research in future.

11.8 Closing remarks

Tackling UIC as a complete system has meant that the research presented in this thesis needed to cover a very large body of knowledge. While this has been challenging, the journey through this research has been rewarding.

I have been able to develop a comprehensive approach to designing, operating, evaluating and improving UICs of varying complexity and across disciplines. My intention now is to work with university, government and industry partners to promote, apply and improve the approach in real-world UICs across Australia and around the world.

Appendix A
Adoption of Research Tools

Towards improved Adoption: Effectiveness of Research Tools in the Real World

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***Abstract*—One of the challenges in the area of software engineering research has been the low rate of adoption by industry of the tools and methods produced by university researchers. We present a model to improve the situation by providing tangible evidence that demonstrates the real-world effectiveness of such tools and methods. A survey of practising software engineers indicates that the approach in the model is valid and applicable. We apply and test the model for providing such evidence and demonstrate its effectiveness in the context of static analysis using FindBugs. This model can be used to analyse the effectiveness of academic research contributions to industry and contribute towards improving their adoption.**

I. Introduction

The success of software engineering research in universities can be measured in terms of the industrial adoption of methods and tools developed by researchers. Current adoption rates are low [1] and this contributes to a widening gap between software engineering research and practice. Consider, for example, code inspections, which according to Fagan's law, are effective in reducing errors in software, increasing productivity and achieving project stability [2]. Static analysis tools developed by university researchers help automate the code inspection process. However, the use of such tools has not obtained widespread adoption in industry. One reason for this limited adoption is that researchers often fail to provide real-world evidence that the methods and tools they develop are of potential value to industry practitioners [1], [3].

One approach to providing such evidence is to conduct experiments that demonstrate the effectiveness of research tools in a real-world context. We apply this approach to analyse the effectiveness of a static analysis tool. In doing so, we demonstrate that such experimentation can contribute to closing the gap between research and practice.

The structure of this paper is as follows: Section II provides the background of our work leading to the proposed model; Section III presents a survey which shows that real world evidence can positively influence the decision of software engineers to use research tools; Section IV explains our experimental method which uses FindBugs [4] to analyse real world bugs in Eclipse [5] code; Section V discusses how simple experiments like ours can encourage more developers to use tools developed by researchers and thus contribute to closing the gap between research and practice. Section VI provides an overview of related research; Section VII presents conclusions and discusses future research.

II. Background

Since the 1970's there have been ongoing efforts to increase the adoption of research outcomes outside of universities [6]. As a result of the United States Bayh Dole Act in 1980 [7], universities began to establish *Technology Transfer Offices* (TTOs) to facilitate the transfer of knowledge from universities to industry [8]. However, the effectiveness of TTOs has been questioned in recent years [9], [10] and there is a need to look beyond TTOs to improve adoption of academic research in industry.

Researchers in universities are working towards addressing significant problems. The outcome of their work can be a tool or method which may or may not achieve wide-spread industry adoption. A key factor limiting the readiness of these research outcomes for adoption in industry is a lack of tangible evidence that they would be effective in practice [1]. This suggests that demonstrating the effectiveness of a tool in practice can contribute to improved adoption.

Figure 1 depicts our model for demonstrating the real-world effectiveness of research tools and methods. The model involves 4 steps with intermediate activities. First step is to identify a problem to address. Step 2 is to develop a tool or a method to address the problem. The intermediate iterative activity involved between these 2 steps is the process of solution formulation, which involves adding new ideas to the available state of the art. These steps are followed by iterative testing for validation in Step 3. Step 3 confirms the readiness of the research outcome for adoption. An idea should be validated in a practical setting [11] to improve its adoption. Our model respects this viewpoint and emphasises the importance of tangible evidence from a practical setting in Step 4. Researchers should test their research outcomes in a scenario that involves real world users who are an important stakeholder for industry to increase the relevance of the evidence for industry. Demonstrating the effectiveness of research outcomes in real-world scenario will lead to change in industry perception and improved adoption of the research outcomes.

We test the applicability of this model in the static analysis context by identifying a static analysis tool created by university researchers and analysing its effectiveness in a real-world scenario.

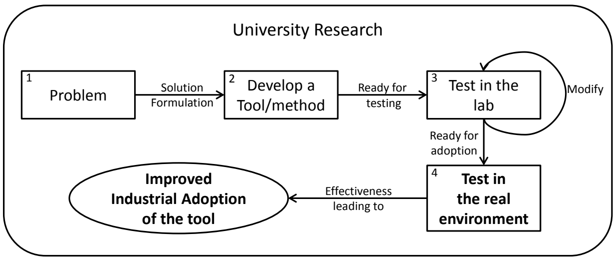

Fig. 1. Proposed model for improving adoption of university research by industry

III. THE IMPACT OF EVIDENCE FROM REAL-WORLD SCENARIO

In order to understand the impact of evidence from a user-scenario on real-world decisions to use a research tool, we conducted an on-line survey of software developers.

The survey uses static analysis as an example and was prepared and delivered using our university's online polling system [12]. Participants were invited by email which included a link to the on-line survey and a participant information statement. On completion of the survey, we manually analysed the results.

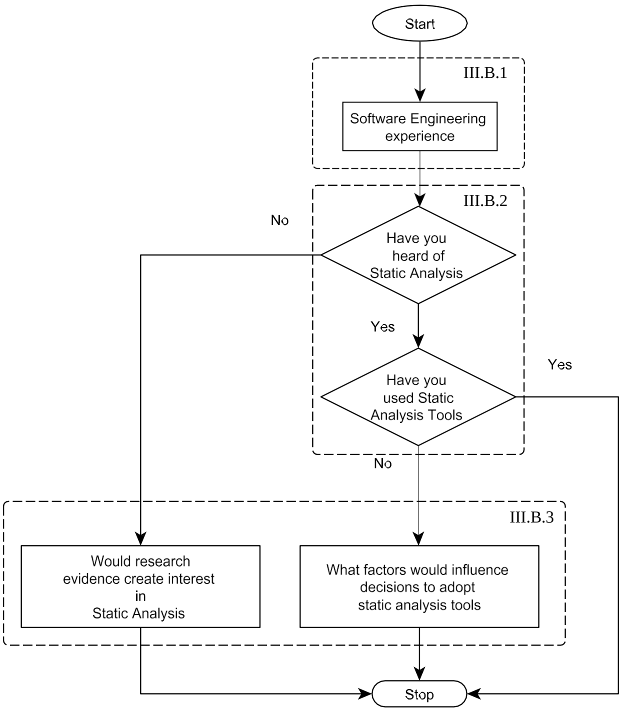

Fig. 2. Flowchart for the survey questionnaire design

A. Participants

We invited 20 software industry practitioners and around 10 computer science researchers with industry experience in software development.

B. Survey Questions

The survey data consisted of responses to the sequence of questions depicted in Figure 2 and described below.

1) Software engineering experience: We gathered information about the level of software development expertise of each participant so that we can understand any relationship between experience and use of static analysis tools.

2) Static analysis knowledge: We asked the following questions to determine each participant's level of understanding and use of static analysis tools.

a) '*Static analysis is the analysis of computer software to find potential bugs without actually executing the software. Have you heard of static analysis before?*'
b) '*Have you used any automated static analysis tools during software development (e.g. FindBugs, Coverity)?*'

Answers to these questions were used to determine the final question we asked, as indicated in Figure 2.

3) The impact of the tangible evidence: At the end of the survey each participant who has not used static analysis tools was asked a question to determine the impact that tangible evidence (that the tool can identify real bugs early in the software development life-cycle) might have on their approach to static analysis. The exact question asked depended on their answers to questions described in Section III-B2. Specifically:

1) Participants who had no knowledge of static analysis were asked '*Would our research results interest you in gaining knowledge of static analysis and adoption of automated static analysis tools?*'.
2) Participants who knew about static analysis but had not used any static analysis tools (our primary group of interest) were asked to rate the impact that the following factors would have on their decision to adopt static analysis tools. A Likert scale was used with 5 options (*No influence, May be, Likely, Highly Likely, and Definitely*).
    a) Effectiveness of tool in finding bugs
    b) Ease of use
    c) Integration of tool to development environment.
    d) License type.
    e) The availability of tangible evidence that the tool can identify real bugs early in the software development life-cycle - before they are reported by users.

C. Analysis of Survey Results

The response rate for our survey was high with 27 responses out of 30 invitations. Responses to the survey indicate that tangible evidence of real-world effectiveness of a tool has positive impact on decisions to adopt static analysis tools.

Analysis of the survey results provides the following specific findings:

1) *Software Engineering Experience* - As expected, participants had varied level of experience in software development. However, we do not find any direct relation between the experience and usage of tools.
2) *Static Analysis Knowledge* - Survey results show that 9 participants (33%) had no prior knowledge of static analysis. It is noteworthy that while the remaining 18 participants knew about static analysis, only 4 of them had used static analysis tools.
3) *Impact of the tangible evidence* - Our survey results show that tangible evidence has a positive impact on decisions to adopt static analysis tools. Out of the 9 respondents who had no prior knowledge of static analysis, 8 said that tangible evidence would interest them in gaining knowledge of static analysis and adopting automated static analysis tools. This is a valuable information indicating that providing evidence of effectiveness could contribute to improved adoption of research tools in industry.
Of the 14 participants who had knowledge of static analysis but who had not used any tools, 7 participants (50%) indicated that tangible evidence would be *Highly Likely* or would *Definitely* influence their decision to adopt static analysis tools (Figure 3). Another four participants indicated that such evidence would be *Likely* to influence their decision. Considering the response of three participants as *May be*, it is possible that they respond positively, which will add to the percentage of participants agreeing that tangible evidence will influence the decision.

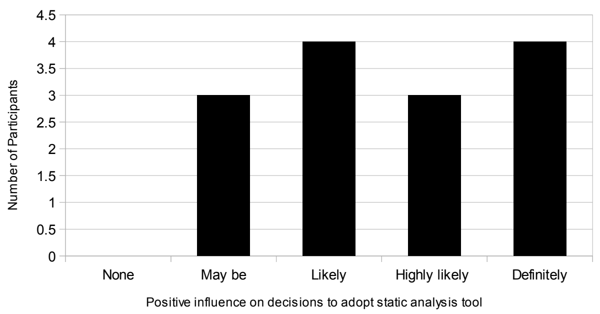

Fig. 3. The impact of tangible evidence on decisions to adopt static analysis tools

As shown in Figure 4, our results also indicate that other factors such as *Ease of use*, *IDE integration* and *License type* have a positive impact on decisions to adopt static analysis tools. It is interesting to note that under the *May be* and *Definitely* category, the top two influencing factors are *License* and *Tangible evidence*.

Our results clearly show that tangible evidence is an important factor in influencing decisions to adopt research tools in industry.

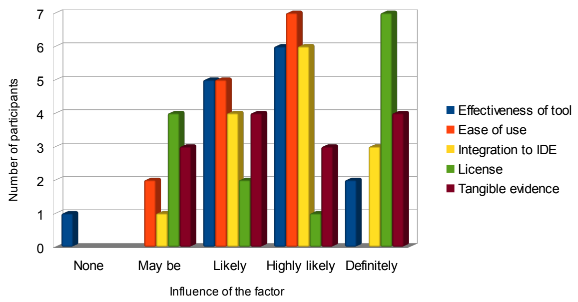

Fig. 4. Other factors influencing decisions to adopt static analysis tools

IV. Applicability of the Model

In order to test the applicability of our proposed model, we first had to identify an appropriate tool developed by researchers and a scenario to test its effectiveness. FindBugs version 3.0 was chosen for our research as according to the tool's website, there are few organizations using FindBugs [4]. This indicates low adoption of the tool in software industry. Also, it is an open-source static analysis tool with a university's trademark. We conducted an experiment with the FindBugs static analysis tool to analyse its effectiveness in the real world. To analyse the effectiveness in real-world, we wanted to determine if FindBugs is capable of finding bugs reported by real users of Eclipse. To do so, we adopted an approach to establishing a connection between warnings generated by the FindBugs static analysis tool and field bugs reported by Eclipse users on Bugzilla [13] that includes the below steps:

1) Use FindBugs to identify potential bugs in Eclipse class files.
2) Search the Eclipse bug-tracking system Bugzilla to identify bug reports that include stack traces.
3) Match the code pointed in Java classes associated with FindBugs warnings identified in 1) with code pointed by stack trace associated with the bugs identified in 2).

A. FindBugs

FindBugs analyses Java class files to report warnings and potential errors in the associated source code. The tool performs analysis on Java class files without needing access to the source code. It is stable, easy to use, and as mentioned in [14] has higher precision compared to other tools such as CodePro Analytix, PMD and UCDetector. It has a low rate of false positives [15], and has more than 400 types of bug classification along with categorization based on severity level. The analysis is based on bug patterns which are classified into nine categories: Bad Practice, Correctness, Experimental, Internationalization, Malicious Code Vulnerability, Multi-threaded Correctness, Performance, Security, and Dodgy Code. The warnings reported by FindBugs can be further categorised within the tool as: Scariest (Ranks 1-4), Scary (Ranks 1-9) and Troubling (Ranks 1-14). The category includes all the bugs with the ranking mentioned, for example, the ‘Scary’ category will list the bugs included under the ‘Scariest’ category, as well.

B. Eclipse

We identified Eclipse as the object of analysis as it is a large widely used open source project with good records of user reported bugs over many years and versions of the software. For our experimentation we focused on the analysis of Eclipse version 4.4 (Luna) because it was the current version at the time of our experimentation.

C. Identification of potential bugs

Java Jars associated with Eclipse versions 4.4 were analysed using FindBugs version 3.0. Findbugs generated a list of warnings pertaining to code considered as faulty.

D. Search for user reported bugs

The Eclipse project uses Bugzilla to track bugs reported by users. In order to identify bugs that could be associated with FindBugs warnings, we needed to identify bug reports that included a documented stack-trace. This was achieved by performing an advanced Bugzilla search for bugs that satisfied the following criteria:

- *Version:* 4.4,
- *Classification:* Eclipse,
- *Status:* NEW, ASSIGNED, VERIFIED [1].

We then inspected the query results to identify those bug reports that included a documented stack-trace.

E. Match FindBugs warnings with user reported Bugs

Our last step was to match warnings generated by FindBugs (Section IV-C) with user-reported bugs (Section IV-D). This was achieved using the following steps:

1) For each of the bugs identified using the procedure described in Section IV-D, we identified the Java class that was the likely source of the reported bug. This class was usually the one appearing at the top of the stack-trace. In some cases, we had to traverse through lower levels in the stack-trace to find matching classes.
2) We then searched for the above classes in the warnings generated by FindBugs (Section IV-C) and analysed the code associated with the warning. We did this by using the FindBugs class name filter feature to show warnings related to the class of interest.
3) Finding a matching line of code in the FindBugs warnings establishes a connection between the warnings generated by FindBugs and the bugs reported by users.

[1]Because our experiment looks at the ability of FindBugs to find bugs that have not been fixed, we ignore the bugs with CLOSED status. In addition, we do not consider the possibility of bugs that have been closed incorrectly.

F. Results of the Experiment

1) Analysis of FindBugs warnings for Eclipse version 4.4: Our analysis of FindBugs warnings for Eclipse version 4.4 showed that static analysis of Eclipse version 4.4 generated warnings in the categories of *Correctness* (652), *Bad Practice* (547), *Experimental* (1), *Multithreaded correctness* (390), *Security* (3), and *Dodgy code* (55) under the rank range of *Troubling* (Rank 1-14), as depicted in Figure 5. We focused on the *Scariest* warnings (Rank 1-4), considering them as real problems requiring attention. There were 82 *Scariest* warnings in total. These comprised 81 warnings in the *Correctness* category and one in the *Multi-threaded correctness* category.

Additional investigation found that warnings in the *Correctness* category included a range of coding errors such as comparisons of incompatible types, null pointer dereferences and reading of uninitialized variables.

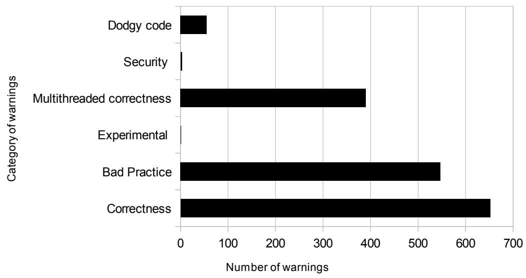

Fig. 5. Number of warnings in each category in Eclipse 4.4

2) Connection between FindBugs warnings and user reported bugs: Execution of the query described in Section IV-D resulted in a dataset of 2575 bugs, which included 347 enhancements. We excluded the enhancements from our analysis. Out of the remaining bugs, we have analysed 1185 bug reports so far, 90 of which included a documented stack-trace.

We used the method described in Section IV-E to compare the stack-trace in these 90 bug reports with the warnings generated by FindBugs (Section IV-F1). We found that six of the user reported bugs could be associated with FindBugs warnings as presented in Table I. The data presented in the table includes the Bugzilla Bug ID, a description of the bug, and a description of the warning generated by FindBugs.

V. Discussion

The model proposed in this paper considers that in order to improve the adoption of university research outcomes, researchers need to demonstrate its effectiveness in a real-world scenario and think about the value of their research outcomes beyond the lab boundaries. Our main purpose in conducting the experiment described was to test the applicability of our proposed model by analysing the value of a research tool in industrial practice. Specifically, we evaluated the performance of the FindBugs static analysis tool by analysing its capability

TABLE I
USER-FILED BUGS IN ECLIPSE WITH ASSOCIATED WARNING IN FINDBUGS

Bug Id	Problem Description	FindBugs Warning
436138	NPE when select SWT.MOZILLA style in control example	Method call passes null for nonnull parameterThis method call passes a null value for a nonnull method parameter. Either the parameter is annotated as a parameter that should always be nonnull, or analysis has shown that it will always be dereferenced. Bug kind and pattern: NP - NP_NULL_PARAM_DEREF
414508	NPE trying to launch Eclipse App	Load of known null value. The variable referenced at this point is known to be null due to an earlier check against null. Although this is valid, it might be a mistake (perhaps you intended to refer to a different variable, or perhaps the earlier check to see if the variable is null should have been a check to see if it was nonnull). Bug kind and pattern: NP - NP_LOAD_OF_KNOWN_NULL_VALUE
433526	browser.getText() is throwing exception after Internet Explorer 11 install	Possible null pointer dereference There is a branch of statement that, if executed, guarantees that a null value will be dereferenced, which would generate a NullPointerException when the code is executed. Of course, the problem might be that the branch or statement is infeasible and that the null pointer exception can't ever be executed; deciding that is beyond the ability of FindBugs. Bug kind and pattern: NP - NP_NULL_ON_SOME_PATH
459025	Can't right-click items in manifest editor's extensions tab on OSX	Non-virtual method call passes null for nonnull parameter A possibly-null value is passed to a nonnull method parameter. Either the parameter is annotated as a parameter that should always be nonnull, or analysis has shown that it will always be dereferenced. Bug kind and pattern: NP - NP_NULL_PARAM_DEREF_NONVIRTUAL
427421	NumberFormatException in periodic Workspace Save Job	Boxing/unboxing to parse a primitive A boxed primitive is created from a String, just to extract the unboxed primitive value. It is more efficient to just call the static parseXXX method. Bug kind and pattern: Bx - DM_BOXED_PRIMITIVE_FOR_PARSING
428890	Search view only shows default page (NPE in PageBookView.showPageRec)	Possible null pointer dereference There is a branch of statement that, if executed, guarantees that a null value will be dereferenced, which would generate a NullPointerException when the code is executed. Of course, the problem might be that the branch or statement is infeasible and that the null pointer exception can't ever be executed; deciding that is beyond the ability of FindBugs. Bug kind and pattern: NP - NP_NULL_ON_SOME_PATH
426485	[EditorMgmt][Split editor] Each split causes editors to be leaked	Possible null pointer dereference There is a branch of statement that, if executed, guarantees that a null value will be dereferenced, which would generate a NullPointerException when the code is executed. Of course, the problem might be that the branch or statement is infeasible and that the null pointer exception can't ever be executed; deciding that is beyond the ability of FindBugs. Bug kind and pattern: NP - NP_NULL_ON_SOME_PATH

in generating warnings relating to real-world bugs reported by users of the Eclipse IDE.

Our results indicate that FindBugs is capable of identifying bugs that will manifest themselves as bugs reported by users. Since real-world evidence would influence the decision to adopt a tool as indicated in the survey results, FindBugs needs to improve the percentage of such warnings to make the evidence convincing. Currently, FindBugs does not have the intelligence to track the bug among the list of false positives that can manifest. Our research provides improvement directions to FindBugs in identifying the important bugs from the warning base by analysing the historical data and user requirement. FindBugs results can be improved by introducing a new 'user-impact' category to classify the warnings which will potentially have an impact in the client environment and hence, need immediate attention. For this, sufficient information from industrial practice needs to be applied into testing the research tool.

The model appears simple but it is challenging for researchers to identify a scenario and approach users and/or data to demonstrate the effectiveness of their tool or methods. It might be difficult for them to find the user-filed data always. Also, once they have the data to demonstrate the effectiveness, they need a mechanism to propagate it to industry. Also, the concern about the relevance of research suggests that researchers need to think about the relevance of the problem they are trying to address. These factors indicate that universities and industry need to start collaborating at an early stage and consider co-developing whenever possible and feasible. This can pave a good start towards improving the relevance and adoption of research outcomes in general, and bridging the gap between industry and academia.

A. Limitations and Threats to Validity

Our experiments were limited by the small number of Eclipse bugs reported with a documented stack-trace. It is important to note that the ability to analyse only 90 of the 1185 bugs considered reflects a limitation of our approach and does not reflect a limitation of FindBugs. There are some limitations to the validity of our experiments:

1) FindBugs does not always point to the exact line number referred to in the stack trace. It might be possible that the source of error could be different from the warnings provided by FindBugs.
2) While it is likely that the FindBugs warnings listed in Table I are the actual cause of the listed real-world bugs reported by Eclipse users, we cannot be certain of this.
3) As there is lack of literature detailing the use of static analysis tools like FindBugs by the Eclipse development team, a comparison study was not feasible.

4) This test highlights the relevance of static analysis tools, though the effectiveness in real-world projects, particularly large scale projects, cannot be confirmed as the sample size of our survey is small. However, by considering the sample sizes of 20 and 18 used in related studies [16], [17], we decided to proceed with our sample size of 27 participants.
5) The conclusion might not be generalised as the results are specific to the static analysis context. The proposed model needs to be validated regarding the tools in other phases of software development.

VI. Related Work

Adoption of software engineering research outcomes in industry practice has been a concern [1], [18]. There have been ongoing efforts to improve the adoption of research outcomes since the 1970's. However, the efforts mainly focused on approaches to increase university-industry collaboration for improving adoption through technology transfer. These efforts include policy changes leading to establishment of TTOs in universities and proposing models for effective technology transfer [8], [19]. However, TTOs generally focus on building collaborative relationships between researchers and industry [20] rather than the readiness of research outcomes for adoption in industry. In this paper we demonstrated how some simple experiments can analyse the effectiveness of software engineering research tools in practice. Specifically we analysed the effectiveness of a static analysis tool.

Various experiments have been conducted to demonstrate the effectiveness of the FindBugs static analysis tool by showing that it is able to detect the specific problems it has been designed to detect [15], [21], [22]. However, our experiment has been conducted in unconstrained environment that involves real-world scenario that has impacted clients. Ruthruff et al. [23] involved developers in determining which reports were useful and which ones were not. This information was used to filter FindBugs warnings so that only those that developers found useful were reported. We retrace the user-filed bug to the warning generated by the static analysis tool. This can pave way to create an intelligent mechanism to prioritise bugs based on user-impact.

Al Bessey et al. [24] identify several factors that impacted the industry adoption of their static analysis tool Coverity [25]. They include trust between the researchers and industry users, the number of false positives, and the capability of the tool to provide warnings relating to problems which have had a significant impact on its users. Our work also confirms that tool's capability is important. It also identifies that licensing, IDE integration and ease of use are significant factors.

Johnson et al. [16] investigated the reasons behind the low adoption rate of static-analysis tools despite their proven benefits in finding bugs. Their investigations confirmed that large numbers of false positives is a major factor in low adoption rates. We note that their findings were based on the survey of developers who had all used static analysis tools. This meant that authors were not able to comment on whether low-adoption rates were due to a lack of awareness of static analysis tools among developers.

None of the work described above analyses the effectiveness of FindBugs in identifying problems that manifest themselves as real-world bugs reported by users. The experiments described in this paper analyse the connection between warnings generated by the FindBugs static analysis tool and field defects reported by Eclipse users on Bugzilla bringing in client into the perspective. The experiments test the applicability of our proposed model in the static analysis context.

VII. Conclusion and Future Work

We have proposed a model to contribute towards improving the adoption of research tools by industry by demonstrating the effectiveness of the tool in real world scenario. We have presented a mechanism which involves a research tool as a medium of building tangible evidence. A survey of software developers supports our hypothesis that such tangible evidence of effectiveness of a tool can have a positive influence on real-world decisions to adopt static analysis tools.

Further experiment for testing the applicability of the model in the static analysis context was conducted. In this experiment, by establishing a connection between user-reported bugs and warnings generated by the FindBugs static analysis tool, we have demonstrated the ability of static analysis tools to eliminate some defects before software is deployed. However, the evidence needs to be stronger regarding the number of such connections in order to be more convincing and improving the industrial adoption of the tool.

Future research would present more detailed analysis of the complete list of the bugs found in Section IV-F2, which will provide us precise data about the effectiveness of the tool according to our approach. Our approach also presents a scenario where industry and university researchers can work together to create more useful tools. We plan to discuss these results with the FindBugs development team to explore the possibility of strengthening the evidence and devising a new classification *user-impact* to indicate the warnings that would manifest in client-environment.

Finally, we would like to adapt this approach to explore the effectiveness of research tools involved in other phases of the software development life-cycle.

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Appendix B

Research material presented to participants of research detailed in Appendix A

Australian National University

Participant Information Sheet

Researcher:
My name is Richa Awasthy and I am pursuing PhD in Computer Science at the College of Engineering and Computer Science, ANU and my area of research is Software Engineering. My research involves exploring the ways to bridge the gap between software engineering research in university and industry practice. In particular, I am interested to investigate the possibility of creating a multi-dimensional approach to bridge the gap.

Project Title: Exploring the impact of tangible evidence on adoption of software engineering tool

General Outline of the Project:
One of the challenges in the area of software engineering research has been the low rate of adoption by industry of the tools and methods produced by university researchers. A key issue is the lack of tangible evidence that demonstrates the effectiveness of these tools and methods to industry. Static analysis tools, which have been mainly developed by university researchers, help automate the code inspection process. However, the use of such tools has not obtained widespread adoption in industry.
In this research, we use one such tool, FindBugs, to do a static analysis of the much used open source development platform, Eclipse. We evaluate the correlation between the warnings issued by FindBugs against the bugs reported by the users of Eclipse. We will investigate the impact of this tangible evidence on the decision-making towards adoption of the tool.

Target participants are a group of university students who are studying Computer Science as major and have an understanding of Software Engineering. Another group of participants will be industry practitioners who are involved in Software Development process at various roles.

The results of the study will be utilized to substantiate the experiment conducted and will be drafted in the form of a paper submitted to a research conference. These results will also form the part of the thesis to be submitted by the investigator on completion of the research.

However, any data used for reporting in this project or in a paper will be anonymized. Participants will get a briefing of the research results if they ask for that.

Participant Involvement:

Participation in this research is voluntary. The participants may withdraw from the research at any time until the preparation of the research report without providing an explanation. If the participants choose to withdraw from this research, their data will be destroyed.

The main technique of this research project consists of:

- Collecting response to survey questionnaire from the participants.
- Running the survey for a period of three days.
- At the end of the survey period, the response of the participants will be assessed in order to measure the impact of this methodology. In particular, the impact of tangible evidence in decision-making will be analysed.

There will not be any kind of invasion on the participants' privacy. No private information is required (i.e. Personal information, salary, or any information that is not related to work tasks)

The results of this project will be used for research purposes only and will not form part of the formal performance appraisal of the participants.

If participation in this research causes any kind of pressure or discomfort to the participants, they may withdraw from it at any time before the preparation of the research report without providing an explanation.

No incentives will be offered for participation.

Confidentiality:

-Only my project supervisors and I will have access to the “quality” data. In addition, we will use the performance data that the organisation regularly collects.

-None of the participants’ names, positions and roles will be mentioned in the research report.

-Confidentiality will be protected as far as the law allows.

Data Storage:

During data collection, the data will be kept on the investigator's password protected laptop and kept for 5 years from publication. A backup secured copy will also be kept on an external hard drive (investigator)

Queries and Concerns:

If you have any queries, please feel free to contact myself at richa.awasthy@anu.edu.au or my primary supervisors Dr. Shayne Flint at Shayne.Flint@anu.edu.au and Dr. Ramesh Sankaranarayana at ramesh@cs.anu.edu.au

Ethics Committee Clearance:

The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee. If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

Australian National University

WRITTEN CONSENT for Participants for Exploring the impact of tangible evidence on adoption of Software Engineering tool

Ethics protocol number: 2015/504

I have read and understood the Information Sheet you have given me about the research project, and I have had any questions and concerns about the project (

____

____)

addressed to my satisfaction. I agree to participate in the project.

YES ☐ NO ☐ I agree to this interview being audio-recorded

YES ☐ NO ☐ I give my permission to the investigator to utilise my response for research purpose.

I agree to be identified in the following way within research outputs:

YES ☐ NO ☐ Software Engineering user

YES ☐ NO ☐ Pseudonym

YES ☐ NO ☐ Complete confidentiality

Signature:………………………………………………. Date…………………..

Survey Questionnaire

This survey is a part of an ongoing research. It is being conducted to understand the impact of evidence in influencing the decision towards adoption of a tool in the area of Software Engineering. The data collected will be analysed and utilised to substantiate my research findings. The responses will be kept anonymous and data will purely be utilised for the purpose of the research.

1. How would you rate your experience in each of the following?

   None 0-2yrs 2-5yrs >5yrs

   1) Analysis -
   2) Design
   3) Programming
   4) Testing
2. Static analysis is the analysis of computer software to find potential bugs without actually executing the software. Have you heard of static analysis before?

   Yes

   No

   If you answered 'No', please skip to question no. 5.

3. There are tools available to automate static analysis. Have you used any static analysis tools during software development (eg. FindBugs, Coverity)?

   Yes

   No

   If you answered 'No', please skip to question no. 5.

4. Which static analysis tools have you used ?
   1) -------------------
   2) -------------------
   3) -------------------

5. What factors would influence your decision to adopt a static analysis tool?

   Effectiveness in finding bugs / Ease of use / Access to tool – free/open-source/paid

   Other – Please list.

6. Research shows that static analysis tools can effectively identify bugs in software widely used by industry, eg. Eclipse. Would such evidence positively influence your decision to use automated static analysis tools?

   Yes / No

7. If you answered 'No' to question 6, can you please list out the reasons?

Appendix C
Collaborative Education

Lifting the Constraints - Closing the Skills Gap with Authentic Student Projects

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***Abstract*—Preparing Software Engineering graduates with skills to satisfy the demands of industry has always been a challenge for universities. One way to overcome this challenge is to provide students with an authentic team project experience. Authentic student projects are those that are as close as possible to real projects in terms of uncertainty, complexity and diversity. In order to achieve this, collaboration with business and other external stakeholders is essential. However, such collaboration is often hindered by constraints around team structure, team and individual student assessment, the use of specific processes and technology, providing technical and other support, and fixed project durations.**

In this paper, we present a simple course structure and assessment process that has allowed us to remove the majority of such constraints, while maintaining integrity around student learning and assessment. By removing these constraints, we are providing students with authentic team project experiences that prepare them well for future employment. Preliminary evaluations of our approach indicate that despite several challenges, the experience has led to high levels of satisfaction among students and our external partners including employers.

I. Introduction

The gap between Software Engineering (SE) education and the requirements of industry has been widely acknowledged [2], [8]. Many initiatives are being taken globally to close this gap, including those involving collaboration between universities and industry to provide students with professional experience [7]. Within the Australian higher education context, there has been a long-standing commitment to encouraging such collaboration to improve the performance of business and higher education [5]. Despite these committments, there remains a serious shortage of skilled graduates [4], and employers continue to express dissatisfaction regarding the skills acquired by graduates while at university [5].

One way to reduce this gap and develop the graduate skills required by industry, is to provide students with authentic team project experiences towards the end of their time at university. These projects should be as authentic as possible. They should expose students to pressures arising from uncertainty, complexity and diversity, as well as stake-holders with diverse and conflicting needs, requirements and constraints that are difficult to navigate. They should be required to learn new things on their own and exercise professional judgement to make appropriate decisions regarding the application of knowledge and skills they have developed during their studies.

In order to ensure this kind of authenticity, student projects should be built around strong collaboration with business and other external stakeholders. Students who plan to create their own jobs after graduation, should have the opportunity to work with local entrepreneurs on their own ideas and start-ups while at university. In both cases, uncertainty, complexity and other real-world characteristics of a customer project or a start-up would ensure the authenticity of projects.

In practice, it can be difficult to support authentic student projects when there is a need to work with university constraints relating to assessment, term times, restrictions on technology and process choices, variations in student competencies and engagement, as well as the management of intellectual property.

This paper presents TechLauncher, a successful collaborative initiative that produces industry-ready graduates who have acquired professional skills through hands-on experience on authentic projects in collaboration with business, government and broader community, or by working with the local innovation ecosystem on their own start-ups. The key to TechLauncher's success is that the program places very few constraints on the types of projects undertaken by students, how they are conducted, the composition of teams, the technologies and processes used, and the deliverables expected. We have worked hard to eliminate as many constraints as possible.

While removing constraints has enabled us to provide students with authentic team project experiences, as well as value to our external partners, it has presented challenges around robust assessment and support for students.

The remaining sections of this paper will outline how TechLauncher deals with these challenges in a simple, but effective manner. We then conclude with preliminary evidence that shows high levels of satisfaction among students and external stakeholders, including those who employ our graduates.

II. TechLauncher

TechLauncher is a program run by the Australian National University (ANU) in collaboration with industry to provide students an authentic project experience. It is actually a 'branding' and common process for running a collection of year-long group project courses taken by students enrolled in a number of undergraduate and postgraduate computing degrees. The learning outcomes for each of these courses are very similar and cover team work, leadership, professional judgement, decision making, communication, creativity, complex problem solving, and management.

At our university, each year is divided into two semesters of 13 weeks each. Each TechLauncher project runs for two semesters and can start in the first or second semester of each year. The first semester intake is significantly larger than the second semester intake. Students spend 25% of a full-time equivalent study load on TechLauncher.

The following sections describe the operation of TechLauncher and highlight those features of the process that address the difficulties associated with running authentic projects within a university context.

A. Project Initiation

1) Student enrolment: As stated above, students from a number of courses are enrolled in TechLauncher. The career, experience and cultural diversity of each cohort, as well as variations in engagement and competence, provides an excellent environment within which students can develop leadership, teamwork, decision making and other engineering competencies. During 2015, 130 students, mostly from Australia, China and India, were enrolled in TechLauncher. In 2016, 150 students were enrolled.

2) Project Proposals: Before the start of each semester, we invite large numbers of business, government, other organisations and individuals to register with TechLauncher and propose projects. The only constraint we place on projects proposals is that students will work on projects for two semesters of 13 weeks each. Within this constraint, we encourage the proposal of a broad range of projects across any domain. In 2016, we received more than 70 project proposals for first semester and 30 proposals for second semester.

3) Project pre-filtering: Because we receive a large number of project proposals, we need to identify a subset of projects that will be offered to students. While teaching staff may remove some projects proposals, an on-line survey of students is the primary mechanism we use to select projects. This reflects a key TechLauncher philosophy of putting as much control as possible in the hands of our students. After all, they are not that far away from graduating and becoming trusted members of our profession. In 2016, students identified around 45 projects to go forward to the next stage in first semester and around 15 in second semester.

4) Team Formation Day - self selecting teams: On the first or second Saturday of each semester, we hold a *Team Formation Day* during which projects are selected and teams are formed. The day begins with a series of three-minute pitches by those who have proposed the projects identified above. Students then meet with project proposers and other stakeholders during an informal networking session over lunch. After lunch, we run an iterative process during which students self-select the team they would like to join. This process is based on the work of Sandy Mamoli and David Mole [9] and achieved very impressive results with around 80% of students happy with their team and 68% satisfied with their project 6-7 weeks after the team formation day.

B. Robust Assessment

A consequence of removing constraints on projects is that they tend to be very diverse in terms of team composition, project type, technology and processes used, external constraints, stakeholders and stakeholder expectations. This can present significant assessment challenges if the focus is on evaluating the artefacts and outcomes produced by students. While such a focus is common in student projects, we are of the view that it is more important to focus on how the professional judgement of students and the quality of their decisions develop during the course. We are also interested in the evidence students use to support and evaluate such decisions, as well as the real value of individual contributions. In doing so, we not only evaluate critical graduate attributes, but we can do so consistently across a diverse range of projects operating within an environment of minimal constraints. The following sections outline the details of our approach.

1) Regular Expert Tutor Meetings and Peer Assessment: Each team meets with an assigned tutor every two weeks. All tutors have industry experience or are current industry practitioners. During these meetings, tutors provide guidance and discuss what has been achieved during the previous two weeks and what the team plans for the next two weeks. The focus is on the decisions being made, the evidence developed and used to support these decisions and the ongoing monitoring of the consequences of these decisions. As time goes on, the nature of these decisions will evolve. At the start of a project, decisions around stakeholder engagement, exploring the problems space and prototyping might be considered. Towards the end of each project, decisions around closing or transitioning the project after completion of the course are often considered. In all cases, it is left to the students to make the decisions. The tutors role is to guide and advise rather than direct the projects.

Another critical element of our approach to assessment is the use of peer assessment to understand the contributions of individual students. The validity and effectiveness of such assessment have been accepted [15]. It provides an opportunity for students to reflect upon the contributions of team members and to provide constructive feedback aimed at improving their performance. Every two weeks, students assess the relative contribution of each team member to the work of the team. They also provide written feedback to each of their peers. All of this data is collected and used to generate an individual report for each student. This report presents their teams mark, their individual mark which is derived from the team mark and their peers assessment of their contribution, and summary statistics and charts for the team and across all TechLauncher teams. While not perfect, we have found that this form of peer assessment and feedback is a quite reliable and efficient approach to assessing individuals within a team.

2) Mid-Term Team Presentations and Peer Assessment: At the half-way point of each semester each student team presents their project to three other teams. The aim of this activity is to help teams benchmark their own performance relative to several other TechLauncher project teams. It also serves as an early practice for the end of semester Project Review described below. Each student must submit a peer assessment of each of the three presentations they attend. This assessment includes written feedback using a provided rubric.

All of this data is collected and used to generate a report for each team. This report presents the written feedback provided by peers along with summary statistics and charts across all TechLauncher teams.

3) Project Review and Peer Assessment: At the end of each semester we conduct a major project review of every project. Each review runs for 90 minutes and is attended by all team members, clients, tutors, mentors (see §II-D2) and guests. Students briefly present the current state of their project and then answer questions from the audience. These reviews can be very intense and are surprisingly effective at uncovering the reality of each project's progress. Similar to the tutor reviews, we focus on decision making. Towards the end of each meeting, we usually take advantage of the fact that all key stakeholders are present, to discuss the next stage of the project or solutions to any problems uncovered during the review. Peer assessment is used to assess the individual contribution of students leading up the the project review.

C. Poster and Public Showcase

At the end of each semester, we hold a public showcase at which every team presents a poster and networks with representatives from business, government and broader community. It provides an opportunity for students to develop their communication skills, and to meet potential employers, investors and collaborators. At the end of 2016, the public showcase was attended by around 250 people, including our students.

D. Project Support

1) TechLauncher Management System: Participant registration and project proposals, as well as the course guide and other resources are managed using Redmine[11], a popular open-source project management system which we tailored for our purposes.

2) External mentor pool: There is a mentor pool of industry experts. Because these mentors are very busy people, often working on multiple income-earning projects, we have been very careful to avoid wasting their time. Students who would like access to one of the mentors can request an introduction from the teaching staff. If the teaching staff finds value in using the proposed mentor, the introductions are made. The students then negotiate meeting times and the scope of engagement with the mentor. This 'utilize when needed' approach leads to efficient and effective utilization of the pool.

3) Workshops: Workshops are sometimes run to provide students and other stakeholders with knowledge and skills in effective software engineering practices. For example, in 2016 a workshop on 'Relative Estimation' [1] was a great success among students and has motivated us to run additional workshops in future.

III. Evaluation of TechLauncher

In order to demonstrate the effectiveness of the course initiative, we present here observations regarding student satisfaction, project successes, and industry satisfaction.

A. Student Satisfaction

In 2015 we conducted an anonymous on-line survey of students enrolled in the course using the university's online polling system. We prepared a set of survey questions to determine participants' satisfaction with the course. Participants were invited by email and a post on Piazza [10], which included a link to the on-line survey and a participant information statement. On completion of the survey, we manually analysed the results.

At the time of writing, we have also collected some limited data based on the 2016 instance of TechLauncher.

1) Participants: In 2015 we invited around 130 students to participate. We received 86 responses out of 130 invitations (66%). Our 2016 survey is not yet complete, but so far, we have received 27 responses from 151 invitations (18%). Because of this, the 2016 results included below are indicative only.

2) Survey Questions: The survey data consisted of responses to a list of questions described below. Questions had either open-ended answers or a Likert scale with five options (Very satisfied, Somewhat Satisfied, Neutral, Somewhat Dissatisfied, Very dissatisfied).

a) Student Satisfaction - The following are the key questions we asked to determine the satisfaction of students with various elements of the course.
   - How satisfied are you with your PROJECT?
   - How satisfied are you with your TEAM?
   - Overall, how satisfied are you with the course?

b) Open-ended Feedback - A set of open-ended questions were used to gather student feedback that might be used to improve the effectiveness of the course. The questions were as follows:
   - List three things you like about TechLauncher.
   - List three things you do NOT like about TechLauncher.
   - What should we do to improve TechLauncher?

3) Analysis of Survey Results: Responses to the survey indicate that the course model has been effective and most of the students are satisfied with their experience through the course. Analysis of the survey results provides the following specific findings:

(a) *Project and Team Satisfaction* - As described above, teams were formed and projects were chosen using a self-selection process. The 2015 survey results show that more than 65% students were satisfied with the project they were working on. It is noteworthy that out of the remaining participants, 21% responded with the 'neutral', which indicates that only 10% of students were dissatisfied with the project they were working on. Preliminary 2016 results indicate a slightly higher project satisfaction rate at 75%.

The 2015 survey results indicate 80% of students were satisfied with their team. Preliminary 2016 results indicate a much lower team satisfaction rate of around 50%. This may be an early indicator that our increased emphasis on peer assessment in 2016, to better establish individual marks, may be sensitising students to problems in their teams.

(b) *Overall Course Satisfaction* - Our 2015 survey results indicate that, along with the above-mentioned factors, overall satisfaction with the course is also good with over 65% of the respondents being satisfied and 18% neutral. Preliminary 2016 results are much the same at 67% and 19% respectively.

(c) *Open-ended Feedback - what students liked* - According to the 2015 survey, students welcomed the ability to create their own Start-Up, encouragement to innovate, freedom to select their project and form a team, and the freedom to make their own decisions regarding the conduct of their project. All this has been achieved by minimizing the constraints. One of the students mentioned what he liked most about TechLauncher was '*The freedom to take initiative with project development. It's up to you to choose the right tools and learn from your mistakes.*'

Many TechLauncher students also liked the teamwork experience, which exposed them to challenging team dynamics.

Other liked attributes included experience of working closely with industry, gaining professional skills such as leadership, project management, communication and client engagement, tutor reviews, access to the mentor pool, opportunity to apply theoretical software engineering knowledge into practice, transparency in the management system, networking, and improving technical skills.

(d) *Open-ended Feedback - what students did not like* - According the the 2015 survey, students did not like mandatory participation in the InnovationACT competition, learning portfolios, and peer assessment. In 2016 we made changes aimed at addressing these concerns.

The InnovationACT program 'provides the necessary skills, tools and networks to those looking to begin their entrepreneurial journey' [6]. In 2015 we required all student-run start-up teams to participate in InnovationACT. Unfortunately, this was seen by many students as additional work that did not contribute well enough to the success of their project and, therefore, marks. In 2016, participation in InnovationACT was strongly encouraged but was not required.

Students also felt that the work involved in preparing learning portfolios didn't contribute to their success nor that of their project. Because we hold the view that the development of portfolios can help student learning, we retained something similar in 2016. To address student concerns, we attempted to make the portfolios more relevant to students by positioning them as individual '*Work Portfolios*' that students can use in support of job, funding and other applications. Preliminary feedback indicates that we still have problems with portfolios. While some students really engage with the process and produce wonderful examples of work, many students still see portfolios as extra work that provides little value.

In 2015, students were required to complete a peer assessment process every two weeks. That is, they were required to assess the performance of team-mates against a specific rubric. These results were then used to derive marks for each individual student. Students found this confronting, confusing, time-consuming and, again, of little value to their project. So, in 2016, we simplified the process significantly by asking students to identify the percentage contribution of each team member to the overall value delivered by the team. Preliminary feedback from 2016 indicates that students are happier with the new system, but still have concerns regarding the work involved.

(e) *Open-ended Feedback - how the course can be improved* In general, feedback regarding improvements to the course centred around the need for additional project management and technical support. In 2015, we attempted to connect each team with an external industry mentor who could provide expert help when needed and was not involved in assessment. We found that this was difficult to do because of the heavy work commitments of many of our mentors. Feedback from mentors also indicated that they felt under-utilised in some cases. So, in 2016 we introduced the concept of a mentor pool as described in section II-D2.

(f) *Open-ended Feedback - general comments* - The following more general student comments are a testimony to the success of TechLauncher in achieving its objective:

'*Feeling like I have learned and grown through the experience of this course. Not least about (responding to) failure and difficulties.*'

'*It's been an awesome way to finally put what we've learned about software engineering into practice.*'

'*The opportunity to work with industry projects. The opportunity to run with a startup idea. The real-life simulation of a project and its expectations.*'

'*It's very unguided and all the decisions/responsibilities are left up to me.*'

'*Allowing us to work on a product for a full year as a team is a good experience. The group mentors are really helpful.*'

B. Projects success

We measure the success of projects in several dimensions. For example, some projects are successful in terms of societal impact. The '*Design Profile*' project which developed the first psychometric profiling tool in the world for design behaviours and tendencies [14], [13], was used by the United Nations in Nairobi before students completed the course. Another project, '*The Game Makers: Ngarlpuputju*' in collaboration with linguistics researchers is blending tradition with technology to create the first computer game in an indigenous language [12], [3]. Other projects were successful in terms of what students learned. For example, our professional services team, which comprised 10 students working concurrently on several small projects during the year, produced one of the best leaders we have seen in a very long time. This student rapidly developed the ability to manage significant diversity and uncertainty in relation to team skills and cultural backgrounds, clients, projects, technology and processes. He led a cohesive team that delivered real-world results across a broad range of projects.

Of course, some projects don't go so well. A small number of projects failed to achieve any real outcomes due, mainly, to student and/or client disengagement, dysfunctional team dynamics or lack of the technical and other skills required to complete the projects.

C. Industry Satisfaction

We have not yet conducted any formal survey of industry clients. However, the number of project proposals received (almost three times the number of projects we required) and repeated participation from clients indicates a healthy level of industry satisfaction with the course. We have also received encouraging feedback from various sectors.

A Government representative states, '*In 2014 the ACT government provided funding and ongoing support for TechLauncher initiative. Since then, TechLauncher has exposed large numbers of students to the local innovation sector. This has provided an exceptional learning environment for students, and local business with access to a pipeline of high quality software development.*'

Success of TechLauncher in the words of a senior university academic/leader - '*TechLauncher in particular has been highly successful with growing number of students across the University engaged in an entrepreneurial program with external mentors that is for course credit. This is an exemplar of how our education programs should be evolving, particularly in Engineering and Computer Science.*'

Venture capitalists have also engaged with TechLauncher - '*For the last couple of years I have been involved with TechLauncher. The interest in the program has surpassed all expectations! I have been very impressed with the ideas, teams, engagement and progress. Many of the projects have commercial potential.*'

TechLauncher has also been commended by representatives of local incubators, co-working spaces and accelerators - '*TechLauncher meets this need well, helping students understand how to use knowledge to either solve organizational challenges(university or commercial), or set up startups to meet real needs through commercially viable model. This need is central to current Federal policy making in the field of innovation. Student experience is engaging, as they not only learn through traditional models of hearing, reading and writing, but also through setting up business ideas and real problem solving.*'

IV. Conclusion and Future Work

In this paper, we present TechLauncher, a group project capstone course that aims to better prepare graduates for the work force. The initiative places a strong emphasis on providing students with an authentic project experience. We do this by minimizing constraints on the types of projects undertaken by students, as well as the way they approach their projects in terms of management, software engineering practices, tools and technology used. This approach leads to a win-win result for students, industry and the university. Students gain valuable employment-related skills and a better understanding of the role that software developers and engineers play in society. Industry are exposed to new and emerging ideas, can influence curriculum, and are able to develop a pipeline of future employees. The university develops a better understanding of industry needs and challenges, and is able to respond through curriculum development and other collaborations including joint research projects.

All of this contributes to closing the gap between software engineering education and industry needs.

We will continue to evolve the TechLauncher initiative. In particular, we will continue to work with students and industry to develop better approaches to assessment and ensuring the success of every student and every project.

V. Acknowledgements

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Appendix D

HUMAN RESEARCH ETHICS COMMITTEE
Application Form

Created by: **u5242932**
Record number: 8110
Protocol type: **Expedited Ethical Review (E1)**
Protocol number: **2016/139**

Date entered: **21/03/2016**
Ethics program type: **Postgraduate**
Requested start date: **21/03/2016**
Requested end date: **16/03/2017**

Protocol title: **Investigate the impact of various approaches to bridging the gap between Software Engineering research in university and industry practice**

Investigators

Name	Role	Department
Awasthy, Richa	Primary investigator	Research School of Engineering, College of Engineering and Computer Science, ANU
Flint, Shayne	Supervisor	Research School of Computer Science, College of Engineering and Computer Science, ANU
Sankaranarayana, Ramesh S	Supervisor	Research School of Computer Science, College of Engineering and Computer Science, ANU

Investigators Detailed

Name: Awasthy, Richa **Role:** Primary investigator

Expertise: I have completed post-graduate degree in Computer Application at University of Mysore, India. I worked as Software Engineer with IBM in India and Sydney. Currently, I am pursuing PhD in Computer Science at College of Engineering and Computer Science, ANU and my area of research is Software Engineering. My research involves exploring the ways to bridge the gap between software engineering research in university and industry practice. In particular, I am interested to investigate the possibility of creating a multi-dimensional approach to bridge the gap.

Name: Flint, Shayne **Role:** Supervisor

Expertise: Dr. Flint has an extensive experience in Software Engineering, Engineering

Systems Design, Engineering Design Methods, Information Systems Development Methodologies, Interdisciplinary Engineering, Distributed and Grid Systems, Simulation and Modelling. He is currently part of SISE (Software Intensive Systems Engineering) - Research School of Computer Science

Name: Sankaranarayana, Ramesh S **Role:** Supervisor

Expertise: Dr. Sankaranarayana has an extensive research experience in Information Retrieval and Software Intensive Systems Engineering. He is currently part of SISE (Software Intensive Systems Engineering) - Research School of Computer Science

External Investigators

Name	Role	Institution

Departments

Primary	Department	Faculty
No	Research School of Computer Science	College of Engineering and Computer Science
Yes	Research School of Engineering	College of Engineering and Computer Science

Project Questions Detailed

Description of Project

Describe the research project in terms easily understood by a lay reader, using simple and non-technical language. Collaboration between university researchers and industry remains a challenge despite its benefits. The literature indicates various existing barriers to this collaboration, which have contributed to a gap between the researchers and industry practitioners. In my research, I explore ways to overcome these barriers and propose a multi-dimensional approach to bridging the gap. I would like to investigate the potential impact of this approach.
We are building an online collaborative platform which will support the application of our multi-dimensional approach. We would like to study the response of potential users to the platform and evaluate its effectiveness.

HUMAN RESEARCH ETHICS COMMITTEE
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Location of Data Collection

Australia Yes

Overseas Yes

Provide country / area where data collection will be conducted Data collection would involve users from Australia and various other countries.

Aims of the Project

List the hypothesis and objectives of your research project. Hypothesis:
A multi-dimensional approach involving access to tangible evidence, maturing technology within universities, and an online platform for collaboration could help in bridging the gap between Software Engineering researchers and industry practitioners.

Objectives:
Investigate the impact of various approaches to bridging the gap between Software Engineering research in university and industry practice

Methodology

In language appropriate for a lay reader, explain why the methodological approach minimises the risk to participants. (For surveys, include justification of the sample size).
Participation in this research is voluntary; No withdrawal penalty will apply.
The main technique of this research project consists of:
- Collecting response to survey questionnaire from the participants.
- Running the survey for a period of 1 month.
- At the end of the survey period, the response of the participants will be assessed in order to evaluate the impact of our approach.
-The data collected will be used for research purposes only.

Provide the survey method, a list of the questions to be asked or an indicative sample of questions. These should give a good sense of the most intrusive/sensitive areas of questioning. Indicative survey questionnaire attached.

What mechanisms do the researchers intend to implement to monitor the conduct and progress of the research project? For example:
How often will the researcher be in touch with the supervisor?
Is data collection going as expected? If not, what will the researcher do?
Is the recruitment process effective?
How will the researcher monitor participant's willingness to continue participation in the research project, particularly when the research is ongoing? Supervisors shall be informed about the survey to be conducted.
Before beginning the survey, I shall take supervisors guidance in drafting the questionnaire.
My supervisors will be updated weekly about the progress of this research project as per the current arrangement.
New participants from within the organization (University and software industry) will be recruited

in the event of withdrawals.

Participants

Provide details in relation to the potential participant pool, including:

target participant group;
identification of potential participants;
initial contact method, and
recruitment method. The target participants are two groups:
1. A group of researchers enrolled for Higher Degree Research at the ANU College of Engineering and Computer Science and other overseas universities.
2. A group of practitioners from software industry.
Potential participants will be identified in the research project as "member" of the focus group; No names will be mentioned.
Initial contact method with the participants will be via email, outlining the purpose of the study and seeking their participation.

Proposed number of participants 120

Provide details as to why these participants have been chosen? As this research project is about bridging the gap between Software Engineering research and industry practice, the selected participants are researchers at the ANU and other universities, and industry practitioners. They have been chosen as the main stakeholders for this research.

Cultural and Social Considerations/Sensitivities

What cultural and/or social considerations/sensitivities are relevant to the participants in this research project? There won't be any kind of invasion of the participants' privacy or beliefs. No confidential or personal information is required. As the survey is being conducted online, participants can submit their response at a time and location convenient to them.

Incentives

Will participants be paid or any incentives offered? If so, provide justification and details. No, participation is voluntary. Participants will not be paid.

Benefits

What are the anticipated benefits of the research? We expect this research to lead to increased collaboration between software engineering researchers and industry practitioners, which will lead to increased productivity.

To whom will the benefits flow? Software engineering practitioners and their clients.

Informed Consent

Indicate how informed consent will be obtained from participants. At least one of the following boxes MUST be ticked 'Yes'.

In writing Yes

Return of survey or questionnaire No

Orally No

Other No

If Oral Consent or Other, provide details. N/A

Confidentiality

Describe the procedures that will be adopted to ensure confidentiality during the collection phase and in the publication of results. Only the investigator and the supervisors will have access to the data.
None of the participants' names, positions and roles will be mentioned in the research report.

Data Storage Procedures

Provide an overview of the data storage procedures for the research. Include security measures and duration of storage. During data collection, the data will be kept on the investigator's password protected laptop and kept for 5 years from publication. A backup secured copy will also be kept on an external hard drive (investigator)

Feedback

Provide details of how the results of the research will be reported / disseminated, including the appropriate provision of results to participants. If appropriate, provide details of any planned debriefing of participants. The results of the study will be utilized to substantiate the experiment conducted and will be drafted in the form of a paper submitted to a research conference. These results will also form the part of the thesis to be submitted by the investigator on completion of the research.

Supporting Documentation

Please ensure electronic copies of any supporting documentation have been uploaded the documents tab of the relevant protocol.

Has this work been approved by another Human Research Ethics Committee (HREC)? No

If yes, please give the name of the approving HREC. N/A

Funding

Is this research supported by external funding? No

Provide the name/s of the external sources of funding. Please include grant number/s if available. N/A

Is the research conducted under the terms of a contract of consultancy agreement between the ANU and the funding source? No

Describe all the contractual rights of the funding source that relate to the ethical consideration of the research. N/A

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High Risk One Summary

Question	Answer
Is this a clinical trial?	No
Does this research involve the intentional recruitment or issues involving Aboriginal and / or Torres Strait Islander Peoples?	No

High Risk Two Summary

Question	Answer
Does this research involve Human Genetics?	No
Does this research involve Human Stem Cells?	No
Does this research involve Women who are pregnant and the Human Foetus?	No
Does the research involve people highly dependent on medical care who may be unable to give consent?	No
Does the research involve people with a cognitive impairment, an intellectual disability or a mental illness?	No
Does this research involve an intention to study or expose or is likely to discover illegal activity?	No
Does this research involve human gametes (eggs or sperm)?	No
Does this research involve excess ART embryos?	No

Expedited Questions Summary

Question	Answer
Third Party Identification	No
Children or Young People	No
Dependent or Unequal Relationship	No
Membership of a Group, or Related Issues	No
Physical Harm	No
Psychological Harm (includes Devaluation of Personal Worth)	No
Social Harm	No
Economic Harm	No
Legal Harm	No
Covert Observation	No
Deception	No
Sensitive Personal Information	No

Question	Answer
Overseas Research	Yes
Collection, use or disclosure of personal information WITHOUT the consent of the participant	No

HUMAN RESEARCH ETHICS COMMITTEE
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Supporting Documentation

Please ensure electronic copies of the supporting documentation have been uploaded into the documents tab of your protocol

These may include (please circle the relevant answer):

List of indicative questions	**Y/N**
Copy of questionnaire / survey	**Y/N**
Invitation or introductory letter/s	**Y/N**
Publicity material (posters etc.)	**Y/N**
Information sheet	**Y/N**
Consent form	**Y/N**
External approval documentation	**Y/N**
Research visa (if applicable)	**Y/N**
Other (specify below)	**Y/N**

For other, please specify:

HUMAN RESEARCH ETHICS COMMITTEE
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SIGNATURES AND UNDERTAKINGS

PROPOSER OF THE RESEARCH

I certify that all the persons listed in this protocol have been fully briefed on appropriate procedures and in particular that they have read and are familiar with the national guidelines issued by the National Health and Medical Research Council (the National Statement on Ethical Conduct in Human Research 2007).

I certify that the above is as accurate a description of my research proposal as possible and that the research will be conducted in accordance with the National Statement on Ethical Conduct in Human Research 2007. I also agree to adhere to the conditions of approval stipulated by the ANU Human Research Ethics Committee (HREC) and will cooperate with HREC monitoring requirements. I agree to notify the Committee in writing immediately of any significant departures from this protocol and will not continue the research if ethical approval is withdrawn and will comply with any special conditions required by the HREC.

Signed:.. Date:..................

ANU SUPERVISOR

I certify that I shall provide appropriate supervision to the student to ensure that the project is undertaken in accordance with the undertakings above:

Signed:.. Date:..................

AS FROM MONDAY 21ST OCTOBER 2013 THE SIGNATURE OF THE HEAD OF ANU DEPARTMENT/GROUP/CENTRE IS NO LONGER REQUIRED.

Appendix E
Improving University-Industry Collaboration

Multi-dimensional approach to bridging the gap between Software Engineering Research and Industry Practice

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ABSTRACT

The success of software engineering research can be measured in terms of the industrial adoption of methods and tools developed by researchers. Current adoption rates are low [6] and this contributes to a widening gap between software engineering research and practice. This indicates that there are some factors which act as a barrier to university-industry collaboration. My research aims to explore ways to bridge the gap between university and industry using a multi-dimensional approach.

1. INTRODUCTION

The potential social and economic impact of collaboration between university and industry has been widely acknowledged [11]. Universities are an important place for creation of new knowledge, and dissemination of existing knowledge. This knowledge, when applied in industries, facilitates economic growth [1]. However, utilisation of scientific knowledge for socio-economic gains, depends upon the degree of technology transfer from universities to industry based on the connection between the two entities.

During 1970s, there was a view building up in the United States (U.S.) that, while a lot of government funding is invested into University research, the research results are not utilized enough for economic and social benefit. The need to address this concern led to enactment of the Bayh Dole Act in 1980. The law was highly applauded and a lot of licensing and patenting activity after 1980 in the U.S. was attributed to this law [8]. It also resulted in the establishment of Technology Transfer Offices(TTOs) at most major universities[7].

In 1980s, various types of university-industry interactions were studied and most of the studies identified that TTOs have gained attention as an instrumental link to connect university researchers with industry [2]. However, the effectiveness of TTOs has been questioned in recent years[8, 9] and there is a need to look beyond TTOs to further reduce the gap between research and practice. We observe that there are certain barriers to communication and knowledge transfer between these two entities and that a multi-dimensional approach to address these barriers may help. In my research, I aim at reviewing the prevailing mechanisms for efficient collaboration between university and industry, and propose a new approach to improve this collaboration.

My research is aimed at proposing a multi-dimensional approach based on tangible evidence, prior evaluation, and a communication platform as the main elements of collaboration. Main contributions are: 1) Demonstrate the importance of strong and effective tangible evidence in order to encourage the adoption of university's research. 2) Demonstrating the research base behind the practices that are successful in industry. 3) Maturing the research findings and technology within universities by researchers before attempts are made to commercialize them. 4) Recognize the importance of communication and bring the three stakeholders- university researchers, industry, and TTOs to an open online/digital collaborating platform.

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2. RESEARCH OBJECTIVE

Primary Goal To develop and evaluate a multi-dimensional approach to better align software engineering research and education with industry practice. In my research, I want to explore answers to the following questions:

1. Will tangible evidence be effective in encouraging industry to adopt university's research methods and tools ?
2. Will empirical evidence from research regarding the successful practices improve confidence in industry about university research ?
3. Can in-house maturing of technology make its adoption easier ?
4. Will an online collaborative platform be more effective to overcome the communication barriers between university researchers and industry professionals ?

3. PROPOSED RESEARCH PROJECTS

Below is the outline of the four tasks that I would like to complete towards building this multi-dimensional approach during the course of my PhD.

3.1 Task 1: Tangible Evidence of the advantages of research-based tools to industry

There are tools produced by university researchers for various software development processes but they do not have wide industry adoption. Adoption of a new process or idea by industry requires tangible evidence supporting the benefits [5]. One approach to providing such evidence is to demonstrate the effectiveness of research tools. We apply this approach to the field of software inspection as inspections are known to be effective in reducing errors in software, increasing productivity, and achieving project stability. Static analysis tools help automate the code inspection process.

To demonstrate the effectiveness of static analysis tool, we establish a connection between the warnings generated by the FindBugs[10] static analysis tool and field bugs reported by Eclipse users on Bugzilla[3]. Our methodology is as follows:

1. Use FindBugs to identify potential bugs in Eclipse class files.
2. Search the Eclipse bug-tracking system Bugzilla to identify bug reports that include stack traces.
3. Match the Java classes associated with FindBugs warnings identified in 1) with classes associated with the bugs identified in 2).

3.2 Task 2: Research-base at the core of successful industry practices

Many of the practices used in industry appear to have been developed through exploration and trial error. We would like to test our hypothesis that existing university research can explain the success of such practices. In doing so, we hope that industry will perceive research more positively and that they will engage with research more effectively. Our methodology for this task is as follows:

1. Identify and review the laws of Empirical Software Engineering
2. Identify a set of successful industrial practices.
3. Attempt to explain the success of the above practices in terms of the above laws.

3.3 Task 3: In-house maturing of technology

Attempts to commercialize university research before it is mature might have uncertain results. It needs to be matured before it can be commercially viable and successful[9]. We propose an approach to maturing research in-house prior to bringing it to a TTO. We hope that this will generate more confidence in the feasibility and significance of university research to industry.

3.4 Task 4: Open Online Collaborative Platform

Prometheus Wiki[4] has been successful in the area of Plant Science research as a sharing platform for research findings. We aim at adapting this to the area of Software Engineering research for effective, quick and efficient dissemination of research results. We will extend it further to bring all the three stakeholders: Industry, Researchers and TTOs to a shared online collaborative platform. We expect that deploying an online collaborative platform will reduce the communication barrier between University researchers and industry.

4. PRELIMINARY RESULTS

A paper presenting the results of our work regarding Task 1 discussed above, has been submitted to ICSE 2016. The abstract is as follows:

One of the challenges in the area of software engineering research has been the low rate of adoption by industry of the tools and methods produced by university researchers. A key issue is the lack of tangible evidence that demonstrates the effectiveness of these tools and methods to industry. Code inspections, according to Fagan's law, are effective in reducing errors in software, increasing productivity and achieving project stability. Static analysis tools, which have been mainly developed by university researchers, help automate the code inspection process. However, the use of such tools has not obtained widespread adoption in industry.

In this paper, we use one such tool, FindBugs, to do a static analysis of the much used open source development platform, Eclipse. We evaluate the correlation between the warnings issued by FindBugs against the bugs reported by the users of Eclipse. Analysis of the results shows that this provides tangible evidence of the effectiveness of FindBugs. To evaluate the impact of this evidence, we conducted a survey of software engineering users and found out that most of the participants agree that such evidence would positively influence their decision to adopt static analysis tools.

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Appendix F
Feedback from Stakeholders

Australian Academy of Technology & Engineering

20 January 2020

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To whom it may concern

Re: A maturity model for University-Industry collaboration

The Australian Academy of Technology and Engineering (ATSE)[1] is pleased to provide comment on our use of the work provided by Richa Awasthy.

ATSE's Industry and Innovation Forum has been developing a toolkit to be used to evaluate maturity levels in six phases of collaboration. This toolkit is designed to evaluate both sides of a collaboration so that it could be used by universities, companies, research agencies or government departments. This project by ATSE is based on evidence produced from Richa Awasthy which includes research published in Awasthy et al (2018)[2], a videoconference meeting and shared notes. Her work has provided insight into different levels of collaboration maturity, and valuable properties the toolkit should embody. Her work has influenced the basis of ATSE's toolkit, currently at ideation stage, which is being developed and workshopped with multiple stakeholders including Richa and her team.

Many thanks to Richa Awasthy and her supervisors for your work. We look forward to working further with you all to make a practical, evidence-based instrument to help collaborators assess the maturity of their relationships.

Kind Regards,

Michelle Low (Policy Analyst)

[1] The Australian Academy of Technology and Engineering operates as a Learned Academy of independent, non-political experts helping Australians understand and use technology to solve complex problems. Bringing together Australia's leading thinkers in applied science, technology and engineering the Academy provides impartial, practical and evidence based advice on how to achieve sustainable solutions and advance prosperity.

[2] Awasthy, R., Flint, S., Jones, R. L., & Sankaranarayana, R. (2018). Uicmm: A maturity model for university-industry collaboration. 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), 1–8. https://doi.org/10.1109/ICE.2018.8436266

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Feedback from Coalfacer

Coalfacer [Coalfacer, 2019] states below regarding the utility and applicability of the model in an email sent to the researcher:

'Richa provided a framework that enabled us to develop a basis for establishing and assessing organisation, team and individual level policies and preparedness toward academic-industry research partnerships. Using Richa's work, we've been able to develop tests to assess the maturity levels of participants against objective measurements. We're using those tests to recommend development steps, blind spots and opportunities for researchers and research-users who are evaluating partnership opportunities. Using the categories identified in Richa's thesis, we developed a binary test to gauge current-status, objectives and the level at which a particular decision is controlled within an organisation to build a profiling tool. With Richa's help, we are finessing that tool so that we can measure user responses against external data that we can obtain through other public sources (such as policy statements and feedback from past collaborators) to validate results. Coalfacer stands to benefit from Richa's work in assessing the landscape, identifying potential to further map the evaluation categories she has identified against performance indicators in research intensive industries and in academia. We aim to provide actionable insights to participants to better support the reconciliation of misaligned objectives and incentives in research collaboration. We look forward to working with Richa to build and refine this tool and see it as a practical implementation of the patterns identified and recommendations made in her thesis.'

Appendix G
Survey Questionnaire for UICMM

KPA	Scope	Question	Maturity Level 1	Maturity Level 2	Maturity Level 3	Maturity Level 4	Maturity Level 5
		1. How well is the organisation doing with respect to collaboration with industry ?	Not interested	Exploring	Encouraging	Well-established	Continually improving
		2. What are the types of collaborations the organisation is engaged in?	None	Exploring	Planning, mainly Low-level	Multiple and deep	Maintaining portfolio*
		3. What is the state of motivations for collaboration?	Undefined	Unclear	Clear	Organizationally aligned	Shared/ co-created
Contextual practices	Organisational	4. How are stakeholders identified?	Not applicable	Randomly, may be on verbal reference	Based on some pre-defined criteria	Defined Process for identification of appropriate partners	Informed selection and review of stakeholders.
		5. Is collaboration recognized as essential for long term success and hence policies are adopted to improve collaboration?	NA	Strongly disagree	Disagree	Agree	Strongly agree
		6. Is collaboration recognized as a key organizational competence?	NA	Strongly disagree	Disagree	Agree	Strongly agree
		7. Is there a formal collaboration strategy in place? Can we get access ?	NA	Strongly disagree	Disagree	Agree	Strongly agree
		8. Is the organizational environment conducive to collaboration - indicated by administrative support and opertional units?	NA	Strongly disagree	Disagree	Agree	Strongly agree
		9. Is there any incentive system in place to encourage collaboration?	NA	No	Encouraging	Contextual	Proper Reward system
		10. Is there a budget specially set aside for promoting collaboration?	NA	No	Random allocation	Fixed budget	Reviewed
Organizational Practices	Organisational	11. Does the organization maintain alumni relationships?	NA	No	Encouraging	Good relationship	Improvement measures taken
	Organisational	12. Have collaborative initiatives resulted in a collaborative culture?	NA	Strongly disagree	Disagree	Agree	Strongly agree
	Organisational	13. Is collaboration incorporated into the overall organizational strategy?	NA	Strongly disagree	Disagree	Agree	Strongly agree
	Organisational/ Project	14. Is there an understanding of each other's mission, and processes?	NA	Strongly disagree	Disagree	Agree	Strongly agree
	Project	15. Is there a clear vision for collaboration?	NA	Strongly disagree	Disagree	Agree	Strongly agree
Cultural Adaptation	Project	16. Is there awareness of time requirements and agreed upon timescales?	NA	Strongly disagree	Disagree	Agree	Strongly agree
	Project	17. How well are objectives associated with defined motivations?	Undefined	Unclear	Clear	Precise - Win-win situation	Measured
	Project	18. Are collaborative projects coordinated by management?	NA	Some times	Using a proper process	Actively managed and approved	Assessed and improved
Collaboration characteristics	Project	19. Are individual roles in collaboration projects defined and given appropriate degree of authority?	NA	No	Some allocation	Clear roles and responsibilities	Skill-based responsibilities with review
	Organisational/ Project	20. How are individuals assigned to collaboration projects?	NA	Random	Suitable people	Boundary spanners	Leadership involvement
Individuals	Organisational	21. Are there any training programs or awareness campaigns for promoting engagement or collaboration with industry? If yes, what are they?	NA	Awareness	Random training organization	Regular training	Assessment
	Project	22. What are the modes of communication?	None	Random	Structured	Regular	Strong (multiple modes)
	Project	23. What is the frequency and level of communication?	none	Minimal	Frequent	Regular	Strong with leadership access
	Organisational/ Project	24. Is the contact information for collaboration accessible?	NA	Strongly disagree	Disagree	Agree	Strongly agree
Communication	Organisational/ Project	25. Dissemination strategy- Are there regular sessions to share outcomes from collaboration?	NA	No	Within team	Regular - Organisational	Portfolio is maintained and digital dissemination adopted
	Organisational/ Project	26. What is the level of commitment among the collaborators?	NA	Lacking commitment	Low commitment - time/resources	High commitment in time or resources	High commitment in terms of both time and resources
Social capital resources	Organisational/ Project	27. What is the level of trust among the collaborators?	NA	Lack of trust	Some level of trust leading to partner preference	Trust built through past positive experiences.	Trust leading to continued engagement. Mutual obligations and common understanding.
	Organisational	28. What is the state of understanding of Intellectual Property?	NA	None	Developing	Common	Strong and Mutually beneficial
Legal aspects	Organisational/project	29. How are IP and contracts managed?	NA	Developing understanding of the legal aspects involved	Shared and enforcebale guidelines established	Clear and mutually agreed IP and publication rights strategy	Understanding of the value of partnerships beyond the narrow project outcomes/IP rights.
	Organisational	30. Is there any form of benchmarking, measure, or assessment of the state of collaboration in the organization?	NA	Some idea of goals.	Clear definition of goals	Outcomes are mutually beneficial	Assessment of the outcomes against the objectives. Feedback mechanism in place.
	Project	31. What are the indicators for assessing the success of collaborations?	NA	None	Vaguely defined	Narrow - such as number of publication/patent	Wide - Considering technological/social/economic impact
Outcome	Organisational	32. How does the organisation or its various organisational units assess the level of engagement?	NA	Not articulated clearly	Planning for a clear assessment process	Using indicators	Measuring, Gathering feedback and optimizing.
Knowledge management	Organisational	33. Does the organization maintain and share collaboration data in order to support future efforts?	NA	Limited to individuals	Team level, organization understands the importance of knowledge management.	Organizational level. Structured processes for knowledge management	Dissemination strategy for wider impact.

Appendix H
The UIC Framework Evaluation Questionnaire

Table A1: Sample questionnaire for Evaluation of the Framework to Evaluate and Improve UIC

	Question	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Section A: Criteria						
Utility, Applicability	Is the framework useful within the UIC context?					
Effectiveness	Does the use of framework improve decision-making ability, especially in the identification of an appropriate approach to deal with UIC?					
Ease of use	Is the framework easy to use?					
	Answer below if you used the UIC Systems Model					
Utility, Applicability	Is the UIC systems model useful within the UIC context?					
Effectiveness	Does the use of UIC systems model improves understanding of the UIC context?					
Effectiveness	Does the use of UIC systems model leads to better decision-making regarding more appropriate type of UIC?					
Ease of use	Is the UIC systems model easy to understand and use?					
	Answer the below if you used the UIC Practices Framework					
Utility, Applicability	Is the UIC practices framework useful within the UIC context?					
Effectiveness	Does the use of the UIC practices framework helps in identifying applicable practices?					
Effectiveness	Did the use of the UIC practices framework led to successful UIC?					
Ease of use	Is the practices framework easy to use?					
	Answer the below if you used the UIC Maturity Model (UICMM)					
Utility, Applicability	Is the UICMM useful for conducting collaboration assessment?					
Effectiveness	Does the UICMM help in identifying required improvements?					
Trust	Do you have confidence in the validity of the UICMM results?					
Ease of use	Is the UICMM easy to understand and use?					
Ease of use	Is the process of application of UICMM is clearly documented?					
Section B:	**Answer the below, if applicable.**					
Do you have any suggestion for improvement to the framework to evaluate and improve UIC?						
Do you have any suggestion to improve the process of application of the framework?						
Do you have any suggestion to improve the UIC Systems Model?						
Do you have any suggestion to improve the UIC Practices Framework?						
Do you have any suggestion to improve the UICMM?						
Do you have any other comments?						

Appendix I
Proposed Digital Platform

Digital Platforms for Collaboration

There has been a rise in various online research platforms to help with communication, networking, and managing references [Martín-Martín et al., 2016]. For example, Academia.edu [Academia, 2015], ResearchGate [ResearchGate, 2015] and arXiv [arXiv, 2015] allow researchers worldwide to share their research work. However, the platforms focused on practical UIC are limited and emerging.

There are some existing platforms for enabling UIC such as ExpertConnect [CSIRO, 2017], Coalfacer [Coalfacer, 2019], and University Industry Innovation Network (UIIN). UIIN is a dynamic network building platform dedicated to knowledge sharing, solution discovery, and relationship building among universities and industry to drive innovation and entrepreneurship. In addition to the virtual platform, it organises conferences and workshops for effective collaboration. Coalfacer is a matchmaking platform to connect relevant and most suitable industries and universities as partners based on pre-defined characteristics. ExpertConnect comes closer to the platform discussed in the qualitative study in terms of its goal of boosting university-industry collaboration. It provides a medium to search for and connect to expertise. However, there are a few limitations to it. The data regarding experts and their expertise is drawn automatically, which may be questionable in terms of authenticity unless the profiles are claimed by the experts. Secondly, though it provides a platform to propose challenges, the data regarding actual collaborations is not available. The limitations may cause concern for both experts and collaborators.

Proposed Digital Platform

The platform proposed during the qualitative study addresses three key aspects: people, projects, and resources. Similar to ExpertConnect, the platform should allow expertise search and networking among experts. However, the profiles should be curated manually to increase their authenticity. The platform should allow a mechanism to propose projects so that relevant experts can find projects of mutual interest. There should be a way to indicate the progress and conclusion of those projects. As mentioned earlier, research may require expensive equipments. In order to reduce the R&D costs, the platform should provide a mechanism to share expensive equipment and facilities. The usage of such resources should be logged in order to understand the actual collaborative activities. The platform should also include the curation of concluded collaborative projects with lessons learned and success factors so that they can provide inputs to future similar projects.

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