On the Evaluation of Interdisciplinary Learning in Taiwan

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Abstract

As technology and science develop, labour market tasks grow in complexity and require collaboration among people across multiple disciplines. Knowledge and expertise in a single disciplinary field may not be sufficient to resolve highly complex problems and meet current labour market needs. Such transition of labour market tasks has challenged the current professional training in higher education and highlighted a need for greater interdisciplinary learning. Interdisciplinary learning is argued to benefit learners in developing skills, such as critical thinking, communication, and integrating knowledge effectively to solve complex problems.

Theories have been developed to suggest that a positive link exists between interdisciplinary learning, skill development outcomes and labour market outcomes. Yet, empirical studies testing these ideas remain qualitative in nature and provide limited quantitative evidence. Quantitative evidence has mainly focused on exploring the impact of particular-discipline interdisciplinary modules on academic performance or skills during university studies. Evidence on the impact of a full range of specialised interdisciplinary degree programmes on their educational outcomes and labour market outcomes remains lacking. Also, a number of studies have seen students majoring in traditional disciplinary programmes as non-interdisciplinary learners. Traditional disciplinary programmes have in recent years tended to incorporate interdisciplinary learning in their programmes. Yet, little evidence exists documenting the effect of interdisciplinary learning on skill development outcomes and labour market outcomes for graduates from traditional disciplinary degree programmes.

This thesis aims to provide a comprehensive analysis of the effect of interdisciplinary learning drawing on a unique administrative dataset from the Taiwanese National Tsing Hua University (NTHU). To this end, this thesis is structured around three research papers. First, it examines whether specialised interdisciplinary Bachelor degree programmes achieve their interdisciplinary programme educational outcomes. Second, we investigate the effect of interdisciplinary learning on skill development for students graduating from traditional disciplinary programmes. Third, we explore the influence of interdisciplinary learning on individual post-graduation plan choices and early labour market outcomes for both traditional disciplinary degree programmes and specialised interdisciplinary degree programmes.

The findings from this thesis contribute to advancing our understanding of the impacts of interdisciplinary education on student skills and labour market outcomes. In the first empirical chapter, we examine educational outcomes of specialised interdisciplinary degree programmes and compare the outcomes across

fields of study. Our findings suggest that specialised interdisciplinary degree programmes do not necessarily lead to better student educational outcomes. Our findings also revealed significant differences in educational outcomes between specialised interdisciplinary programmes across fields of study.

The second empirical chapter focuses on the impact of interdisciplinary learning for graduates from traditional disciplinary programmes on skill development outcomes. We propose two statistical indicators to measure the extent of interdisciplinary learning by calculating the proportion of credits that were offered by other schools or by a different field. Results show that students' perception of their skill development outcomes may be damaged with the increment of their extent of interdisciplinary learning. Our results also reveal that only graduates who were moderately involved in interdisciplinary learning benefited in skill development outcomes, relative to those who were more involved.

The third empirical chapter examines the influence of interdisciplinary learning on graduates' post-graduation plans using a set of logistic regression models. We find that interdisciplinary learning increases the probability to pursue future study and employment in a field that differs from the original college degree. We also explore the effect of interdisciplinary learning on labour market outcomes with cross-classified multilevel models. The results indicate that interdisciplinary learning leads to greater average salary and full-time employment over time but outcomes vary slightly across fields of study.

The findings of this thesis have made contributions to evidence and knowledge, theory, and education policy. In terms of evidence and knowledge, this thesis provides the first comprehensive understanding of the effects of interdisciplinary learning on skill development and post-graduation outcomes for graduates from both traditional disciplinary and specialised interdisciplinary degree programmes. In relation to theory, this thesis contributes towards expanding conceptual links between interdisciplinary learning and skill development outcomes and modifying a positive monotonic relationship between interdisciplinary learning and student skill outcomes to a non-monotonic relationship. Regarding education policy, this thesis suggests that it is valuable to develop interdisciplinary education by allowing traditional disciplinary students freely choosing their modules with certain degrees. Higher education institutions need to ensure students get the optimal degree of discipline-specific knowledge before exposing them to interdisciplinary learning and should adjust supporting measures from the experience of successful specialised interdisciplinary degree programmes.

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Declaration

I, Ya-Wen Tseng, confirm that the work presented in this thesis is my own and not copied from any other person's work. Where information has been derived from other sources, I confirm that this has been indicated within this thesis.
I declare the research articles submitted to peer-reviewed journals were directed and led by myself, and the co-authors included in these articles were involved in a supportive manner throughout the research process.

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Introduction

1.1 Background

Knowledge has become a central pillar of the global economy, increasing the demand for highly-skilled workers. The emergence of technology and science has facilitated collaboration and interaction between various fields. Work has become increasingly based on a project in collaboration with different fields of specialists (Graham and Gareth, 2014). Such developments have blurred the lines between various disciplines and altered the demand for skills in an interconnected global marketplace. In such circumstances, traditional, single and disconnected disciplinary knowledge training may not be efficiently addressed real-world complex problems (Jacob, 2015). Recent studies of future workforce demands call for individuals who have general knowledge in various disciplines that can integrate specialist knowledge from specific disciplines, can communicate and solve complex problems across disciplines, conduct interdisciplinary collaboration, and use integrative potentials to create innovations (Brassler and Dettmers, 2017; Joynes et al., 2019; Mansilla et al., 2009).

Interdisciplinary learning, as the process of learning knowledge and skills across different fields, has been proposed over the last two decades as a way to better prepare students for the workforce in the 21st century. Interdisciplinary learning is believed to help learners integrate knowledge effectively, and benefit learners in developing skills, such as critical thinking, communication, and appreciation of ethical concerns (Hains-Wesson and Ji, 2020; Ivanitskaya et al., 2002; Lattuca et al., 2004). These are all critical skills which are in the demand in the current labour market as the complexity of economic activities increases, with artificial intelligence (AI) and data-driven approaches becoming central supportive pillars of decision-making processes.

Much attention has been paid to interdisciplinary learning. Universities have developed interdisciplinary programmes in various formats. The most prevalent form has been around interdisciplinary modules which may be carried out by a team-taught or drawing students from a broad selection of disciplinary backgrounds. The second type is collaborative projects involving actors from different modules. Students from different modules are put together and formed groups to work on a unique project. Both interdisciplinary modules and interdisciplinary collaborative projects are short-term interdisciplinary learning opportunities that undergraduates can choose to participate while studying. The third format is specialised interdisciplinary Bachelor degree programmes which enable students to develop dual specialities. A specialised interdisciplinary degree programme is a long-term interdisciplinary learning mechanism. High-school students need to apply for the programme before entering universities. A fourth interdisciplinary learning option is to allow students from traditional disciplinary degree programmes to freely choose their modules from different disciplines and schools. Generally, the module selection pool of traditional disciplinary students is limited to their own programmes and schools. As the concept of interdisciplinary learning becomes widespread, universities have relaxed restrictions against module selection on traditional disciplinary degree programmes.

Interdisciplinary education has thus been seen as transformative. Yet, little is understood about the effectiveness of interdisciplinary programmes. The lack of detailed records on courses, modules and credits taken by individual students to identify their engagement in interdisciplinary learning may be a key factor. Understanding about the effects of interdisciplinary education may however be key in the design or redesign of interdisciplinary programmes and guide resource allocation to increase their effectiveness. This thesis aims to investigate the association between the extent of interdisciplinary education and students' skill and career development outcomes to inform the design or redesign of interdisciplinary programmes in Higher Education Institutions (HEIs).

The next section provides a brief overview of the literature and identifies the main deficiencies in prior empirical work assessing the impacts of interdisciplinary education on student skill development and post-graduate outcomes and choices. Section 1.3 describes the main three aims of this thesis before providing relevant information on our study context in Section 1.4. Data used in this thesis is introduced in Section 1.5. The final section describes the structure of this thesis.

1.2 Research gaps in interdisciplinary learning in higher education

A growing body of literature has provided empirical evidence assessing the effects of interdisciplinary learning on undergraduates' skill development. Cumulative evidence indicates that interdisciplinary learning is positively associated with various individual student outcomes, such as critical thinking skills, creativity, and self-learning (Burkholder et al., 2017; Hains-Wesson and Ji, 2020; Mansilla et al., 2009). However, there are still key deficiencies in understanding the effects of interdisciplinary learning on individual student outcomes. I elaborate on this below.

Specialised interdisciplinary Bachelor degree programmes

The focus of previous research has been primarily on the effects of short-term interdisciplinary modules and collaborative projects (Borrego et al., 2000; Hains-Wesson and Ji, 2020; Khandakar et al., 2020). Yet, interdisciplinary modules and collaborative projects are only two of existing ways to deliver interdisciplinary education. Specialised interdisciplinary Bachelor degree programmes are also a way to deliver interdisciplinary education. To date, little attention has been paid to the effects of long-term interdisciplinary Bachelor degree programmes, as compared to single modules, courses or projects. Understanding the effects of long-term interdisciplinary Bachelor degree programmes is of great importance as the design and implementation of a specialised interdisciplinary degree programme require more investment and involve higher levels of complexity compared to a semester-long interdisciplinary module. Establishing a new Bachelor degree programme needs to set up educational objectives, design credit requirement, recruit faculty members, among other things. Specialised interdisciplinary Bachelor degree programmes in particular require coordination and collaboration across university programmes and schools.

The current evidence on specialised interdisciplinary degree programmes is mixed and limited. Studies have pointed to a positive effect of interdisciplinary degree programmes on critical awareness (Mansilla et al., 2009). However, studies have also identified a negative association between interdisciplinary degree programmes and critical thinking skills and a tendency to engage in and enjoy cognitive activities (Lattuca et al., 2017). Evidence has also been limited to particular study fields, such as humanities and social science (Lattuca et al., 2017; Mansilla et al., 2009). Less is known about how interdisciplinary learning would impact student skills development outcomes in science, technology, engineering, and mathematics (STEM) disciplines, for example. Understanding the effects of interdisciplinary learning across study fields is important because there are variations in pedagogic practices and different learning methods are more appropriate in different study fields, such as lab experiments in chemistry vs. lectures in economics. These differences may result in varied students' educational outcomes if a single, systematic approach is used to design and deliver interdisciplinary education (Badcock et al., 2010; Walsh and Hardy, 1999).

Traditional disciplinary degree programmes

Traditional disciplinary degree programmes are ubiquitous and they are the most common way to embed interdisciplinary content in programmes. Yet, little evidence exists documenting the effect of interdisciplinary learning on skill development outcomes from traditional disciplinary degree programmes. Partly this deficiency seems to stem from the fact that traditional disciplinary programmes are not seen as a potential mechanism to deliver interdisciplinary learning. Generally, the educational goal of traditional disciplinary programmes is to provide students specialist knowledge in a single discipline. Thus, a number of studies have seen students majoring in traditional disciplinary programmes as non-interdisciplinary learners and evaluated the impact of interdisciplinary learning by comparing the learning outcomes of students majoring in specialised interdisciplinary degree programmes with those of students in traditional disciplinary programmes (Lattuca et al., 2017; Mansilla et al., 2009). However, traditional disciplinary programmes have in recent years tended to incorporate interdisciplinary content in their curriculums. The chance to freely choose modules outside students' disciplines provides traditional disciplinary students with the possibility to learn interdisciplinarily. Offering students with the opportunity to freely choose their modules outside their immediate disciplinary programme is more easily implemented than a brand new specialised interdisciplinary degree programme which requires coordination across programmes and schools. Therefore, investigating the effects of interdisciplinary learning in traditional disciplinary programmes is also important for providing universities with guidance on where they should put their resources in developing interdisciplinary learning.

In addition to limited empirical evidence in traditional disciplinary programmes, there has been little work seeking to understand the trade-off between breadth of general knowledge and depth in specialist content gained through interdisciplinary learning. Interdisciplinary learning is suggested to contribute to students' breadth of knowledge at the expense of depth of knowledge in a particular discipline (Misiewicz, 2016; Monson and Kenyon, 2018). Students stretching their time across multiple disciplines may only gain an overview of the respective disciplines. This argument can be conceptualised by the perspective of "Too-Much-of-a-Good-Thing effect (TMGT effect)". Getting too much of a good thing (breadth of knowledge) may diminish the possible advantage of the product (interdisciplinary learning) being consumed (Grant and Schwartz, 2011; Knifsend and Graham, 2012; Langfred, 2004). Flexible module-based interdisciplinary learning in traditional disciplinary programmes is easier for students to grasp too much interdisciplinarity by registering more module credits from other schools. This underlines the need to explore the existence of the TMGT effect in interdisciplinary learning to guide traditional disciplinary students to an optimal extent of interdisciplinary learning.

Post-graduation outcomes

Although enhancing employability is a key argument for developing interdisciplinary learning programmes, there has been no concerted attempt to assess the impact of interdisciplinary learning on student post-graduation plan choices and labour market outcomes. These deficiencies can be attributed to the lack of readily available datasets covering student background while studying such as module lists, and their post-graduation outcomes, such as salary and employment conditions. Current research on interdisciplinarity has tended to focus on student skills development and academic performance during their study period (Burkholder et al., 2017; Khandakar et al., 2020; Lattuca et al., 2017).

In addition, there is very little understanding of the variation in the effects of interdisciplinary learning on students' post-graduation outcomes across academic disciplines. Previous work has shown that academic disciplines greatly influence earnings in early working life and the effects of socioeconomic status on earnings vary across academic disciplines (Arcidiacono et al., 2012; Park, 2015; Rumberger and Thomas, 1993). What is still uncertain is whether a particular discipline benefits more significantly in labour market outcomes than others from interdisciplinary learning. It is necessary to understand the association between interdisciplinary learning and post-graduation outcomes across study fields because interdisciplinary learning is not necessary to benefit all academic fields. Some disciplines may benefit little from acquiring knowledge from other disciplines, or because of deficiencies in the design of programmes in certain fields. Understanding the variation in the effects of interdisciplinary learning across disciplines provide students in each field to understand whether interdisciplinary learning is a good instrument to better prepare them for the workplace and provide institutions with guidance on where they should strengthen their resources to develop interdisciplinary education.

1.3 Thesis aims

Building on the above shortcomings, the main aim of this thesis is to develop a better understanding of the effect of interdisciplinary learning on student skill development, post-graduation plan choices and labour market outcomes. Specifically, this thesis has three objectives:

1. *To assess the educational outcomes of specialised interdisciplinary Bachelor degree programmes across fields of study.*
   This objective seeks to examine whether specialised interdisciplinary Bachelor degree programmes achieve their educational goals of enhancing students' knowledge acquired, global perspective, and skills improvement, and whether the extent of these achievements varies across fields of study. To this end, this thesis employs three suites of logistic regression models. First, I compare outcomes between graduates from specialised interdisciplinary degree programmes and traditional disciplinary programmes. I treat traditional disciplinary graduates as the benchmark group. Controlling for relevant factors, the difference in outcomes between specialised interdisciplinary and traditional disciplinary graduates can be viewed as the effects of the newly established specialised interdisciplinary degree programmes. Then, I adopt subsample analyses by splitting our sample into seven schools and comparing outcomes between graduates from specialised interdisciplinary degree programmes and traditional disciplinary programmes in each school. Subsample analyses enable us to restrict the sample to a group of students with similar backgrounds and learning environments. Finally, I restrict the sample to specialised interdisciplinary degree graduates to compare the outcomes of specialised interdisciplinary degree programmes across seven schools. The results reveal that whether specialised interdisciplinary degree programmes achieve their educational goals of enhancing certain student development attributes partially relies on the fields of study. The most striking result is that the most effective specialised interdisciplinary degree programme is the programme at the School of Humanities and Social Sciences. Overall, this objective seeks to provide evidence for the effects of long-term specialised interdisciplinary Bachelor degree programmes across seven fields of college degrees.

2. *To investigate the effect of interdisciplinary learning on skill development outcomes of students from traditional disciplinary programmes, and to ex-*

plore the potential TMGT effect of interdisciplinary learning.
Focusing on graduates from traditional disciplinary programmes, the second objective seeks to examine the effects of interdisciplinary learning on students' skills development outcomes. Unlike previous research adopting a binary classification of students into interdisciplinary learning programmes, this thesis proposes two continuous indicators to measure the degree of interdisciplinary learning calculating the proportion of credits that were offered by other schools or different fields of study. This thesis then uses a suite of logistic regression models to examine the association between the two proposed interdisciplinary learning indicators and five learning outcomes: (1) profound discipline-specific knowledge, (2) use of discipline-specific knowledge flexibly, (3) critical-thinking skills, (4) concern about social justice and well-being, and (5) self-discipline and reflection. This thesis conducts subsample analyses to investigate whether getting too much interdisciplinary learning may diminish potential benefits from interdisciplinary learning. The results display a negative association between interdisciplinary learning and students' skill development. The findings indicate that by learning interdisciplinarily in a traditional disciplinary programme students may overstretch to learn across too many different fields and distant from one another and that process may diminish their knowledge capacity absorption. The contribution of this objective, for the first time, explores the effects of interdisciplinary learning on the skills development outcomes of students from traditional disciplinary programmes.

3. *To establish the association between interdisciplinary learning, individual post-graduation plan choices, and early labour market outcomes.*
The third objective seeks to evaluate the long-term effects of interdisciplinary learning on graduates' post-graduation plan choices and labour market outcomes for graduates from both traditional disciplinary and specialised interdisciplinary degree programmes. This thesis adopts logistic regression models to explore the relationship between interdisciplinary learning and individual post-graduation plans and uses cross-classified multilevel models to examine the impact of interdisciplinary learning on programme-mean salary and employment rate. The results show that interdisciplinary learning increases the probability to pursue future study and employment in a field that differs from graduates' college degrees. But the impact on planning to continue studies or enter the workforce varies across traditional disciplinary and specialised interdisciplinary degree programmes. In addition, this thesis reveals that higher interdisciplinarity tends to lead to greater average salary and chances of full-time employment over time. How-

ever, these outcomes vary across fields of study. This objective contributes to filling a research gap by providing one of the first investigations into the effects of interdisciplinary learning on post-graduation plan choices and early labour market outcomes.

1.4 Case study

This thesis was conducted in one of the largest national research universities in Taiwan, National Tsing Hua University (NTHU). In 2021, NTHU has a student population of 16,917 with 8,628 undergraduates and 8,289 postgraduates in a full range of degree programmes in ten schools: Humanities and Social Sciences, Technology Management, Science, Life Science, Nuclear Science, Electrical Engineering and Computer Science, Engineering, Education, and Arts. According to QS World University Rankings in 2023, NTHU is ranked 177 in QS World University Rankings, and 34 in Asia University Rankings.

As one of the premier universities in Taiwan, NTHU has been devoted to developing interdisciplinary education. NTHU offers two types of interdisciplinary programmes: (1) specialised interdisciplinary Bachelor degree programmes and (2) flexible module-based interdisciplinary learning in traditional disciplinary programmes. Four years after the deregulation of the University Act in Taiwan in 2005, NTHU is the first higher institution in Taiwan to develop a specialised interdisciplinary Bachelor degree programme in each of their schools. NTHU has also gradually loosened the restrictions against modules chosen in traditional disciplinary degree programmes to allow students to select module credits of their own interests in other fields of study. Since NTHU has implemented two kinds of long-term interdisciplinary learning mechanisms for a sufficient time period and this thesis has access to unprecedented datasets covering student background while studying such as module lists, and their post-graduation outcomes, NTHU provides a unique opportunity to understand the impact of two types of interdisciplinary education on student educational outcomes and early labour market outcomes.

1.5 Data sources

This thesis uses a unique dataset from three sources: (1) NTHU administrative data, (2) NTHU Graduation Survey (GS) data, and (3) career tracking data integrated by the Taiwanese Ministry of Education (MoE). First, NTHU administrative data are collected by different sections across NTHU. It consists of detailed students' backgrounds, such as programme of study and admission methods, and module profiles, including programmes, credits, and module GPA. The detailed module profiles enable us to measure interdisciplinary learning with calculating the proportion of credits that were offered by other schools or by a different field.

Second, NTHU GS data is conducted by the Center for Institutional Research of NTHU annually since 2012. It collects information about graduates' family background, self-reported evaluation of skills (such as critical thinking), time allocation, and plans after graduation while they were studying at NTHU. The response rate of GS is very high, which returns around 98% each year. Administrative data and GS data from NTHU are obtained in the format of a single assembled dataset which has been de-identified personal information. The dataset comprises a total of 7,712 individual students who graduated from 2012 to 2017, including six cohorts, 24 degree programmes and 7 schools. The detailed individual dataset includes nearly all students graduating from NTHU from 2012 to 2017 and enables us to examine the effect of interdisciplinary education under nearly the whole population who graduated from NTHU from 2012 to 2017.

Third, career tracking data integrated by MoE collects post-graduation records, such as monthly salary and employment status of all graduates in Taiwan since 2010 and tracks graduates annually from up to five years after graduation. However, we only have access to the NTHU programme-level career tracking data because of Taiwanese privacy and personal data protection laws. In the analysis of post-graduation labour market outcomes, we transform the administrative and GS individual-level dataset into a programme level to develop a dataset to track career outcomes at the programme level. This programme-level dataset comprises a total of 720 programme records from 2012 to 2017, including 24 programmes, six cohorts, and one to five years after graduation.

1.6 Thesis structure

This thesis seeks to provide empirical evidence for the impact of interdisciplinary learning on undergraduate skill development and post-graduation labour market outcomes. To this end, this thesis is conducted as a case study at NTHU, utilising a set of logistic regression models and cross-classified multilevel models, to analyse whether interdisciplinary education enhances student interdisciplinary understanding and early labour market outcomes. We address our research aims in three individual chapters – Chapter 2, Chapter 3, and Chapter 4. Each chapter is organised as an independent research paper incorporating the relevant background and dedicated literature review to identify the research gaps and provide empirical evidence to address each thesis objective. Chapter 4 has been accepted for publication in the Studies in Higher Education.

Chapter 2 addresses the first thesis objective. It focuses on assessing the educational outcomes of specialised interdisciplinary Bachelor degree programmes across fields of study. The chapter first treats traditional disciplinary graduates as the benchmark group comparing outcomes between specialised interdisciplinary and traditional disciplinary graduates and then compares the outcomes of specialised interdisciplinary degree programmes across seven study fields. Evidence revealed that specialised interdisciplinary degree programmes do not necessarily lead to better student educational outcomes. The impacts of specialised interdisciplinary degree programmes on student educational outcomes varied across study fields.

Chapter 3 turns the focus to the effects of interdisciplinary learning on skill development outcomes of graduates from traditional disciplinary programmes as an alternative mechanism to specialised interdisciplinary programmes. The chapter proposes two continuous indicators to measure the extent of interdisciplinary learning of graduates from traditional disciplinary programmes and then examines the relationship between the two indicators and five skill development outcomes. Evidence revealed that a higher extent of interdisciplinary learning in traditional disciplinary programmes tends to have a negative impact on student development outcomes. Traditional disciplinary graduates may overstretch to learn across too many different fields and diminish their knowledge capacity absorption. Chapter 2 and Chapter 3 both seek to examine the effects of interdisciplinary learning on graduates' skill development outcomes during their study period.

Chapter 4 addresses the third thesis objective. It makes use of the two measures of interdisciplinarity proposed in Chapter 3 to evaluate the long-term effects of interdisciplinary learning on the post-graduation plan choices and labour market outcomes of graduates from both traditional disciplinary and specialised interdisciplinary graduates. Chapter 4 thus focuses on post-graduation outcomes, as opposed to skills development outcomes during the time of study. The results reveal that interdisciplinary learning affects student post-graduation outcomes by increasing the probability to pursue future study and employment in a field that differs from graduates' college degrees and leading to a greater average salary and chances of full-time employment over time.

Chapter 5 summarises the key findings in terms of the findings of each analytical chapter. This chapter also points up how the findings make substantive contributions to the development of interdisciplinary education in higher education. It also discusses key limitations of this thesis and suggests potential avenues for further research on evaluating the effects of interdisciplinary education.

2

Assessing the Impact of Specialised Interdisciplinary Bachelor Degree Programmes on Educational Outcomes

Given the increasing importance of interdisciplinary learning, higher education institutions have sought to integrate interdisciplinary activities into their programmes. Previous studies indicate that interdisciplinary learning is positively associated with students' skill development such as critical thinking skills. However, empirical evidence is limited to studying the impact of short-term interdisciplinary activities. The effect of long-term interdisciplinary degree programmes on educational outcomes is less clear. This study aims to empirically examine the effect of specialised interdisciplinary Bachelor degree programmes on student educational outcomes drawing on a unique administrative dataset from National Tsing Hua University. Logistic regression analysis was employed to assess the influence of interdisciplinary learning on three sets of programme outcomes (knowledge acquired, global perspectives, and skills improved) and, identify variations across study fields. Results indicate that specialised interdisciplinary degree programmes do not always achieve their educational objectives. The association between educational outcomes and interdisciplinary learning varied across study fields. We reveal that interdisciplinary learning has a greater influence on interdisciplinary graduates from Humanities and Social Science by displaying greater confidence in acquiring profound discipline-specific knowledge and higher awareness of social justice and well-being compared to traditional disciplinary graduates from the same school. Moreover, interdisciplinary graduates from Humanities and Social Science show better educational outcomes than graduates from specialised interdisciplinary degree programmes in other schools, especially in the aspect of

knowledge acquired and skills improved. By contrast, interdisciplinary graduates from Life Science and Technology Management generally show the worst educational outcomes, compared to traditional disciplinary graduates in their schools and to other specialised interdisciplinary programmes.

2.1 Introduction

Over the past two decades, the number of specialised interdisciplinary degree programmes has increased, especially in the United States and Europe (Monson and Kenyon, 2018; Schijf et al., 2022). The U.S. National Center for Educational Statistics reported that in 2019, 55,022 students graduated with a degree in multi- or interdisciplinary studies, compared with only 6,324 in 1970. Recent developments in specialised interdisciplinary degree programmes have highlighted the need for interdisciplinarity in higher education. With the rapid growth of technology and globalisation, work-related tasks have become increasingly more complex. Understanding and solving real-world complex problems with a single-discipline knowledge framework is highly challenging (Jacob et al., 2015). Under such circumstances, interdisciplinary education can arguably prepare students to tackle these tasks and problems by equipping them with relevant individual interdisciplinary competence, enhancing critical thinking, collaboration, and integration knowledge effectively (Hains-Wesson and Ji, 2020; Ivanitskaya et al., 2002; Lattuca et al., 2004).

The development of interdisciplinary education has expanded across the world, including both western and eastern Asian countries. In Taiwan, with the deregulation of the University Act in 2005, various higher institutions have developed specialised interdisciplinary Bachelor degree programmes. Within four years, National Tsing Hua University (NTHU) was the first higher institution in Taiwan to develop a specialised interdisciplinary Bachelor degree programme for each school. However, some higher institutions which had specialised interdisciplinary programmes decided to terminate their programmes, such as National Sun Yat-Sen University and Ming Chuan University. Coupled with a broad range of skills in a particular field, the difficulty of teacher collaboration, module integration in specialised interdisciplinary programmes and a balance of in-depth knowledge deepen the difficulty of implementing specialised interdisciplinary degree programmes and may have unexpected negative consequences on student interdisciplinary learning (Benson and Miller, 1982; Jones, 2010; Pharo et al., 2012). There is an urgent need to investigate the effectiveness of specialised interdisciplinary degree programmes to provide higher education institutions with suggestions on whether it is worth establishing specialised interdisciplinary degree programmes and how they can be improved.

In light of these developments, assessing whether specialised interdisciplinary degree programmes are effective in enhancing learners' interdisciplinary competence is of key importance. Existing evidence indicates that student outcomes tend to be positively associated with interdisciplinary learning, such as critical thinking skills, creativity, and self-learning (Burkholder et al., 2017; Hains-Wesson and Ji, 2020; Mansilla et al., 2009). However, previous research has principally focused on a single, small interdisciplinary module or collaborative project (Borrego et al., 2000; Hains-Wesson and Ji, 2020; Khandakar et al., 2020). Little is known about the impacts of larger, university-scale specialised interdisciplinary degree programmes on student outcomes. Furthermore, existing evidence has failed to address differences in student learning outcomes across fields of study (Lattuca et al., 2017; Mansilla et al., 2009). Learning environments and pedagogical practices in different fields of study are conducive to different forms of skill development (Badcock et al., 2010; Neumann, 2001; Walsh and Hardy, 1999). For example, students from humanities and social sciences tend to be confident in broad general knowledge and critical thinking skills as they are usually exposed to exam questions requiring analysis and synthesis of course content (Badcock et al., 2010; Neumann, 2001). Moreover, variations in the curricular and organisational features of interdisciplinary programmes, such as the percentage of faculty members whose appointment was within the programme, may have a direct impact on student learning outcomes (Knight et al., 2013; Lattuca et al., 2017).

To redress these gaps, this study aims to tackle three research objectives. First, we seek to examine whether specialised interdisciplinary degree programmes achieve their programme educational goals. To this end, we classified and analysed eight educational goals into three sets of outcomes, i.e., knowledge acquired, global perspective, and skills improved, and compared the achievement of these outcomes between traditional disciplinary and specialised interdisciplinary programmes. Second, we analyse variations in the impact of specialised interdisciplinary degree programmes across study fields. We examine whether the learning outcomes of graduates from specialised interdisciplinary degree programmes differ from those of graduates from traditional disciplinary programmes across schools. Third, we compare the educational outcomes among interdisciplinary degree programmes across fields of study to see which specialised interdisciplinary degree programme shows better educational outcomes than graduates from specialised interdisciplinary degree programmes in other schools. We tackle these objectives by using a set of logistic regression models and a combination of administrative and survey data from NTHU in Taiwan.

The rest of this paper is structured as follows. In the next section, we review literature on interdisciplinary learning to offer a description of the conceptual mechanisms between specialised interdisciplinary degree programmes and student educational outcomes. We also provide relevant information on NTHU's specialised interdisciplinary degree programmes. Section 2.3 introduces the data used in our analysis before describing the methodological strategy in Section 2.4. The empirical results are presented in Section 2.5. The final section discusses the key findings and their implications.

2.2 Background

2.2.1 Theoretical perspectives: Why do specialised interdisciplinary degree programmes promote student educational outcomes?

Specialised interdisciplinary degree programmes are believed to benefit learners because of the pedagogic strategies and learning environment that are commonly adopted in such programmes (Lattuca et al., 2004; Newell, 1994). Particularly, these pedagogic strategies include (1) offering students options and autonomy (Lattuca et al., 2004); (2) creating a student environment conducive to active learning (Lattuca et al., 2004; Noy et al., 2017); (3) using open-ended and real-world questions (Dirsch-Weigand et al., 2016; Lattuca et al., 2004); and (4) emphasising classroom and interactional contexts (Lattuca et al., 2004; Orillion, 2009). These four pedagogic strategies are supported to effectively promote learning outcomes by a number of learning theories (Bada and Olusegun, 2015; Deci and Ryan, 2000; Piaget, 2003).

First, offering students choices of a wide range of elective modules and providing students autonomy to form their own study plans can increase students' intrinsic motivation and interest. Self-determination learning theories propose that the experience of autonomy, competence, and relatedness are beneficial to the development of internalised motivation and interest, and further enhance learning performance, persistence, and creativity (Beachboard et al., 2011; Deci and Ryan, 2000; Lattuca et al., 2004).

Second, active learning pedagogy which is usually adopted in specialised interdisciplinary degree programmes encourages student participation in meaning-making (constructivist learning theories) and provides them with an immediate opportunity to incorporate new knowledge into existing schemes (cognitive theories). Constructivist learning theories posit that students produce knowledge and form meaning based on their experiences. Participation in meaning-making helps students construct their own interpretation of reality and enhances their problem-solving and critical-thinking skills (Bada and Olusegun, 2015). In the context of cognitive theories, active learning facilitates the arrangement of knowledge, increasing the possibility of long-term memory and promoting effective learning

(Piaget, 2003).

Third, interdisciplinary education tends to ask students to work on a team project discussing real-world problems. Involvement in real-world problems engages students in authentic tasks and interaction with the environment. On the basis of situated learning theories, such engagement may promote sophisticated forms of learning (Lattuca et al., 2004; Lave and Wenger, 1991; Schommer and Dunnell, 1994). Open-ended questions, on the other hand, require the use of reflective judgement and critical thinking, promoting the acquisition of these skills (Kay and Young, 1986; Lattuca et al., 2004).

Fourth, a team project in interdisciplinary education creates classroom interactional contexts and promotes the development of comprehensive perspectives. Situated and sociocultural theories frame cognition as a social interaction. Cultural and social interactions trigger conflicting ideas, enabling students to ponder over multiple perspectives and reconfigure preformed personal perspectives and create new neural connections (Perry, 1981, 1999; Vygotsky and Cole, 1980).

2.2.2 Empirical evidence on the impacts of interdisciplinary education

With the ongoing growth of interdisciplinary activities in higher education, a growing body of literature has investigated the empirical evidence on the effects of interdisciplinary learning on undergraduates' skill development. The existing studies support theoretical perspectives on a positive association between interdisciplinary learning and student learning outcomes (Burkholder et al., 2017; Hains-Wesson and Ji, 2020; Khandakar et al., 2020). For example, Hains-Wesson and Ji (2020) showed that a short-term interdisciplinary project increased participants' sharing of knowledge across disciplines, enhanced the management of complexity, and developed agility and creativity. Burkholder et al. (2017) explored the efficacy of a three-course curriculum and indicated that this interdisciplinary curriculum improved students' interdisciplinary thinking, self-confidence and public speaking.

While a positive relationship between interdisciplinary education and skill development has been documented, much of the evidence is limited to short-term interdisciplinary modules or collaborative projects (Borrego et al., 2000; Hains-Wesson and Ji, 2020; Khandakar et al., 2020). The evidence on long-term specialised interdisciplinary degree programmes is limited and mixed, and is restricted to particular study fields (Lattuca et al., 2017; Mansilla et al., 2009). Mansilla et al. (2009) adopted a paired sample t-test and revealed that the mean score of critical awareness for senior students in the School of Interdisciplinary

Studies was significantly higher than the score for students in traditional disciplinary programmes. However, there are likely additional factors affecting differences between traditional and interdisciplinary students, including students' characteristics, family backgrounds, and major fields (Lattuca et al., 2017; Pascarella et al., 2004; Roksa et al., 2017). Failure to control these factors is likely to bias the estimates of the effect of specialised interdisciplinary degree programmes.

A recent study by Lattuca et al. (2017) employed multilevel models to control students' characteristics and academic motivation at college matriculation. They found a negative association between interdisciplinary programmes and critical thinking and the need for cognition, compared with students in traditional disciplinary programmes. This negative finding contrasts with what was shown in Mansilla et al. (2009) and also contrasts with a positive relationship that has been found in short-term interdisciplinary activities. Yet, evidence from Lattuca et al. (2017) is limited to students in liberal arts colleges. The differential in pedagogic practices and learning environments across fields of study may result in a differential in students' educational outcomes (Badcock et al., 2010; Walsh and Hardy, 1999). For example, Badcock et al. (2010) proposed that students in arts subjects tended to score higher on interpersonal understanding than students in other subjects because arts subjects usually involve extensive interactive tutorial participation.

Taken together, the impact of long-term specialised interdisciplinary degree programmes on students' learning outcomes remains understudied. This study therefore seeks to assess the educational outcomes of specialised interdisciplinary degree programmes, and investigate the ways in which these effects vary across fields of study.

2.2.3 Case study

This study was conducted in one of the largest comprehensive research universities in Taiwan, National Tsing Hua University. Currently, the university consists of 10 schools, 26 Bachelor degree programmes, 27 graduate institutes as well as 10 independent master's and doctoral programmes, with around 8,628 undergraduates and 8,289 postgraduates in 2021. NTHU offers a wide range of degree programmes in Science, Life Science, Nuclear Science, Electrical Engineering and Computer Science, Engineering, Humanities and Social Sciences, Technology Management, Education, and Arts. According to QS World University Rankings in 2023, NTHU is ranked 177 in QS World University Rankings, and 34 in Asia University Rankings.

As one of the premier universities in Taiwan, NTHU emphasises interdisciplinary education. It is the first higher institution in Taiwan to develop a school-level specialised interdisciplinary Bachelor degree programme in each school. Specialised interdisciplinary degree programmes at NTHU began at the School of Science (SCI) and Technology Management (CTM) in 2006 following the deregulation of the University Act in 2005. In the following years, the School of Engineering (ENGI), Humanities and Social Sciences (HSS), Life Science (LS), and Engineering and Computer Science (EECS) also developed school-level specialised interdisciplinary degree programmes. After the School of Nuclear Science (NS) set up their school-level specialised interdisciplinary degree programmes in 2009, all seven schools at NTHU have established specialised interdisciplinary Bachelor degree programmes. Since, each school now has one specialised interdisciplinary degree programme and a set of traditional disciplinary programmes.

The application methods for high-school students to enrol in a specialised interdisciplinary degree programme or a traditional disciplinary programme are the same. High-school students can apply to university degree programmes through two main routes – (1) the application and recommendation or (2) the examination and placement. The main differences between specialised interdisciplinary and traditional disciplinary programmes lie in staffing and curricular strength. First, faculty members in specialised interdisciplinary degree programmes are usually composed of a group of faculty in traditional disciplinary programmes in their school. Unlike traditional disciplinary programmes, specialised interdisciplinary degree programmes do not possess their own faculty.

Second, a feature of specialised interdisciplinary degree programmes is to enable students to learn across different fields of study without the extra need for credits. Table 2.1 presents the hierarchical structure of 7 schools and 24 Bachelor degree programmes that NTHU had from 2012 to 2017 and corresponding credit requirements.[1] Generally, undergraduates are required to take a total of 128-132 credits, including university credits, school credits, programme credits, elective credits and free elective credits. In traditional disciplinary programmes, the highest proportion of degree credits that students need to take is programme credits. Programme credits are required to be taken within their discipline aiming to help students acquire a single but professional disciplinary knowledge. While in specialised interdisciplinary degree programmes, programme credits are divided into two specialities, and school credits are added to the total required credits. Students in specialised interdisciplinary degree programmes are required to take fundamental subjects in their field in the first year (labelled as school credits), such as Introduction to Engineer in the interdisciplinary ENGI programme and

[1]NTHU merged with the National Hsinchu University of Education and added the Colleges of Arts and Education in 2016.

Table 2.1: The structure and requirement of NTHU Bachelor degree programs.

Seven Schools	Twenty Four Programmes	Total Required Credits	University Credits	School Credits	Programme Credits		Elective Credits	Free Elective Credits
					First Speciality	Second Speciality		
Science (SCI)	Interdisciplinary programme of Sciences	128	28	18-26	29-36	27-33		12-20
	Department of Chemistry	128	28		67		12	21
	Department of Mathematics							
	applied mathematics division	128	28		57			43
	pure mathematics division	128	28		54			46
	Department of Physics							
	physics division	128	28		60		12	28
	astronomical physics division	128	28		68		5	27
	photoelectric division	128	28		71		6	23
Engineering (ENGI)	Interdisciplinary programme of Engineering	128	28	26	33-38	26-33		3-15
	Department of Chemical Engineering	128	28		88			12
	Department of Industrial Engineering and Engineering Management	130	28		72		21	9
	Department of Materials Science and Engineering	130	28		84		9	9
	Department of Power Mechanical Engineering	129	28		67		15	19
Humanities and Social Sciences (HSS)	Interdisciplinary programme of Humanities and Social Sciences	128	28	30	30	18		22
	Department of Chinese Literature	128	32		54		24	18
	Department of Foreign Languages and Literature	128	28		67		12	21
Life Science (LS)	Interdisciplinary programme of Life Science	128	28	27	28	27-33		11-17
	Department of Life Science	128	28		68		12	20
	Department of Medical Science	128	28		68		12	20
Nuclear Science (NS)	Interdisciplinary programme of Nuclear Science	128	28	31	36-37	26-33		0-7
	Department of Engineering and System Science	128	28		58-60		30	10-12
	Department of Biomedical Engineering and Environmental Science	128	28		58		30	12
Technology Management (CTM)	Interdisciplinary programme of Management and Technology	132	28	38	27-33	27-33		0-12
	Department of Quantitative Finance	128	28	24	59			17
	Department of Economics	130	28	24	24		30	24
Electrical Engineering and Computer Science (EECS)	Interdisciplinary programme of Electrical Engineering and Computer Science	128			38	30	18	14
	Department of Computer Science	128	28		52		36	12
	Department of Electrical Engineering	128	28		53		33	14

Notes: At NTHU, "college" is the term used to refer to what would be a "school" in countries like the Australia, Canada and UK". The formal name of "Interdisciplinary Programme of Management and Technology (IPMT)" is "Department of Double Specialty Programme of Management and Technology". The requirement of credits for each department is the regulation in the academic year 2017.

Principles of Economics in the interdisciplinary CTM programme. Starting from their second year, specialised interdisciplinary students are required to select one of the disciplines within their school as the first speciality, while the second speciality can be chosen from any other disciplines in the university based on their interests (labelled as the first and second speciality credits respectively).

Nevertheless, there are some notable differences in programme design between the seven specialised interdisciplinary degree programmes. First, students in the interdisciplinary ENGI programme have more choices in the second year. They can have two specialities as other specialised interdisciplinary programmes or can switch their degree programme to traditional disciplinary programmes within their school without any requirement. By contrast, the regulation in the interdisciplinary EECS programme is relatively more rigid. The choices of two specialities are limited to their own school, except for an agreement with their tutor. Second, regarding faculty, the interdisciplinary HSS programme is the only interdisciplinary programme that has its own faculty. The faculty from the interdisciplinary HSS programme delivers almost all the teaching in the interdisciplinary HSS programme.

Table 2.2 lists the numbers of students graduating in each school in our sample period and the corresponding percentages of graduates in traditional disciplinary and specialised interdisciplinary degree programmes. Overall, 14.5% of graduates at NTHU graduated from specialised interdisciplinary degree programmes. As shown in Table 2.2, about 40.3% of graduates in the HSS were from the specialised interdisciplinary programme, which is the largest share within seven schools. By contrast, the size of interdisciplinary ENGI programmes is the smallest, with only 5.4% of graduates from the local specialised interdisciplinary programme.

Table 2.2: Numbers and percentages of graduates based on type of programme.

School	(1) Total	(2) Traditional	(3) Trad./Total%	(4) Interdisciplinary	(5) Interdiscip/Total%
HSS	563	336	59.7%	227	40.3%
CTM	846	676	79.9%	170	20.1%
EECS	1,131	1,041	92.0%	90	8.0%
ENGI	1,453	1,375	94.6%	78	5.4%
LS	359	262	73.0%	97	27.0%
NS	704	642	91.2%	62	8.8%
SCI	866	731	84.4%	135	15.6%
Total	5,922	5,063	85.5%	859	14.5%

2.3 Data and Measures

2.3.1 Data source

The dataset for our analysis comes from two sources: administrative data and Graduation Survey (GS) administrated by NTHU. The administrative data is collected by the Office of Academic Affairs and consists of detailed information on students' backgrounds, including gender, place of residence, high school, university entrance grades, admission methods, and degree programmes. The GS is conducted by the Center for Institutional Research and collects information on the learning experience of graduates annually since 2012, while they were studying at NTHU. GS data includes questions about students' family backgrounds, self-reported evaluation of skills (such as critical thinking), time allocation, and plans after graduation. The response rate of GS is very high by international standards. For instance, the response rate in 2015 is 98.2%, which is relatively higher than a rate of 70 or below in international graduate surveys (Rowe et al., 2013; Tang et al., 2021). The high response rate of the GS enables us to examine the effectiveness of specialised interdisciplinary degree programmes under nearly the whole population who graduated from NTHU at a point in time.

Pooling six waves of GS data and linking them to administrative data, we obtained a sample of 7,712 individuals who graduated from 2012 to 2017.[2] We excluded 549 graduates who had transferred to another discipline because identifying their disciplines was challenging. We further excluded 536 graduates whose parents' years of education were missing and 705 graduates who did not have entrance scores available. As a result, our final sample consisted of 5,922 graduates.[3]

2.3.2 Variables description

2.3.2.1 Dependent variables

Generally, the educational objectives in seven specialised interdisciplinary degree programmes include (1) acquisition of profound discipline-specific knowledge, (2) use of discipline-specific knowledge in a flexible way, (3) developing a global perspective and (4) "soft" abilities (critical thinking, social justice, self-discipline

[2] Following the instructions of Taiwan's privacy and personal data protection laws, all the personal data used in this study were de-identified. Specific persons and their identities cannot be identified either directly or indirectly.

[3] To address the concern regarding potential bias introduced by the deletion process, I employed the conditional mean imputation method to substitute missing values based on a regression approach. The detailed discussion of the sensitivity analysis is described in A.4.

and interaction). In this study, we aim to examine whether specialised interdisciplinary degree programmes achieve these educational objectives. Three sets of outcome variables are used to capture the educational objectives of specialised interdisciplinary degree programmes at NTHU, i.e., knowledge acquired, global perspective, and skills improved. To measure "knowledge acquired", the GS included two questions with a three-point Likert scale: (1) acquisition of profound discipline-specific knowledge, (2) use of discipline-specific knowledge in a flexible way. Regarding "global perspective", two binary questions were acquired from the GS to assess graduates' global perspectives: (1) whether they have visited a foreign university as an exchange student or not, and (2) whether they have worked as a volunteer overseas or not. Although the GS does not include specific questions related to Global Perspective Inventory (GPI), which is a survey instrument designed to measure participants' global perspectives, existing evidence suggests that individuals who have experiences of studying abroad and engaging in service learning tend to have higher global perspective scores compared to those who have not (Braskamp et al., 2014; Engberg and Fox, 2011; Merrill et al., 2012). In terms of "skills improved", we used four three-point Likert scale questions, including (1) critical thinking, (2) concerns about social justice and well-being, (3) self-discipline and reflection, and (4) interpersonal interaction. The descriptions of three groups of dependent variables are listed in Table 2.3.[4]

Table 2.3: Description of dependent variables.

Variables	Description of Variables			
knowledge acquired		Disagree	Neutral	Agree
discipline knowledge	profound discipline-specific knowledge	13.93%	5.27%	80.80%
knowledge usage	use the discipline-specific knowledge flexibly	24.48%	6.35%	69.17%
global perspective		No	Yes	
foreign exchange	1 for having been a foreign exchange student	92.01%	7.99%	
volunteer overseas	1 for having worked as a volunteer overseas	88.97%	11.03%	
skills improved		Disagree	Neutral	Agree
critical thinking	critical thinking skill	7.58%	4.04%	88.38%
social justice	concerns about social justice and well-being	13.37%	5.08%	81.54%
self-discipline	self-discipline and reflection	7.31%	4.10%	88.58%
interaction	interpersonal interaction	7.23%	3.92%	88.86%

[4]We employed subjective self-reported outcomes as a means of measuring educational outcomes due to limitations in available data. A significant challenge related to this approach is the potential for students to offer responses they believe are expected or socially desirable, rather than providing accurate assessments. To investigate the extent to which the self-reported outcomes within our dataset reflect students' real achievements, we computed correlations between students' self-reported abilities and their entry and exit academic grades. The results reveal a positive correlation between students' academic grades and their skill outcomes. These correlation findings suggest that the subjective self-reported outcomes in our study can to some extent serve as indicators of students' skill outcomes.

2.3.2.2 Independent variables

Specialised interdisciplinary degree programme participation is our primary variable of interest. A binary variable was employed to identify a graduate with the completion of interdisciplinary participation from the official record. Students enrolled in a specialised interdisciplinary degree programme but have transferred to a traditional disciplinary programme, were excluded from our analysis. A number of student-related and household characteristic variables were included in the analysis to control for potential confounding factors in line with the literature (Lattuca et al., 2017; Pascarella et al., 2004; Roksa et al., 2017). We included gender, admission methods, cohorts, schools, parents' occupations, family income status, and living areas as dummy variables to account for variations in students' educational outcomes. Continuous variables were included to capture outcome differentials according to students' university entrance grades, motivation to undertake university study, hours of participating in clubs and part-time jobs per week, and parents' years of education. An ordinal variable was also controlled to capture variations across students' academic rank in high school. Table 2.4 describes and summarises all of the independent variables in our analysis.

2.4 Estimation Strategy

To examine the effectiveness of interdisciplinary learning on programme educational objectives at the student level, three suites of logistic regression models were employed. First, our analysis was conducted on a sample of 5,922 students to examine differences in outcomes between specialised interdisciplinary graduates and traditional disciplinary graduates. We used binary and ordinal logistic regression models to reflect the binary and ordinal nature of three sets of dependent variables – knowledge acquired, global perspective, and skills improved. "Knowledge acquired" and "skills improved" outcomes were three-point Likert scale responses, therefore we constructed ordered logistic regression models as follows:

$$\begin{aligned} y_{1i}^{*} &= \alpha + \gamma interdisciplinarity_i + \sum_{s} \delta_s \cdot school_{si} + x_i'\beta + \varepsilon_i, \\ y_{1i} &= m \text{ if } \tau_{m-1} < y_{1i}^{*} < \tau_m \text{ for m=1 to 3,} \end{aligned} \tag{2.1}$$

where y_{1i}^{*} is a latent variable measuring graduate i' scale of skills, including profound discipline-specific knowledge, use of the discipline-specific knowledge in a flexible way, critical-thinking skills, concerns about social justice and well-being, self-discipline and reflection, and interaction. Once y_{1i}^{*} crosses a certain value,

Table 2.4: Description of independent variables.

Variables	Description of Variables	Mean	Std. Dev.
Main Independent Variables			
interdisciplinarity	1 for being enrolled in a specialised interdisciplinary degree programme, 0 for in a traditional disciplinary programme	0.145	0.352
Other Control Variables			
Student-related variables			
male	1 for male and 0 for female	0.664	0.472
high-school rank	rank in high school, from 1 (bottom 20%) to 5 (top 20%)	2.003	1.226
motivation to undertake university study			
external	the external motivation such as peer influence	-0.011	0.903
internal	the internal motivation such as self-exploration	0.003	0.839
admission methods			
exam	1 for Examination and Placement	0.526	0.499
application	1 for Recommendation and Screening or Star programme	0.469	0.499
others	1 for other programmes	0.005	0.071
entrance scores	the total score in General Scholastic Ability Test	66.123	4.194
club hours	hours of participating in student clubs per week	4.190	3.385
part-time hours	hours of participating in part-time job per week	2.913	3.296
Cohorts			
cohort2012	1 for graduating in 2012	0.161	0.367
cohort2013	1 for graduating in 2013	0.163	0.370
cohort2014	1 for graduating in 2014	0.179	0.384
cohort2015	1 for graduating in 2015	0.190	0.392
cohort2016	1 for graduating in 2016	0.192	0.394
cohort2017	1 for graduating in 2017	0.115	0.319
Schools			
Humanities & Social Sciences	1 for the Humanities and Social Sciences	0.095	0.293
Technology Management	1 for the Technology Management	0.143	0.350
Electrical Engineering & Computer Science	1 for the Electrical Engineering and Computer Science	0.191	0.393
Engineering	1 for the Engineering	0.245	0.430
Nuclear Science	1 for the Nuclear Science	0.119	0.324
Life Science	1 for the Life Science	0.061	0.239
Science	1 for the Science	0.146	0.353
Household characteristic variables			
father's occupation			
white-collar	1 for a white-collar worker	0.769	0.421
blue-collar	1 for a blue-collar worker	0.154	0.361
other-collar	1 for a other-collar worker	0.077	0.266
mother's occupation			
white-collar	1 for a white-collar worker	0.633	0.482
blue-collar	1 for a blue-collar worker	0.049	0.215
other-collar	1 for a other-collar worker	0.318	0.466
father's yos	father's years of education	15.057	3.431
mother's yos	mother's years of education	14.216	3.024
lowincome family	1 for belonging to low-income households as defined in Article 4 of the Taiwanese Public Assistance Act[a]	0.021	0.143
municipality	1 for living in six special municipalities (Taipei, New Taipei, Taoyuan, Taichung, Tainan, and Kaohsiung)[b]	0.759	0.428

[a]According to Article 4 of the Taiwanese Public Assistance Act, the low-income households described in this Act shall qualify under the following conditions: they are approved by their local municipality competent authority via application; their average divided monthly income among each person in the household falls below the lowest living index; and their total household assets do not exceed the specific amount announced by the central and municipality competent authorities in the year of application.

[b]According to Article 4 of the Taiwanese Local Government Act, regions with population of not less than one million and two hundred fifty thousand and have special requirements in their political, economic, cultural, and metropolitan developments may establish special municipalities.

graduate i would report disagreeing, then neutral, then agree that they possess such skills. y_{1i} denotes the self-reported evaluation of skills. $interdisciplinarity_i$ denotes our main variable of interest, with 1 indicating if a student i graduated from a specialised interdisciplinary degree programme and 0 if they graduated from a traditional disciplinary programme. $school_{si}$ is a school dummy variable indicating if graduate i belongs to school s, with HSS being the reference school. x_i' is a vector of control variables including student-related variables, cohorts, and household characteristics listed in Table 2.4. α, γ, δ, and β represent parameters to be estimated. γ is the parameter of interest, which measures the effects of specialised interdisciplinary degree programmes. m is the ordinal scale representing disagree, neutral and agree. The distribution of the error term ε_i was assumed to follow a logistic distribution. Separate models were estimated for each of our outcome variables with clustered standard errors by schools.[5]

The third set of outcomes, "global perspective", was conceptualised as two binary variables. Logistic regression models were applied as follows:

$$\begin{aligned} y_{2i}^* &= \alpha + \gamma interdisciplinarity_i + \sum_s \delta_s \cdot school_{si} + x_i'\beta + \varepsilon_i, \\ y_{2i} &= 1 \text{ if } y_{2i}^* > 0; \end{aligned} \tag{2.2}$$

where y_{2i}^* is a latent utility for the decision to be a foreign exchange student or not, or for the decision to work as a volunteer overseas or not. y_{2i} denotes the

[5]To address the concern regarding the validation of the modelling assumptions, I adopted several strategies. First, I conducted the link test to detect any potential model specification errors. The results collectively support the notion that most of my models are appropriately specified. Second, I conducted goodness-of-fit tests to evaluate the alignment between the predicted probabilities generated by the model and the observed outcomes. For the logit model, I adopted the Hosmer and Lemeshow's goodness-of-fit test, while for the ordered logistic model, I employed the Pearson chi-squared and deviance statistics test. The results of these tests underscore the robust fitting of my models to the data. Furthermore, in addressing the validity of the parallel slopes assumption intrinsic to the ordered logit model, I undertook the likelihood ratio test. Regrettably, the results indicate a violation of the proportional odds assumption. In navigating this challenge, the approach I adopted within this chapter aligned with the common practice of disregarding the assumption violation. To validate the robustness of the thesis results, I proceeded to execute the multinomial logit model. Intriguingly, the findings from the ordered logit models within the thesis closely mirrored those obtained from the multinomial logit models, particularly in estimating the ratio of the probability of selecting "agree" over "disagree." This congruence underscores the robustness of my outcomes.

self-reported individual choice.[6]

Second, to explore the effects of specialised interdisciplinary degree programmes within each school, we split our sample of 5,922 graduates into seven subgroups based on their graduated school. For each subgroup, we used model specifications similar to Equation 2.1 and 2.2, excluding school-dummy variables $school_{si}$. The parameter of interest in each subgroup model, γ, investigates the extent of differences in outcomes between specialised interdisciplinary graduates and traditional disciplinary graduates in each individual school.

Third, we compared the effects of specialised interdisciplinary degree programmes across seven fields of study. In this analysis, our sample was restricted to 859 students who graduated from specialised interdisciplinary degree programmes. We constructed one set of ordered logistic regression models for "knowledge acquired" and "skills improved" outcomes as shown in Equation 2.3, and the other set of logistic regression models for "global perspective" outcomes as Equation 2.4 as follows:

$$y_{1i}^* = \alpha + \delta_1 CTM_i + \delta_2 EECS_i + \delta_3 ENGI_i + \delta_4 LS_i + \delta_5 NS_i + \delta_6 SCI_i + x_i'\beta + \varepsilon_i, \quad (2.3)$$
$$y_{1i} = m \text{ if } \tau_{m-1} < y_{1i}^* < \tau_m \text{ for m=1 to 3,}$$

$$y_{2i}^* = \alpha + \delta_1 CTM_i + \delta_2 EECS_i + \delta_3 ENGI_i + \delta_4 LS_i + \delta_5 NS_i + \delta_6 SCI_i + x_i'\beta + \varepsilon_i, \quad (2.4)$$
$$y_{2i} = 1 \text{ if } y_{2i}^* > 0;$$

where δs are the parameter of interest. By setting HSS as the reference group, a positive $\widehat{\delta_1}$ indicates the effect of the interdisciplinary CTM programme on one of eight educational objectives was higher than that of interdisciplinary HSS programmes. Other specifications are the same as the setting in Equation 2.1 and 2.2.

2.5 Empirical Results

2.5.1 Descriptive evidence: differences between specialised interdisciplinary and traditional disciplinary graduates

Table 2.5 reports the sample mean of variables by type of degree programme and the difference between traditional disciplinary and specialised interdisci-

[6] The decision to adopt the logit model for "global perspective" outcomes is driven by the model's congruence with the other two sets of outcomes, namely "knowledge acquired" and "skills improved" outcomes. In essence, this choice strives to ensure consistency across the three groups.

Table 2.5: Summary statistics of outcomes and individual attributes by type of programme.

	(1) Interdiscplinary	(2) Traditional	(3) Difference	(4) Signif. Level
Panel A. Outcome Variables				
knowledge acquired				
discipline knowledge	2.662	2.670	-0.007	
knowledge usage	2.438	2.448	-0.011	
global perspective				
volunteer overseas	0.107	0.075	0.032	***
foreign exchange	0.136	0.106	0.030	***
skills improved				
critical thinking	2.828	2.805	0.023	
social justice	2.737	2.672	0.065	***
self-discipline	2.802	2.815	-0.012	
interaction	2.795	2.820	-0.025	
Panel B. Individual Attributes Relating to Programme Determining				
male	0.553	0.683	-0.130	***
admission methods				
application	0.508	0.529	-0.022	
exam	0.487	0.466	0.021	
others	0.006	0.005	0.001	
high-school rank	1.966	2.010	-0.043	
entrance scores	65.588	66.214	-0.626	***
father's occupation				
white-collar	0.774	0.768	0.006	
blue-collar	0.157	0.154	0.003	
other-collar	0.069	0.078	-0.009	
mother's occupation				
white-collar	0.650	0.630	0.020	
blue-collar	0.056	0.048	0.008	
other-collar	0.295	0.322	-0.028	*
father's yos	0.017	0.021	-0.004	
mother's yos	14.955	15.075	-0.120	
lowincome family	14.277	14.205	0.072	
municipality	0.754	0.759	-0.005	

Notes: * $p < 0.1$, **$p < 0.05$, ***$p<0.01$.

plinary graduates. Panel A presents our educational outcomes. Panel B displays students' attributes that may underpin varying levels of engagement with a specialised interdisciplinary or a traditional disciplinary programme. As shown in the difference column of Panel A, relative to traditional disciplinary graduates, graduates from specialised interdisciplinary degree programmes were roughly 3.0% significantly more likely to have been a foreign exchange student and worked as a volunteer overseas during their studies. Also, ratings of their ability of concerns about social justice and well-being were significantly higher for specialised interdisciplinary graduates than traditional disciplinary graduates. This preliminary evidence suggests that specialised interdisciplinary degree programmes tend to meet their educational outcomes of developing global perspectives and enhancing students' concerns about social justice and well-being. Panel B shows no significant differences between specialised interdisciplinary and traditional disciplinary graduates, except for gender and university entrance scores. In comparison to traditional disciplinary programmes, specialised interdisciplinary programmes had a more balanced gender composition and slightly lower university entrance scores.

2.5.2 No effect of specialised interdisciplinary degree programmes on educational objectives at university level

To address our first research question on whether specialised interdisciplinary degree programmes delivered their specified educational outcomes, logistic regression models (Equation 2.1 and Equation 2.2) were fitted and are reported in Table 2.6. The estimated marginal effects are displayed in Figure A1 in A.1.

These results show that graduates from specialised interdisciplinary and traditional disciplinary programmes achieve similar outcomes in terms of knowledge acquired, global perspective and skills, except for self-discipline. Specialised interdisciplinary graduates are less likely to agree that they have mastered self-discipline by the end of the degree, compared to traditional disciplinary graduates. Yet, the negative effect on self-discipline was not economically significant, as indicated by the predicted marginal effect reported in column "self-discipline" of Figure A1 in A.1. Specialised interdisciplinary graduates were merely 1% less confident in self-discipline skills than traditional disciplinary graduates.

The results also indicate a significant and positive association between our set of educational outcomes and student-related attributes, including graduation cohorts, rank in high school, hours participating in part-time jobs while at university and students' external motivation to undertake university study. Graduates with higher participating hours in part-time jobs while at university, for instance, were more confident in using discipline-specific knowledge flexibly and possessing

Table 2.6: Log-odds estimates for interdisciplinary educational objectives.

	Knowledge Acquired		Global Perspective		Skills Improved			
	discipline knowledge	knowledge usage	volunteer overseas	foreign exchange	critical thinking	social justice	self-discipline	interaction
interdisciplinarity	0.044	-0.029	0.196	0.075	0.032	0.089	-0.135*	-0.101
	(0.116)	(0.092)	(0.123)	(0.230)	(0.212)	(0.150)	(0.072)	(0.131)
schools								
CTM	-0.369***	-0.964***	0.331***	-0.252***	-0.732***	-0.713***	-0.165**	0.448***
	(0.032)	(0.026)	(0.046)	(0.052)	(0.085)	(0.050)	(0.069)	(0.071)
EECS	0.236***	-0.179***	-0.470***	-0.403***	-0.793***	-0.789***	-0.089	0.633***
	(0.052)	(0.063)	(0.089)	(0.096)	(0.172)	(0.082)	(0.142)	(0.138)
ENGI	0.278***	-0.562***	-0.199***	-0.674***	-0.815***	-0.808***	-0.064	0.702***
	(0.052)	(0.056)	(0.071)	(0.082)	(0.169)	(0.077)	(0.138)	(0.136)
LS	-0.003	-0.898***	0.249***	-0.143**	-1.231***	-1.145***	-0.515***	0.111
	(0.060)	(0.068)	(0.070)	(0.067)	(0.138)	(0.059)	(0.116)	(0.118)
NS	0.080*	-0.470***	-0.030	-0.515***	-0.592***	-0.748***	-0.273***	0.575***
	(0.045)	(0.043)	(0.059)	(0.074)	(0.140)	(0.072)	(0.095)	(0.100)
SCI	-0.091**	-0.806***	-0.380***	-0.947***	-0.946***	-1.123***	-0.603***	-0.002
	(0.038)	(0.059)	(0.064)	(0.073)	(0.144)	(0.073)	(0.122)	(0.115)
cohorts								
cohort2013	0.712***	0.333***	0.150	0.139	0.920***	0.632***	1.029***	1.042***
	(0.090)	(0.085)	(0.238)	(0.190)	(0.190)	(0.166)	(0.217)	(0.214)
cohort2014	0.795***	0.098	0.277	0.417*	1.284***	0.837***	1.150***	1.199***
	(0.136)	(0.125)	(0.236)	(0.223)	(0.135)	(0.132)	(0.149)	(0.266)
cohort2015	0.615***	0.791***	0.463*	0.384	0.843***	1.359***	1.556***	1.607***
	(0.180)	(0.109)	(0.243)	(0.243)	(0.147)	(0.114)	(0.138)	(0.118)
cohort2016	0.723***	0.310***	0.299*	0.605**	1.986***	1.347***	1.679***	1.421***
	(0.086)	(0.084)	(0.165)	(0.264)	(0.165)	(0.107)	(0.157)	(0.158)
cohort2017	0.664***	0.332***	0.441	0.419	1.347***	1.082***	1.409***	1.058***
	(0.127)	(0.100)	(0.325)	(0.265)	(0.096)	(0.193)	(0.110)	(0.156)
male	0.099	0.363***	-0.674***	-0.605***	0.009	-0.291***	-0.334***	-0.445***
	(0.096)	(0.074)	(0.090)	(0.118)	(0.136)	(0.097)	(0.110)	(0.075)
high-school rank	0.047***	0.018	0.028	0.286***	0.008	0.033	0.110**	0.066

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	Knowledge Acquired		Global Perspective		Skills Improved			
	discipline knowledge	knowledge usage	volunteer overseas	foreign exchange	critical thinking	social justice	self-discipline	interaction
	(0.013)	(0.024)	(0.053)	(0.036)	(0.042)	(0.032)	(0.043)	(0.045)
entrance scores	0.022	0.007	0.015	0.069***	0.015	-0.017*	-0.012	-0.019
	(0.015)	(0.012)	(0.011)	(0.017)	(0.019)	(0.010)	(0.018)	(0.020)
club hours	-0.018*	-0.017**	0.073***	0.012	0.012	0.017*	-0.003	0.038***
	(0.010)	(0.008)	(0.017)	(0.010)	(0.016)	(0.009)	(0.010)	(0.012)
part-time hours	0.002	0.018***	0.030	0.003	0.027**	0.033***	0.042***	0.030*
	(0.013)	(0.004)	(0.019)	(0.013)	(0.013)	(0.010)	(0.011)	(0.017)
motivation to undertake university study								
external	0.594***	0.599***	-0.097	0.122*	0.713***	0.657***	0.692***	0.791***
	(0.080)	(0.062)	(0.065)	(0.074)	(0.096)	(0.048)	(0.064)	(0.070)
internal	-0.033	-0.013	0.002	-0.010	0.042	-0.012	0.089	0.167
	(0.057)	(0.048)	(0.092)	(0.042)	(0.064)	(0.101)	(0.056)	(0.120)
admission methods								
exam	-0.016	-0.111***	-0.038	0.063	0.113*	0.034	0.131	0.054
	(0.046)	(0.035)	(0.154)	(0.145)	(0.061)	(0.078)	(0.133)	(0.083)
others	0.276	-0.101	-0.168	-0.115	1.052***	-0.210	-0.103	-0.239
	(0.362)	(0.255)	(0.859)	(0.289)	(0.195)	(0.419)	(0.511)	(0.253)
Household characteristic variables								
father's occupation								
blue-collar	-0.056	-0.107	-0.459***	-0.338***	0.209**	0.004	0.110	-0.074
	(0.074)	(0.065)	(0.099)	(0.101)	(0.099)	(0.068)	(0.071)	(0.093)
other-collar	-0.252**	0.023	-0.226*	0.022	-0.001	0.001	-0.082	-0.110**
	(0.106)	(0.052)	(0.124)	(0.157)	(0.146)	(0.098)	(0.116)	(0.053)
mother's occupation								
blue-collar	-0.128	-0.105	-0.266	-0.334*	0.194	-0.190	-0.094	-0.213
	(0.152)	(0.139)	(0.376)	(0.173)	(0.141)	(0.153)	(0.120)	(0.152)
other-collar	0.044	-0.011	-0.100	-0.063	0.011	0.015	-0.052	-0.022
	(0.106)	(0.070)	(0.093)	(0.097)	(0.067)	(0.035)	(0.068)	(0.101)
father's yos	-0.028**	0.004	-0.033**	0.020	0.012	-0.025	0.021	-0.017
	(0.012)	(0.008)	(0.013)	(0.019)	(0.020)	(0.019)	(0.021)	(0.028)

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continued

	Knowledge Acquired		Global Perspective		Skills Improved			
	discipline knowledge	knowledge usage	volunteer overseas	foreign exchange	critical thinking	social justice	self-discipline	interaction
mother's yos	0.021**	-0.001	0.036***	-0.018	0.032	0.012	0.006	0.011
	(0.009)	(0.007)	(0.011)	(0.017)	(0.021)	(0.023)	(0.022)	(0.026)
lowincome family	0.036	0.260*	-0.387	0.099	-0.277	-0.056	-0.114	-0.291**
	(0.247)	(0.139)	(0.500)	(0.238)	(0.327)	(0.124)	(0.215)	(0.127)
municipality	0.061	-0.077	-0.104	0.186***	0.106*	0.059	0.270***	0.005
	(0.093)	(0.094)	(0.117)	(0.070)	(0.056)	(0.067)	(0.092)	(0.068)
cons1	-0.090	-0.955	-3.410***	-5.944***	-0.685	-3.457***	-2.530**	-3.090**
	(1.009)	(0.804)	(0.730)	(1.333)	(1.210)	(0.727)	(1.250)	(1.438)
cons2	0.322	-0.606			-0.166	-3.032***	-1.983	-2.549*
	(1.014)	(0.814)			(1.238)	(0.731)	(1.283)	(1.452)
N				5,922				
pseudo R-sq	0.059	0.062	0.057	0.061	0.102	0.089	0.111	0.124

Notes: Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p<0.01$. The reference group of schools is HSS. The reference group of cohorts is cohort 2012. The reference group of admission methods is the recommendation and screening or star programme. The reference group of parents' occupations is white-collar workers.

soft abilities than those with lower participating hours. The association between our set of educational outcomes and other student-related controls, such as gender and admission methods, do not follow a consistent pattern. For example, male graduates were more likely to report a higher ability to use discipline-specific knowledge in a flexible way than females, while their self-reported global perspective and abilities of concerns about social justice, self-discipline and interaction were significantly lower than females. In terms of household characteristics, as expected, graduates whose parents were in white-collar occupations (the reference group) displayed a positive relationship with their global perspective. Parents' years of schooling, yet, displayed an opposite association with children's educational outcomes. Father's years of schooling had negative relationships with children's confidence in acquiring profound discipline-specific knowledge and the probability of having worked as a volunteer overseas, while mother's years of schooling had positive associations with the two outcomes.

The results also indicate variations in individual outcomes across schools. Graduates from HSS (the reference group) had a higher probability of having an experience of a foreign exchange student, and were more likely to have a feeling of possessing higher abilities in using discipline-specific knowledge in a flexible way, critical thinking, concerns about social justice, and self-discipline – compared to graduates in other schools. Differences are particularly prominent for the skills of critical thinking and concerns about social justice. By contrast, graduates from HSS were less confident in their interpersonal interaction skills than graduates in other schools.[7]

2.5.3 Varying effects of specialised interdisciplinary degree programmes on educational objectives across schools at school level

We next investigated the educational outcomes of specialised interdisciplinary degree programmes by school. For each school, we performed two suites of logistic regression models as described in Section 2.4. Table 2.7 reports the estimated log-odds of *interdisciplinarity* from Equations 2.1 and 2.2, excluding school-dummy variables. Each row represents the effects of specialised interdisciplinary degree programmes across our eight outcome measures in each school.

[7]We have adopted two distinct methodologies to address the potential issue of model overfitting. First, we simplified the model by removing variables lacking practical significance. Notably, the results remained consistent irrespective of the presence of non-significant controls. Second, we embarked on a comprehensive exploration of various regularisation techniques, including lasso, elastic-net, ridge, and adaptive methods, in order to ascertain their effectiveness in variable selection. The outcomes of these investigations advocate for the inclusion of all independent variables in our regression models.

Associated marginal effects are reported in Figures A2, A3 and A4 in A.2.

Table 2.7 reveals wide variations in the effects of specialised interdisciplinary degree programmes across schools. It is apparent from this table that six out of eight statistically significant coefficients are positive. The positive coefficient indicates graduates from specialised interdisciplinary programmes reported more positive educational outcomes compared to graduates from traditional disciplinary programmes. Specifically, row (1) of Table 2.7 shows that graduates from the interdisciplinary HSS programme had significantly higher profound discipline-specific knowledge and concerns about social justice and well-being compared to traditional disciplinary graduates at HSS. In terms of predicted marginal effects, interdisciplinary HSS graduates were 5.7% more likely to agree that they had profound discipline-specific knowledge than traditional HSS graduates and 1.1% more on the ability of concerns about social justice and well-being (as shown in Figure A2 and Figure A4 in A.2). Interdisciplinary ENGI graduates were 5.7% more likely to have worked as an overseas volunteer and 8.3% more confident in their critical thinking skills – compared to traditional disciplinary graduates (see Figure A3 and Figure A4 in A.2). For EECS and SCI, graduates from interdisciplinary programmes were more likely to exchange to a foreign university than graduates from their traditional disciplinary programmes, with 7.4% and 7.3% higher respectively (see Figure A3 in A.2).

Contrary to expectations, the results indicate a significantly negative association between graduating from specialised interdisciplinary programmes and soft skills at CTM and LS. This result suggests that interdisciplinary learning may also negatively impact students' abilities, or could signal that field-specific conditions are less favourable for interdisciplinary learning. Associated marginal effects indicate that interdisciplinary CTM graduates were 5.3% less likely to agree that they possessed critical thinking skills than traditional disciplinary CTM graduates. Similarly, interdisciplinary LS graduates were 7.2% less confident in their interpersonal interaction skills than traditional disciplinary LS graduates (see Figure A2 in A.2). For NS graduates, none of the differences in educational objectives between specialised interdisciplinary graduates and traditional disciplinary graduates was statistically significant, suggesting that there is no effect of interdisciplinary NS degree programmes on their intended educational outcomes.[8]

[8]We conducted the Chow test for each of the eight outcome variables to assess whether the seven subgroups exhibited significantly different parameters. The results consistently rejected the null hypothesis, indicating notable variations in parameters among the seven subgroups (schools).

Table 2.7: Log-odds estimates for interdisciplinary educational objectives by schools.

	Knowledge Acquired		Global Perspective		Skills Improved			
	discipline knowledge	knowledge usage	volunteer overseas	foreign exchange	critical thinking	social justice	self-discipline	interaction
HSS	0.410*	0.322	0.071	-0.312	0.606	1.906***	-0.149	0.055
	(0.237)	(0.229)	(0.298)	(0.256)	(0.482)	(0.532)	(0.363)	(0.326)
CTM	-0.249	-0.040	0.181	-0.433	-0.701**	-0.221	-0.281	0.073
	(0.200)	(0.192)	(0.268)	(0.290)	(0.282)	(0.271)	(0.319)	(0.309)
EECS	0.216	0.108	-0.041	0.746**	-0.213	0.193	-0.102	0.028
	(0.344)	(0.281)	(0.556)	(0.291)	(0.360)	(0.306)	(0.340)	(0.409)
ENGI	0.467	-0.410	0.829**	0.062	1.033*	0.132	-0.032	-0.393
	(0.441)	(0.277)	(0.358)	(0.410)	(0.621)	(0.392)	(0.489)	(0.432)
LS	-0.293	0.057	-0.092	-0.146	0.090	-0.029	-0.384	-0.869**
	(0.312)	(0.258)	(0.409)	(0.350)	(0.364)	(0.307)	(0.403)	(0.386)
NS	0.069	-0.162	0.015	-0.272	0.395	-0.165	-0.218	-0.180
	(0.458)	(0.377)	(0.465)	(0.513)	(0.809)	(0.489)	(0.631)	(0.706)
SCI	0.019	-0.214	0.577	0.994***	0.216	-0.204	-0.072	0.251
	(0.262)	(0.213)	(0.398)	(0.315)	(0.319)	(0.233)	(0.276)	(0.302)

Notes: Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p<0.01$.

2.5.4 Comparison of the outcomes of interdisciplinary degree programmes between seven schools

We also aimed to compare the educational outcomes of specialised interdisciplinary degree programmes between seven schools, i.e., HSS, CTM, EECS, ENGI, LS, NS, and SCI. The analysis restricted a sample of 859 graduates from specialised interdisciplinary degree programmes. Table 2.8 displays the estimated log-odds related to the effect of interdisciplinarity from Equations 2.3 and 2.4, i.e., $\hat{\delta_1}$ to $\hat{\delta_6}$. By setting HSS as the reference group, the estimates in Table 2.8 represent the difference in the educational outcomes between specialised interdisciplinary graduates from a given school to those from graduates from HSS.[9]

Table 2.8 reveals that interdisciplinary HSS graduates (the reference group) achieved better outcomes compared to interdisciplinary graduates from other schools, while interdisciplinary LS, SCI, and CTM graduates had the least favourable outcomes, especially in "Knowledge Acquired" and "skills improved". First, focusing on "Knowledge Acquired", Table 2.8 reports the smallest coefficients for CTM. The result indicates that interdisciplinary CTM graduates achieved the least favourable outcomes in terms of acquiring profound discipline-specific knowledge and using this knowledge in a flexible way – compared to graduates from other interdisciplinary programmes. Marginal estimates suggest interdisciplinary CTM graduates were 11.6% less likely to agree that they have acquired profound discipline-specific knowledge during their degree programme compared to interdisciplinary HSS graduates, followed by SCI and LS, with 5.7% and 5.0% less respectively (see Figure A5 in A.3). Moreover, interdisciplinary CTM graduates

[9] Estimated marginal effects are presented in Figure A5, Figure A6, and Figure A7 in A.3.

were 23.8% less confident in using discipline-specific knowledge in a flexible way than interdisciplinary HSS graduates, followed by SCI (21.7%), ENGI (18.3%), and LS (17.5%).

Second, regarding the set of “Skills Improved”, interdisciplinary LS graduates seem to have achieved the least favourable outcomes, followed by the interdisciplinary SCI programme. As shown in Table 2.8, compared to interdisciplinary HSS graduates, interdisciplinary LS graduates had less confidence in their critical thinking, social justice, self-discipline and interaction skills. Similarly, interdisciplinary SCI graduates were 6.0% less confident in their critical thinking skills than interdisciplinary HSS graduates, 23.6% less in concerns about social justice and well-being, and 3.2% less in skills of self-discipline and reflection (see Figure A7 in A.3). In terms of “Global Perspective”, interdisciplinary CTM, ENGI, and NS graduates were less likely to have the experience of being a foreign exchange student compared to interdisciplinary HSS graduates, especially for interdisciplinary NS graduates, with a 5% reduction.

Table 2.8: Log-odds estimates: comparison of specialised interdisciplinary degree programmes in seven schools.

	Knowledge Acquired		Global Perspective		Skills Improved			
	discipline knowledge	knowledge usage	volunteer overseas	foreign exchange	critical thinking	social justice	self-discipline	interaction
CTM	-0.897***	-1.176***	0.630***	-0.458***	-1.599***	-2.236***	-0.208	0.161
	(0.122)	(0.142)	(0.154)	(0.165)	(0.098)	(0.257)	(0.183)	(0.181)
EECS	0.307	0.071	-0.205	0.388	-1.229***	-2.277***	0.309	0.136
	(0.246)	(0.238)	(0.259)	(0.311)	(0.341)	(0.401)	(0.284)	(0.357)
ENGI	0.556**	-0.906***	0.982***	-0.464**	-0.122	-2.276***	0.205	-0.291
	(0.242)	(0.187)	(0.185)	(0.222)	(0.203)	(0.348)	(0.300)	(0.235)
LS	-0.386***	-0.864***	0.256	-0.049	-1.503***	-2.703***	-0.525***	-0.825***
	(0.113)	(0.160)	(0.214)	(0.190)	(0.220)	(0.264)	(0.135)	(0.181)
NS	-0.013	-0.482*	0.122	-0.892***	-0.266	-2.230***	0.024	0.236
	(0.156)	(0.261)	(0.177)	(0.178)	(0.278)	(0.288)	(0.272)	(0.248)
SCI	-0.437***	-1.074***	0.243	-0.130	-1.142***	-2.893***	-0.424**	-0.280
	(0.160)	(0.203)	(0.151)	(0.267)	(0.235)	(0.307)	(0.167)	(0.259)
N	859	859	854	854	859	859	859	859
R-sq	0.097	0.080	0.090	0.068	0.164	0.152	0.112	0.156

Notes: The reference group is HSS. Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p<0.01$.

Table 2.8 also reveals few but three positive estimates in acquiring profound discipline-specific knowledge and having worked as a volunteer overseas. Interdisciplinary ENGI graduates were 7.2% significantly more likely than interdisciplinary HSS graduates to agree on acquiring profound discipline-specific knowledge (see Figure A5 in A.3). Interdisciplinary ENGI and CTM graduates were more likely to work as a volunteer overseas than interdisciplinary HSS graduates, with 10.5% and 5.7% more respectively (see Figure A3 in A.3).

2.6 Discussion and Conclusion

With the increasing prevalence of interdisciplinary education, there is a compelling need to develop a more comprehensive understanding of the impacts of interdisciplinary education on students' educational outcomes. However, empirical evidence has been restricted to the impacts of short-term interdisciplinary modules or projects within a specific academic discipline. Less is known about the influence of long-term specialised interdisciplinary Bachelor degree programmes. This paper aims to investigate the educational outcomes of specialised interdisciplinary Bachelor degree programmes across fields of study, in the context of a Taiwanese comprehensive research university, NTHU.

Our findings indicated that interdisciplinary learning does not necessarily benefit learners. We present evidence of large variations in the impact of specialised interdisciplinary degree programmes on student educational outcomes across fields. We found a positive association between interdisciplinary learning and student educational outcomes for graduates from Humanities and Social Sciences, Engineering, Electrical Engineering and Computer Science, and Science but negative or no relationships for Technology Management, Life Science, and Nuclear Science. Our evidence also reveals that the effects of interdisciplinary learning vary with educational outcomes. For example, interdisciplinary graduates from Humanities and Social Sciences were more confident in their profound discipline-specific knowledge and the skill of concern about social justice and well-being than traditional disciplinary graduates from the same school. Interdisciplinary graduates from Engineering reported significantly higher critical thinking skills and had a higher probability of having worked as a volunteer overseas than traditional disciplinary graduates from the same school. A possible explanation for the variation across fields of study may be the existence of advanced supporting measures and regulations in a specific interdisciplinary programme. For instance, having the experience of learning or being an intern overseas is one of the graduation requirements in interdisciplinary Engineer programmes.

Our findings also revealed more beneficial impacts of interdisciplinary learning for graduates from the interdisciplinary programme of Humanities and Social Sciences compared to interdisciplinary programmes from other schools, especially regarding "Knowledge Acquired" and soft skills (critical thinking, social justice, and self-discipline). This result can be explained in part by the design of specialised interdisciplinary programmes, learning environments and pedagogic practices. Regarding the design of specialised interdisciplinary programmes, the interdisciplinary programme of Humanities and Social Sciences is the only interdisciplinary programme at NTHU whose faculty members were appointed within the programme and deliver most of the modules for their students. The other specialised interdisciplinary programmes are coordinated and delivered by faculties which also coordinate and deliver traditional disciplinary programmes. Faculty members of the interdisciplinary programme of Humanities and Social Sciences can therefore focus on tutoring their students and improving programme performance (Knight et al., 2013; Monson and Kenyon, 2018). Also, interdisciplinary graduates from the Humanities and Social Sciences are more likely to feel more connected with faculty members than in the other six interdisciplinary programmes. Learning environments promoting connectedness with faculty members have been linked positively to outcomes such as self-efficacy and engagement (Beachboard et al., 2011; Inkelas et al., 2007). Our evidence suggests that learning environments with connectedness promote a larger range of outcomes, including the acquisition of profound discipline-specific knowledge, the use of discipline-specific knowledge in a flexible way, critical thinking skills, and concerns about social justice and well-being.

Learning environments and pedagogic practices are another possible explanation for the positive educational outcomes of the interdisciplinary programme of Humanities and Social Sciences among seven fields of study. School of Humanities and Social Sciences, comprising of the Department of Chinese Literature and the Department of Foreign Languages and Literature at NTHU, is classified as a soft pure discipline (Neumann, 2001). Previous research has argued that soft pure disciplines place greater importance on broad general knowledge and student growth, and are more likely to have exam questions requiring analysis, and dealing with more realistic problems than hard disciplines such as physics (Braxton, 1995; Liu and Shi, 2015; Neumann, 2001). According to situated learning theories, involvement in real-world problems can promote sophisticated forms of learning and is easier to recall (Lattuca et al., 2004; Lave and Wenger, 1991; Schommer and Dunnell, 1994). The use of reflective judgement and critical thinking can promote the acquisition of reflective judgement and critical thinking (Kay and Young, 1986; Lattuca et al., 2004).

We also offer evidence of the poor performance of Life Science, Science, and Technology management graduates from specialised interdisciplinary programmes compared to graduates from other specialised interdisciplinary degree programmes. Our results showed interdisciplinary graduates from Technology management achieved the least favourable outcomes in acquiring profound discipline-specific knowledge and using this knowledge in a flexible way; interdisciplinary graduates from Life Science and Science had the least confidence in their soft skills. This result may be explained by the fact that natural sciences tend to place greater emphasis on theories, principles and methods which may not be suitable for developing soft skills (Biglan, 1973; Swarat et al., 2017). Also, natural sciences are viewed as demanding subjects (Wu et al., 2019). Students in such demanding subjects may need to focus on specific knowledge and are more likely to struggle to learn interdisciplinarily, which led to poor educational outcomes.

Taken together, our findings indicate that specialised interdisciplinary degree programmes do not necessarily lead to their intended educational outcomes. Although positive associations between interdisciplinary learning and educational outcomes were found for Humanities and Social Sciences, Engineering, Electrical Engineering and Computer Science, and Science, negative effects on the critical thinking skill for interdisciplinary graduates from Technology Management and on interpersonal interaction for interdisciplinary graduates from Life Science were also revealed. Interdisciplinary education still has room for improvement, especially for interdisciplinary programmes of Life Science and Technology Management. An option could be to organise their own faculty to promote connectedness between students and faculty members in learning environments which has been shown a positive link to educational outcomes (Beachboard et al., 2011; Monson and Kenyon, 2018). In addition, faculty members may adjust their pedagogic strategies such as adopting open-ended questions to promote the development of soft skills (Lattuca et al., 2004; Lave and Wenger, 1991; Schommer and Dunnell, 1994).

Our results revealed a negative association between interdisciplinary learning and educational outcomes for interdisciplinary graduates from Technology Management and Life Science compared to traditional disciplinary graduates. Although we try to explain the negative association with the lack of advanced supporting measures and regulations, the reason is not yet clear. The precise reason for these unexpected negative patterns in interdisciplinary learning remains to be elucidated. More studies need to be carried out in order to help higher education institutions to find the right antidote and thus lead to intended educational outcomes. This study examined the short-term impacts of specialised interdisciplinary degree programmes on student learning during their study period. Further work is needed to investigate the long-term benefits of interdisciplinary learning such as future labour market outcomes. Interdisciplinary learning may have moderate immediate impacts but these impacts may be cumulative and may grow as students gain more work experience and develop their careers. We used subjective self-reported outcomes to measure educational outcomes. Yet, self-reported outcomes may not be completely objective and tend to underestimate or overestimate students' abilities (Dunning, 2011). Future research could expand our analysis to objective outcomes. Evidence from both subjective and objective outcomes would be beneficial to build more robust evidence in relation to the impacts of interdisciplinary learning.

3

Assessing the Impact of Interdisciplinary Learning within Traditional Disciplinary Degree Programmes on Individual Skill Development Outcomes

The growing complexity of labour market tasks has sparked advocacy in interdisciplinary learning. Yet, empirical evidence on the effects of interdisciplinary learning on individual skill outcomes is incipient. This study seeks to assess the impact of interdisciplinary learning within traditional disciplinary programmes on individual skill outcomes drawing on graduation survey and administrative data from the National Tsing Hua University in Taiwan. Two measures of interdisciplinary learning are proposed with calculating the proportion of module credits outside students' schools and from different fields. Results indicate that students' perception of their ability to use discipline-specific knowledge in a flexible way, the ability of concerns about social justice and well-being, and the ability of self-discipline and reflection may be damaged with the increment of their extent of interdisciplinary learning. Nevertheless, the results of sub-sample analyses support that "too-much-of-a-good-thing effect" exists in interdisciplinary learning; undergraduates who were moderately involved in school-level interdisciplinary learning (i.e., the lowest 10%) benefited in acquiring profound discipline-specific knowledge, ability to use discipline-specific knowledge in a flexible way, and critical-thinking skills, relative to those who were more involved (i.e., the highest 10%). These findings are of significant value for guiding students in traditional disciplinary programmes on the way to conduct interdisciplinary learning.

3.1 Introduction

As technology and science develop, the world has transitioned from an industrial-based to a knowledge-based economy, becoming increasingly dependent on knowledge and information (OECD, 1996). Such transition has arguably been accompanied by growing complexity in labour market tasks, new services, products and solutions. Workers are required to acquire a range of skills and continuously adapt to labour market needs (OECD, 1996). The Partnership for 21st Century Learning in the United States defines a set of skills required for twenty-first-century workers including critical thinking, problem-solving, communication, collaboration, creativity and innovation. Knowledge and expertise in a single disciplinary field may not be sufficient to understand, resolve problems and meet current labour market needs. Learning interdisciplinarily has as result gained salience for both employability and long-life career development reasons.

Interdisciplinary learning is argued to benefit learners in distinctive ways. First, interdisciplinary learning facilitates learners to develop critical thinking skills, stimulate creativity, foster innovation, and appreciate ethical concerns through repeated exposure to cross-field knowledge and required communication and interaction with members from other disciplines (Astin, 1993; Ivanitskaya et al., 2002; Lattuca et al., 2004). Second, acquiring fundamental knowledge in multiple disciplines and integrating effectively may facilitate knowledge transfer to solve complex problems (Ivanitskaya et al., 2002; Styron, 2013; Weller and Appleby, 2021). Third, interdisciplinary learning develops and enhances self-directed learning skills. The practice of self-directed learning provides individuals with a chance to learn self-discipline abilities (Barnett and Brown, 1981; Buchbinder et al., 2005; Summers et al., 2005). Self-discipline relates to independence and initiative representing important characteristics that can enhance current and future work performance (Hagger and Hamilton, 2019).

In the context of growing demand for interdisciplinary skills, Higher Education Institutions (HEIs) have turned to design and offer interdisciplinary learning opportunities. A well-known interdisciplinary learning opportunity in HEIs is labelled as interdisciplinary Bachelor degree programmes. It is a recently implemented programme aiming to provide students a chance to acquire two specialities from two different disciplines without the extra need for graduation credits. The literature in interdisciplinarity has focused particularly on the effects of interdisciplinary programmes. The existing empirical studies assessed the effects of interdisciplinary learning by employing a pre- and post-comparison of skill development outcomes for students participating in an interdisciplinary programme (Burkholder et al., 2017; Hains-Wesson and Ji, 2020), or comparing the skill development outcomes of students enrolled in interdisciplinary programmes with those of students in traditional disciplinary programmes (Khandakar et al., 2020; Lattuca et al., 2017; Mansilla et al., 2009). Students enrolled in traditional disciplinary programmes are viewed as non-interdisciplinary learners.

Recent developments in interdisciplinary learning also appear in traditional disciplinary programmes. Traditionally, students in traditional disciplinary programmes need to take most of their module credits within their programmes. In recent years, traditional disciplinary programmes have begun to loosen module choice restrictions gradually. Allowing traditional disciplinary students to freely choose their module credits also offers an opportunity for interdisciplinary learning if modules from different disciplines are selected. However, it is still not known the effect of interdisciplinary learning in traditional disciplinary programmes. Understanding the effects in traditional disciplinary programmes is important as they can be more easily implemented. By contrast, the design and implementation of interdisciplinary degree programmes are more complex requiring coordination and identification of module credit correspondence across university programmes and schools. Yet, a main risk of interdisciplinary learning in traditional disciplinary programmes is that the lack of instruction and integration modules may diminish the potential advantage of interdisciplinary learning on student's formation and developmental outcomes (Graham and Gareth, 2014; Jones, 2010).

Furthermore, although the advantages of interdisciplinary learning are well recognised, questions exist about the breadth and depth gained through interdisciplinary learning (Misiewicz, 2016; Monson and Kenyon, 2018). Students stretching their time across multiple disciplines may only gain an overview of the respective disciplines. They are less likely to internalise knowledge in that discipline than those highly committed individuals. This argument can be accounted for by the theoretical perspective of "Too-Much-of-a-Good-Thing effect (TMGT effect)"; that is, getting too much of a good thing may diminish the possible advantage of product or good being consumed (Grant and Schwartz, 2011; Knifsend and Graham, 2012; Langfred, 2004). Students with higher levels of interdisciplinary learning engagement may experience diminishing or even negative returns from learning interdisciplinarily as they may lack sufficient discipline-specific knowledge. Yet, to the best of our knowledge, no prior quantitative analysis in interdisciplinarity has investigated the possible drawbacks and applied the perspective of TMGT effect to interdisciplinary learning.

Drawing on unique administrative and survey data from the Taiwanese National Tsing Hua University (NTHU), this paper aims to analyse the effect of interdisciplinary learning on skill development outcomes for students graduating from traditional disciplinary programmes. Specifically, it proposes two statistical indicators to measure the extent of interdisciplinary learning at the school and field level, and explores the effect of interdisciplinary learning on five key individual skill development outcomes (i.e. discipline knowledge, knowledge usage, critical thinking, social justice and self-discipline) across seven broad disciplines of knowledge using a suite of the ordered logistic regression models. Moreover, it conducts sub-sample analyses to investigate whether the TMGT effect exists in interdisciplinary learning.

The rest of this paper is organised as follows. The next section reviews the current state of the literature in interdisciplinary learning and identifies existing research gaps. Section 3.3 describes the data and methodological strategy before presenting our proposed indices to measure the extent of interdisciplinary learning in Section 3.4. Next, we present the results in Section 3.5. Section 3.6 provides some final concluding remarks, and discusses key implications for future research and interdisciplinary educational programme design.

3.2 Background

The concept of "interdisciplinarity" can be traced back to the 1920s, particularly in the meeting rooms of the Social Science Research Council in New York City where it was used to describe the collaboration between constituent societies (Frank, 1988). In research, interdisciplinary learning has been used to describe varying processes. Brassler and Dettmers (2017) used it to describe a process by which individuals and groups integrate insights and modes of thinking from two or more disciplinary fields. Graham and Gareth (2014) added that interdisciplinary learning also involves advancing the understanding of a subject or problem that extends beyond the scope of any single discipline. In line with this work, we adopt the view that interdisciplinary learning represents the process of learning integrating knowledge and skills from different disciplines.

3.2.1 Conceptual links between interdisciplinary learning and skill development

Learning theories can be used to understand how and why interdisciplinary learning may lead to favourable learning outcomes. First, cognitive theories suggest that effective learning depends on the connection between new and past knowledge (Lattuca et al., 2004), and interdisciplinary learning is seen as a valuable integration mechanism of different disciplinary fields to build new knowledge on the basis of past knowledge, leading to improved academic skills, such as critical thinking (Orillion, 2009). Second, interdisciplinary learning usually involves complex, real-world problems and requires practice in reflective judgment. According to situated learning theories (Lave and Wenger, 1991), this practice may promote sophisticated forms of learning by means of engaging students in authentic tasks, and developing skills in direct interaction with the environment through experiential learning (Lattuca et al., 2004; Schommer and Dunnell, 1994). Third, sociocultural theories propose that cultural and social interactions are often influential elements of learning and acquiring knowledge (Vygotsky and Cole, 1980). Interdisciplinary learning can be conceived as a trigger of conflicting ideas, enabling learners to ponder over multiple perspectives and reconfigure preformed personal perspectives and create new neural connections (Perry, 1981, 1999).

Fourth, interdisciplinary education usually provides students with a certain extent of autonomy to form their own study plan and commonly organise different-field students into a collaborative project. In the context of self-determination learning theories, competence, relatedness and autonomy are three basic human needs (Deci and Ryan, 2013, 2000). Integrating these basic needs by learning different skills (competence), experiencing a sense of belonging (relatedness) and feeling in control of behaviours (autonomy) can foster volition, motivation and engagement (Deci and Ryan, 2013, 2000). These experiences can enhance individual performance, persistence and creativity (Deci and Ryan, 2013, 2000).

Fifth, interdisciplinary education usually facilitates active learning using a constructivist pedagogy (Lattuca et al., 2004). Constructivist learning assumes that active learning can increase student participation in meaning-making helping students construct their personal epistemology, to make sense of life events, relationships and themselves. Based on cognitive theory principles, active learning provides students with an immediate opportunity to incorporate new knowledge into existing schemes, increasing the chances of long-term memory storage for subsequent recall (Piaget, 2003).

3.2.2 Empirical evidence on the impacts of interdisciplinary learning on individual skill development

Empirical studies testing the conceptual links between undergraduates' interdisciplinary learning and skills outcomes have been carried out in interdisciplinary education (Hains-Wesson and Ji, 2020; Lattuca et al., 2017; Mansilla et al., 2009). The cumulative evidence in interdisciplinary education indicates that most student outcomes are positively influenced by participating in interdisciplinary education. For example, Hains-Wesson and Ji (2020) employed a pre- and post-comparison showing that the experience of a short-term interdisciplinary project increased students' sharing of knowledge across disciplines, enhanced the management of complexity, developed agility and creativity. Mansilla et al. (2009) revealed that the mean score of critical awareness for senior students in the School of Interdisciplinary Studies was significantly higher than the score for students in traditional disciplinary programmes. However, no attention has been paid to the role of interdisciplinary learning in traditional disciplinary programmes. In recent years, traditional disciplinary programmes start to provide their students a chance to learn interdisciplinarily by freely choosing their module credits outside their discipline. By contrast, students enrolled in interdisciplinary degree programmes follow a sequence of interdisciplinary modules designed by faculty. Different designs of interdisciplinary learning opportunities in interdisciplinary degree programmes and traditional disciplinary programmes may lead to different learning outcomes (Graham and Gareth, 2014; Jones, 2010).

Additionally, the existing empirical research failed to address potential challenges of interdisciplinary learning, a trade-off between breadth and depth of knowledge (Misiewicz, 2016; Monson and Kenyon, 2018). Interdisciplinary learning contributes to students' breadth of knowledge at the expense of depth. In contrast, traditional disciplinary training provides students specialist knowledge but in a single discipline. The TMGT effect can be used to conceptualise and complement this argument. Getting too much of a good thing (breadth of knowledge) may diminish the possible advantage of interdisciplinary learning.

The TMGT effect has been applied and explored in a number of fields, such as psychology, management, and education (Grant and Schwartz, 2011; Knifsend and Graham, 2012; Langfred, 2004). Grant and Schwartz (2011), for instance, investigated the relationship between the breadth of extracurricular participation (four activity domains) and academic outcomes during adolescence. Their results indicated that adolescents who were moderately involved (i.e., in two domains) in extracurricular activities benefited in academic engagement and grade point average, relative to those who were more or less involved. In the context of interdisciplinary learning, the TMGT effect predicts that being involved in interdisciplinary learning excessively may suppress the potential benefits of interdisciplinary learning on skill developments and result in unexpected negative outcomes. Previous empirical work has focused on assessing the benefits of interdisciplinary learning, while its potential drawbacks have remained little understood. Understanding these drawbacks is key to establish the overall impact of interdisciplinary learning on students' skills development. Focusing only on the benefits may provide a biased picture of the overall impact of interdisciplinary learning, ultimately impacting the design of interdisciplinary education.

Taken together, empirical evidence on the impact of interdisciplinary learning is restricted to interdisciplinary programmes and fails to address the possibility of lacking a depth understanding of disciplines because of excessive interdisciplinary learning. Our study contributes to the understanding of the effect of interdisciplinary learning comprehensively by evaluating the impact of interdisciplinary learning on individual skill outcomes for students in traditional disciplinary programmes and conducting analyses to investigate the potential TMGT effect.

3.3 Data and Estimation Strategy

3.3.1 Case study

This study uses data from the National Tsing Hua University in Taiwan. NTHU has a student population of 16,917 with 8,628 undergraduates and 8,289 postgraduates across 10 schools, 26 programmes, 27 graduate institutes, and 10 independent master's and doctoral programmes in 2021.[1] NTHU offers a wide range of degree programmes in Humanities and Social Sciences, Technology Management, Science, Life Science, Nuclear Science, Electrical Engineering and Computer Science, Engineering, Education, and Arts. The hierarchical structure of NTHU Bachelor degree programmes along with the graduation requirement of credits in our sample period (2012 – 2017) are presented in Table 3.1.[2] Each undergraduate student is required to take 128-132 credits before graduation (depending on programme-specific regulations). In general, the total required credits are made up of university credits, school credits, programme credits, elective modules, and free elective modules.

On the basis of the regulation on programme credits, these 24 Bachelor degree programmes can be broadly classified into two types of programmes – 7 interdisciplinary degree programmes and 17 traditional disciplinary programmes. The first group is the 7 interdisciplinary degree programmes, which has been established in 7 schools separately for promoting interdisciplinary education. It involves a split in programme credits between first-speciality credits and second-speciality credits. The first speciality credits are credits that must be taken from one of the traditional disciplinary programmes within the school, while the second speciality credits can be taken from any traditional disciplinary programmes at NTHU. The second group is 17 traditional disciplinary programmes. Students enrolled in these traditional disciplinary programmes can only take programme credits within their programmes. Nevertheless, students in traditional disciplinary pro-

[1] At NTHU, "college" is the term used to refer to what would be a "school" in countries like the Australia, Canada and UK".

[2] We exclude the School of Arts and Education because they were merged into NTHU in 2016.

Table 3.1: The structure and requirement of NTHU Bachelor degree programmes.

Seven Schools	Twenty Four Programmes	Total Required Credits	University Credits	School Credits	Programme Credits		Elective Credits	Free Elective Credits
					First Specialty	Second Specialty		
Science (SCI)	Interdisciplinary Programme of Sciences (IPSCI)	128	28	18-26	29-36	27-33		12-20
	Department of Chemistry (CHEM)	128	28		67		12	21
	Department of Mathematics (MATH)							
	applied mathematics division	128	28		57			43
	pure mathematics division	128	28		54			46
	Department of Physics (PHYS)							
	physics division	128	28		60		12	28
	astronomical physics division	128	28		68		5	27
	photoelectric division	128	28		71		6	23
Engineering (ENGI)	Interdisciplinary Programme of Engineering (IPE)	128	28	26	33-38	26-33		3-15
	Department of Chemical Engineering (CHE)	128	28		88			12
	Department of Industrial Engineering and Engineering Management (IEEM)	130	28		72		21	9
	Department of Materials Science and Engineering (MS)	130	28		84		9	9
	Department of Power Mechanical Engineering (PME)	129	28		67		15	19
Humanities and Social Sciences (HSS)	Interdisciplinary Programme of Humanities and Social Sciences (IPHSS)	128	28	30	30	18		22
	Department of Chinese Literature (CL)	128	32		54		24	18
	Department of Foreign Languages and Literature (FL)	128	28		67		12	21
Life Science (LS)	Interdisciplinary Programme of Life Science (LSIP)	128	28	27	28	27-33		11-17
	Department of Life Science (DLS)	128	28		68		12	20
	Department of Medical Science (DMS)	128	28		68		12	20
Nuclear Science (NS)	Interdisciplinary Programme of Nuclear Science (IPNS)	128	28	31	36-37	26-33		0-7
	Department of Engineering and System Science (ESS)	128	28		58-60		30	10-12
	Department of Biomedical Engineering and Environmental Science (BMES)	128	28		58		30	12
Technology Management (CTM)	Interdisciplinary Programme of Management and Technology (IPMT)	132	28	38	27-33	27-33		0-12
	Department of Quantitative Finance (QF)	128	28	24	59			17
	Department of Economics (ECON)	130	28	24	24		30	24
Electrical Engineering and Computer Science (EECS)	Interdisciplinary Programme of Electrical Engineering and Computer Science (IPEECS)	128			38	30	18	14
	Department of Computer Science (CS)	128	28		52		36	12
	Department of Electrical Engineering (EE)	128	28		53		33	14

Notes: At NTHU, "college" is the term used to refer to what would be a "school" in countries like the Australia, Canada and UK". The formal name of "Interdisciplinary Programme of Management and Technology (IPMT)" is "Department of Double Specialty Programme of Management and Technology". The requirement of credits for each programme is the regulation in the academic year 2017.

grammes still have a chance to learn interdisciplinarily. Free selective credits in Table 3.1 are designed to allow students to take module credits of their own interests from other disciplines. For example, students enrolled in the Department of Economics can take 24 credits from any other discipline. As our study focuses on interdisciplinary learning in traditional disciplinary programmes, we exclude students in 7 interdisciplinary degree programmes.

3.3.2 Data source

We drew on a unique dataset of administrative data and Graduation Survey (GS) data gathered by NTHU. Administrative data from different sections across NTHU were obtained and assembled into a single dataset. We obtained information on module profiles, such as module numbers, credits, programmes, years and semesters, and module GPA – and students' backgrounds including individual admission methods, university entrance grades, high school, programme, school, academic performance at NTHU, gender and place of residence.

We also obtained GS data collected by the NTHU Center for Institutional Research. GS data has been collected annually since 2012. The survey aims to collect information on the learning experience of graduates while they were studying at NTHU. It collects data on students' individual and family background information, and non-academic outcomes. This information is self-reported and includes skill development outcomes, such as critical thinking, social justice and self-discipline. A critical concern of graduate surveys is their low response rate. However, by international standards, this is very high for the NTHU Graduation Survey. For example, the survey in 2015 returns a response rate of 98.2%. International graduate surveys would have a rate of 70 or below (Rowe et al., 2013; Tang et al., 2021).

Matching students' cohort graduation year, we assembled a unique dataset of NTHU individual graduates records from 2012 to 2017 which captures graduates' experience and outcomes during their studies at NTHU.[3] The dataset comprises a total of 7,712 individual records and captures information on six cohorts of undergraduate students graduating from 2012 to 2017. Because we aim to examine the impact of interdisciplinary learning for students graduating from traditional disciplinary programmes, we excluded 1,422 students in the interdisciplinary degree programmes. We also excluded 173 students who changed their programmes as they would be affiliated to two different programmes and made the identification of module credits taken in other programmes and schools difficult, potentially bi-

[3]Following the instructions of Taiwan's privacy and personal data protection laws, all the personal data used in this study were de-identified, so that specific persons and their identities cannot be identified either directly or indirectly.

asing our results. Additionally, we also excluded observations with missing values leaving a total sample of 5,063 observations.

3.3.3 Variables description

We examined the association between interdisciplinary learning and five possible learning outcomes: profound discipline-specific knowledge, the ability to use discipline-specific knowledge flexibly, critical-thinking skills, the ability of concerns about social justice and well-being, and the ability of self-discipline and reflection. We classified these outcomes into two groups. The first group relates to knowledge-related outcomes, involving the self-perceived depth of discipline-specific knowledge, and the self-perceived ability to use this knowledge in flexible ways. The second group relates to social-related abilities, involving self-perceived critical-thinking skills, the ability of concerns about social justice and well-being, and self-discipline and reflection. All these outcomes were collected via Graduation Survey with an ordinal scale (disagree, neutral and agree), indicating the level of agreement or disagreement on the students' abilities acquired during their undergraduate studies. A description of the dependent variables and percentage of each category is provided in Table 3.2.

Table 3.2: Description of dependent variables.

Variables	Description of Variables	Disagree	Neutral	Agree
Knowledge-related outcomes				
discipline knowledge	profound discipline-specific knowledge	13.83%	5.37%	80.80%
knowledge usage	use the discipline-specific knowledge flexibly	24.33%	6.50%	69.17%
Social-related abilities				
critical thinking	critical thinking skill	7.66%	4.21%	88.13%
social justice	concerns about social justice and well-being	13.79%	5.19%	81.02%
self-discipline	self-discipline and reflection	7.17%	4.21%	88.62%

To capture the impact of interdisciplinary learning on students' skill development outcomes, we included a set of student-related variables and household characteristic variables, controlling for potential confounding factors. Dummy variables were included to capture skill development differentials according to gender, graduation cohorts, schools, admission methods, parents' occupations, family income status and living areas.

We also included continuous variables to account for variations in skill development according to university entrance grades, time allocation (such as hours of participating in clubs and part-time jobs per week), motivation to undertake university study and parents' years of education. The GS data includes six reasons for pursuing university studies. Using factor analysis, we reduced this information to two key factors representing distinctive domains relating to extrinsic and intrinsic reasons. These factors were then used as independent variables in our

Table 3.3: Description of independent variables.

Variables	Description of Variables	Mean	SD
Main Independent Variables	(the indices of interdisciplinary learning)		
school-level interdisciplinarity	the proportion of credits offered by different schools	0.251	0.100
field-level interdisciplinarity	the proportion of credits offered by different fields	0.131	0.050
Other Control Variables			
Student-related variables			
male	1 for male	0.683	0.466
Motivation to undertake university study			
external	the external motivation such as peer influence	-0.025	0.897
internal	the internal motivation such as self-exploration	0.013	0.834
club hours	hours of participating in student clubs per week	4.211	3.391
part-time hours	hours of participating in part-time job per week	2.861	3.276
entrance scores	the total score in General Scholastic Ability Test	66.214	4.126
high-school rank	rank in high school, 1 is top 20%, 5 is bottom 20%	2.990	1.230
Admission methods			
exam	1 for Examination and Placement	0.466	0.499
application	1 for Recommendation, Screening or Star programme	0.529	0.499
others	1 for other programmes	0.005	0.070
Cohorts	six graduation cohorts		
cohort2012	graduated in 2012	0.163	0.370
cohort2013	graduated in 2013	0.165	0.371
cohort2014	graduated in 2014	0.177	0.382
cohort2015	graduated in 2015	0.187	0.390
cohort2016	graduated in 2016	0.189	0.392
cohort2017	graduated in 2017	0.118	0.323
Schools			
Humanities & Social Sciences	1 for the Humanities and Social Sciences	0.066	0.249
Technology Management	1 for the Technology Management	0.134	0.340
Electrical Engineering & Computer Science	1 for the Electrical Engineering and Computer Science	0.206	0.404
Engineering	1 for the Engineering	0.272	0.445
Nuclear Science	1 for the Nuclear Science	0.052	0.222
Life Science	1 for the Life Science	0.127	0.333
Science	1 for the Science	0.144	0.352
Household characteristic variables			
Father's occupation			
white-collar	1 for a white-collar worker	0.768	0.422
blue-collar	1 for a blue-collar worker	0.154	0.361
other-collar	1 for a other-collar worker	0.078	0.268
Mother's occupation			
white-collar	1 for a white-collar worker	0.630	0.483
blue-collar	1 for a blue-collar worker	0.048	0.213
other-collar	1 for a other-collar worker	0.322	0.467
father's yos	father's years of education	15.075	3.450
mother's yos	mother's years of education	14.205	3.021
lowincome family	1 for belonging to low-income households as defined in Article 4 of the Taiwanese Public Assistance Act[a]	0.021	0.143
municipality	1 for living in six special municipalities (Taipei, New Taipei, Taoyuan, Taichung, Tainan, and Kaohsiung)[b]	0.759	0.428

[a]According to Article 4 of the Taiwanese Public Assistance Act, the low-income households described in this Act shall qualify under the following conditions: they are approved by their local municipality competent authority via application; their average divided monthly income among each person in the household falls below the lowest living index; and their total household assets do not exceed the specific amount announced by the central and municipality competent authorities in the year of application.

[b]According to Article 4 of the Taiwanese Local Government Act, regions with population of not less than one million and two hundred fifty thousand and have special requirements in their political, economic, cultural, and metropolitan developments may establish special municipalities.

models. We also added an ordinal variable indicating students' academic rank in high school to control variations in skill development attributing to intelligence. Table 3.3 lists the independent variables in our analysis.[4]

The last two columns of Table 3.3 report the mean value and standard deviation of control variables in our analysis. Focusing on the composition of students, about 68.3% is male. The average time taken to participate in the student club at university and in part-time jobs per week is 4.211 and 2.861 hours, respectively. The mean value of university entrance grades is 66.214.[5] The main channel for university admission is the recommendation and screening or star program, which accounts for 52.9%. Each wave of graduates accounts for around 17% of the total sample, ranging from 16.3% in 2012 to 18.9% in 2016. The 2017 cohort makes up the smallest share (11.8%) because of missing information for parents' years of education. Engineering dominates the largest share of graduates, whereas Life Science constitutes the smallest proportion. Turning to household characteristics, the largest share of parents' occupations relates to white-collar workers, being 76.8% for fathers and 63.0% for mothers: 2.1% of them belong to the low-income family. The mean value of fathers' and mothers' years of education is 15.075 and 14.205 years.

3.3.4 Estimation strategy

To analyse the effect of interdisciplinary learning on individual skill development outcomes, we used two sets of ordered logistic regression models to distinguish different indices of interdisciplinary learning: a school-level interdisciplinary indicator in Equation 3.1 and a field-level indicator in Equation 3.2 as follows:

$$\begin{aligned} y_i^* &= \alpha + \gamma \ \textit{school-level interdisciplinarity}_i + \sum_s \delta_s \cdot \textit{school}_{si} + x_i'\beta + \varepsilon_i, \\ y_i &= m \text{ if } \tau_{m-1} < y_i^* < \tau_m \text{ for m=1 to 3,} \end{aligned} \tag{3.1}$$

[4] To mitigate problems of multicollinearity, we assessed the correlations between predictors but none of the covariates displayed a significant degree of correlation; that is, over 0.7.

[5] The value of university entrance grades in Taiwan is between 0 to 75.

$$y_i^* = \alpha + \gamma \textit{ field-level interdisciplinarity}_i + \sum_s \delta_s \cdot \textit{school}_{si} + x_i'\beta + \varepsilon_i,$$
$$y_i = m \text{ if } \tau_{m-1} < y_i^* < \tau_m \text{ for m=1 to 3,} \tag{3.2}$$

where y_i is one of our five ordinal outcomes, i.e., profound discipline-specific knowledge, use the discipline-specific knowledge flexibly, critical-thinking skills, the ability of concerns about social justice and well-being, and self-discipline and reflection. $\textit{school-level interdisciplinarity}_i$ and $\textit{field-level interdisciplinarity}_i$ are our proposed indices of interdisciplinary learning; $\textit{school}_{si}$ is a school-dummy variable indicating student i belonging in school s; x_i' is a vector of control variables including the variables listed in Table 3.3; m is the ordinal scale representing disagree, neutral and agree. We included dummy variables to capture school fixed effects and cluster standard errors by schools. α, γ, δ, and β represent the coefficients to be estimated. γ is the parameter of interest, which measures the effects of interdisciplinary learning. ε_i is the error term and the distribution of ε_i is assumed to follow a logistic distribution. Separate models were estimated for each of our five outcome variables.[6]

Moreover, we sought to test whether the TMGT effect exists. To this end, we divided the sample into four sub-samples on the basis of students' levels of interdisciplinary learning. The logic of this analysis is that we treated students with low levels of interdisciplinary learning as appropriate interdisciplinary learners and viewed students with high levels of interdisciplinary learning as getting too many credits outside their schools. The first two sub-samples, denoted as Highest 10% and Highest 25%, are students whose extent of interdisciplinary learning belongs to the highest 10% and the highest 25%, respectively. The other two sub-samples, denoted as Lowest 10% and Lowest 25%, are students whose extent of interdisciplinary learning belongs to the lowest 10% and the lowest 25% respectively. For each sub-sample, we applied the same ordered logistic regression model as shown in Equation 3.1 and 3.2 to evaluate the effect of interdisciplinary learning.

[6]To tackle the concern about validating the modelling assumptions, I conducted both the link test, which aims to detect potential specification errors, and the goodness-of-fit test, designed to ascertain the alignment between the predicted probabilities generated by the model and the actual observed outcomes. The results of the link test suggest that I have selected relevant predictors and underscore the correct specification of the majority of my models. Additionally, the results from the goodness-of-fit test provide further evidence of a strong correspondence between the predicted probabilities generated by my models and the actual observed outcomes. To address the concern about the parallel slope assumption under the ordered logit model, we conducted the likelihood ratio test, which unfortunately revealed a violation of the assumption. To tackle this challenge, we employed the multinomial logit model, enabling differentiation in the relationship across various group pairs. The outcomes corroborate the robustness of the findings from the ordered logit models, particularly in estimating the likelihood ratio of selecting “agree” over “disagree.”

The TMGT effect predicts that students with a moderate degree of engagement with interdisciplinary learning may gain a clear advantage from learning interdisciplinarily while students may experience negative returns if their levels of interdisciplinary learning engagement are high. Thus, we predict that the impact of interdisciplinary learning on individual skills outcomes for students displaying low levels (that is, those in the Lowest 10% and Lowest 25%) would be positive. By contrast, for students with high levels of interdisciplinary learning (Highest 10% and Highest 25%), the effect of interdisciplinary learning might be negative.

3.4 Measuring the Extent of Interdisciplinary Learning

We proposed two indices to measure the extent of interdisciplinary learning of undergraduates within traditional disciplinary programmes, rather than in interdisciplinary programmes. Previous studies assessed the effects of interdisciplinary learning by comparing students who participated in interdisciplinary programmes (viewed as interdisciplinary learners) with students who participated in traditional disciplinary programmes (viewed as non-interdisciplinary learners). Unlike previous studies, we argued that traditional disciplinary students can also engage in interdisciplinary learning because they are allowed to freely take a portion of their module credits from different disciplines. Thus, we proposed two indices to measure the extent of interdisciplinary learning of traditional disciplinary students based on the number of module credits registered by students outside their schools or fields, as follows:

$$\textit{school-level interdisciplinarity}_i = \frac{\textit{sum (credits student i took from other schools)}}{\textit{total credits student i took}} \tag{3.3}$$

$$\textit{field-level interdisciplinarity}_i = \frac{\textit{sum (credits student i took from the different field)}}{\textit{total credits student i took}} \tag{3.4}$$

We classified students' module credits into three groups and three subgroups as Figure 3.1. Broadly, total module credits registered by a student could be divided into three categories: (1) offering by their own programme, (2) offering by other programmes in their own school, and (3) offering by other schools. Because interdisciplinary learning represents learning and integrating knowledge and skills from different disciplines, we proposed an index calculating the proportion of credits that were offered by other schools (Equation 3.3) to represent the extent of interdisciplinary learning. We argued that students acquiring more credits from other schools have a higher extent of interdisciplinary learning.

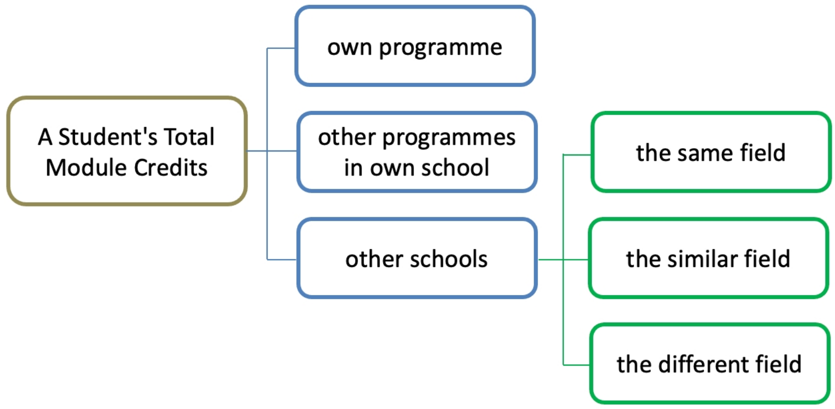

Figure 3.1: The structure of a student's module credits.

In addition, we further classified the modules offered by other schools into three subgroups (as shown in Figure 3.1) and proposed a second measure of interdisciplinary learning (Equation 3.4). It considered the degree of divergence between the field of students' discipline and the field of the modules they registered. Some disciplines could be considered to have greater proximity or overlaps than others. For instance, knowledge of Electrical Engineering and Computer Science may be similar to Engineering, and less similar to Humanities and Social Sciences studies. Students taking module credits from a different field may need to make more efforts on integrating knowledge and experience difficulties in understanding than those taking module credits from a similar field (Brassler and Dettmers, 2017). The degree of divergence between the field of students' discipline and the field of the modules they registered may result in different learning performances (Taylor, 2018). Therefore, we proposed Equation 3.4 which computed the proportion of credits that were offered by the different field to distinguish the level of interdisciplinary learning.

The issue is how to compare the similarity between the field of students' disciplines and modules. We first classified the seven schools at NTHU into three disciplinary fields based on the International Standard Classification of Education (ISCED) (UNESCO Institute for Statistics, 2014) and then compared the similarity between these three fields. The ISCED categorises programmes and qualifications into 11 broad fields, 29 narrow fields, and about 80 detailed fields. The Ministry of Education (MoE) in Taiwan applies this three-level hierarchy and adds a fourth level. MoE classifies 11 broad fields into humanity, society and technology field. According to this classification, the School of Humanities and Social Sciences belongs to the field of *Humanity*; the School of Technology Management belongs to *Society*; and the other five schools, including Electrical

Engineering and Computer Science, Engineering, Science, Nuclear Science and Life Science, belong to *Technology*.

Next, we sought to compare the similarity between the three fields. According to Biglan's hard-soft and pure-applied two-dimensional space, the humanity (comprising Chinese Literature and Foreign Languages) and society field (comprising Economics and Finance) are more similar to each other than the technology field (comprising Science and Engineering) (Biglan, 1973; Kolb, 1981). Therefore, for a student majoring in the humanity or society field, if they registered a module offered by the technology field, the relevant module was classified as a module offered by the different field. On the other hand, the technology field is more similar to the society field than the humanity field (Biglan, 1973; Kolb, 1981). By comparing the similarity between the field of students' programme and the field of the module, we categorised the modules offered by other school into three subgroups, i.e., offered by the same field, offered by the similar field, and offered by the different field (as shown in Figure 3.1). An example of module classification is presented in Table 3.4. We could thus calculate the proportion of credits that were offered by the different field to form the second index of interdisciplinary learning (Equation 3.4). Our second index captures the level and extent of interdisciplinary learning simultaneously.

Yet, some modules could not be classified into any of the three categories. We excluded these modules because they included modules that all students must take (such as Physical Education), or were offered for a specific purpose (such as Military Education). To avoid double-counting credits, we excluded modules which students failed. Most of these modules were identified in their own field of study and students were required to retake these modules so they were captured in our analysis. We also adjusted modules that were offered by other programmes but belonged to students' compulsory modules (such as Calculus, General Chemistry, and General Physics) to be considered as modules offered by their own programme.

3.5 Results

3.5.1 The distribution of two measures of interdisciplinary learning

Figure 3.2 and Figure 3.3 show the distribution of our two indices – school-level and field-level interdisciplinarity, by schools. According to Figure 3.2, it reveals a low level of interdisciplinary learning in Humanities and Social Sciences, and higher level of interdisciplinary learning in the Life Sciences, with around 50%

Table 3.4: Examples of module classification.

Students' School	Students' Field	Students' Module Profile	Field of the Module	Module Group
1. Student A's school is Humanities and Social Science	Humanity	70% from Humanities and Social Sciences	Humanity	own school
		20% from Technology Management	Society	other school: similar field
		10% from Engineering	Technology	other school: different field
2. Student B's school is Technology Management	Society	60% from Technology Management	Society	own school
		25% from Science	Technology	other school: different field
		15% from Life Science	Technology	other school: different field
3. Student C's school is Engineering	Technology	80% from Engineering	Technology	own school
		15% from Science	Technology	other school: same field
		5% from Humanities and Social Sciences	Humanity	other school different field

of students registering over 40% module credits outside their school, followed by Nuclear Science and Engineering.

Figure 3.3 presents the distribution of our second measure of interdisciplinary learning – field-level interdisciplinarity. The second measure computed the proportion of credits that were offered by the different field. It excluded the credits that were offered by the same and similar field, which were included in the first measure – school-level interdisciplinarity. It is apparent from Figure 3.3 that students in Humanities and Social Sciences registered a low level of credits from the different field. It is the same as the results shown in Figure 3.2. The highest level of field-level interdisciplinarity goes to Technology Management (CTM), more than half of students in CTM registered over 17% of credits different from their degree field. It is different from the results in Figure 3.2, which shows the highest school-level interdisciplinarity is students in Life Sciences.

3.5.2 Mean difference of outcome variables by the percentile of two measures of interdisciplinary learning

Table 3.5 reports the mean difference of our five outcome variables between the highest 25% and the lowest 25% in the school-level interdisciplinarity and field-level interdisciplinarity. As can be observed in Column (1) of Table 3.5, relative to students in the highest 25%, students in the lowest 25% display higher average ability to use discipline-specific knowledge flexibly, critical thinking skills, and the ability of concerns about social justice and well-being.

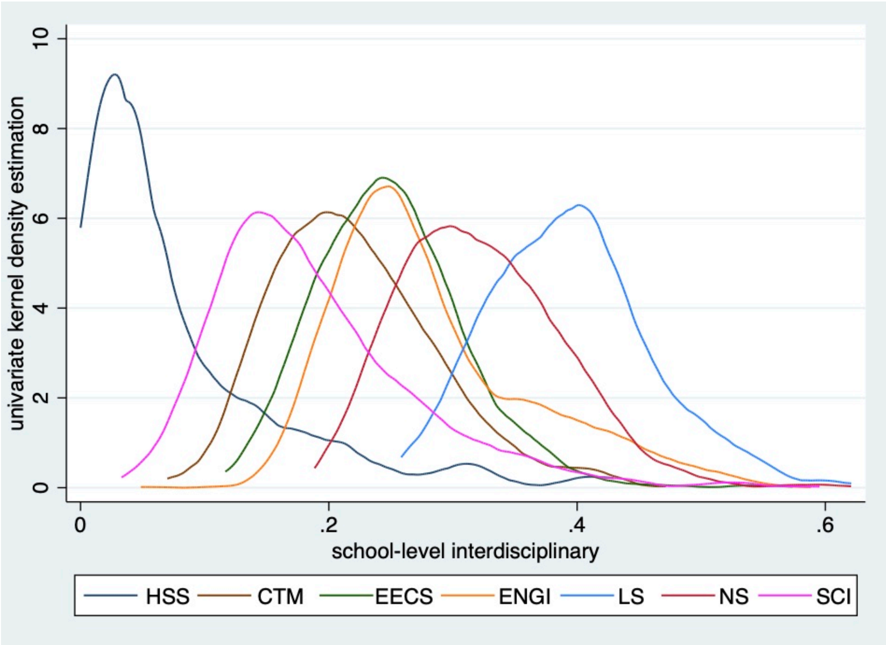

Figure 3.2: The distribution of school-level interdisciplinarity. *Notes:* School-level interdisciplinarity is the proportion of credits offered by different schools.

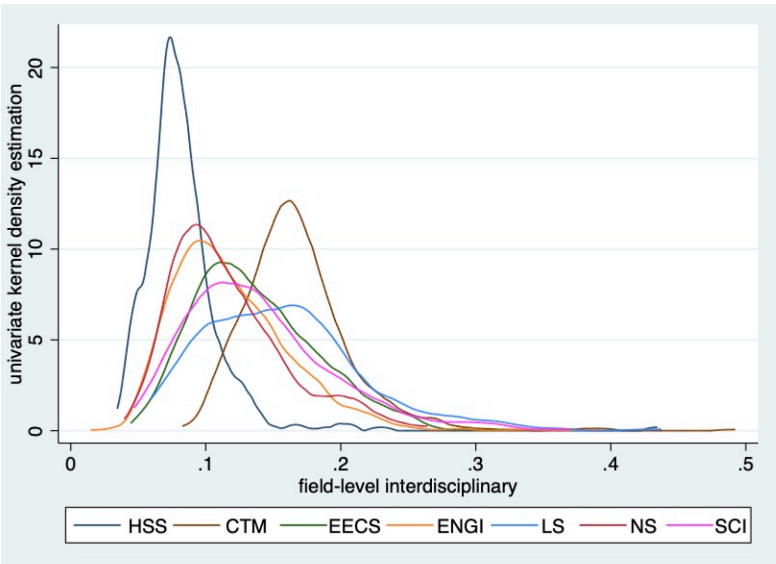

Figure 3.3: The distribution of field-level interdisciplinarity. *Notes:* Field-level interdisciplinarity is the proportion of credits offered by different fields.

Theoretical approaches suggest that by effectively integrating knowledge and collaborating with students from different disciplinary fields, interdisciplinary learners are likely to reconfigure preformed personal perspectives, and create new neural connections, enhancing their skills. Contrasting with these expectations, our preliminary results reveal that students with a higher extent of interdisciplinary learning tend to self-report a lower overall level of skills development, suggesting that interdisciplinary learning may not necessarily enhance students' learning outcomes, at least not at the same extent.

Table 3.5: Mean difference of outcomes by the percentile of the index of interdisciplinary learning.

	(1) School-level Interdisciplinarity	(2) Field-level Interdisciplinarity
	the highest 25% - the lowest 25%	the highest 25% - the lowest 25%
discipline knowledge	0.024	-0.086***
knowledge usage	-0.072**	-0.233***
independent thinking	-0.057***	-0.007
social justice	-0.076***	-0.097***
self-discipline	-0.027	-0.032*

Notes: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The column "School-level Interdisciplinarity' ' and "Field-level Interdisciplinarity" are used to distinguish the index measuring the extent of interdisciplinary. "The highest 25% - the lowest 25%" presents the difference between the sample means of the sub-samples that whose extent of interdisciplinary learning is the highest 25% and the lowest 25%.

The results for our field-level measure in Column (2) are similar to those found based on at the school-level measure (Column (1)). Relative to students in the highest 25%, students in the lowest 25% display higher average ability to use discipline-specific knowledge flexibly and the ability of concerns about social justice and well-being. The main dissimilarity lies in the magnitude of the difference in the mean score. In Column (2), the mean difference between the highest 25% and the lowest 25% in the ability to use discipline-specific knowledge flexibly is three times more than the mean difference in Column (1). As expected, this preliminary result reveals that the degree of divergence between the field of students' discipline and the field of the modules they registered seems to result in different learning performances. However, these preliminary results do not rule out the influence of other factors such as student characteristics in students' skill development outcomes. The evidence needs to be complemented with regression analysis.

3.5.3 Interdisciplinary learning and skill development outcomes

To assess the association between interdisciplinary learning and improvement in students' skill acquisition, we estimated a series of ordered logistic regression models as described in Section 3.3.4. Separate models were estimated for each skill development outcome and two models were generated for each outcome based on (1) our school-level measure and (2) field-level measure of interdisciplinary learning. Table 3.6 reports the semielasticity (d(y)/d(lnx)) of our indices of interdisciplinary learning on five outcome variables. The results are shown for each of the three categories of our outcome variables (i.e. disagree, neutral and agree). We estimated the marginal effect of the extent of interdisciplinary learning by holding all other covariates fixed at their sample means. The results systematically show a negative estimate for agree and positive estimates for neutral and disagree. These results indicate that students with a higher extent of interdisciplinary learning are less likely to agree that they possess profound discipline-specific knowledge, the ability to use discipline-specific knowledge flexibly, critical-thinking skills, the ability of concerns about social justice and well-being, and the ability of self-discipline and reflection.

To be specific, estimates on school-level interdisciplinary learning in Column (1) of Table 3.6 show a statistically significant and negative association with knowledge use, social justice and self-discipline. The coefficient “agree” for “knowledge usage” indicates that increasing one more percent of credits outside their school (i.e. greater level of interdisciplinary learning) leads to a decline of 7.1% in the average probability of a student agreeing that they can use their discipline-specific knowledge in a flexible way. The results also indicate that an additional one percent of credits from other schools decreases the average probability of agreeing to have the ability of concerns about social justice and well-being, and of self-discipline and reflection by 3.4% and 1.9% respectively.

Focusing on interdisciplinary learning at the field-level measure in Column (2), the results display a similar pattern to the school-level measure in Column (1). An increase of one percent in credits from the different field leads to a decline of 7.0% in the average probability of a student agreeing that they can use their discipline-specific knowledge in a flexible way and a decrease of 2.9% on the ability of concerns about social justice and well-being. Differences between the results of the two measures are observed in the significance of self-discipline and reflection. In contrast to the significant negative effect of interdisciplinary learning on self-discipline and reflection at the school-level measure, a negative but non-significant effect was found at the field-level measure. Taking more credits from other fields implies that students must make more efforts on integrating different kinds of knowledge, such as humanity and natural science. Students who registered credits from different fields require more time management than students who only registered credits from the same and similar fields. This extra effort may offset the observed negative effect of interdisciplinary learning on self-discipline and reflection.

Table 3.6: Marginal effects of ordered logistic regression.

Panel A. discipline knowledge	(1) school-level interdisciplinarity	(2) field-level interdisciplinarity
(1) disagree	0.015	0.013
	(0.020)	(0.012)
(2) neutral	0.005	0.005
	(0.007)	(0.005)
(3) agree	-0.021	-0.018
	(0.028)	(0.016)

Panel B. knowledge usage	(1) school-level interdisciplinarity	(2) field-level interdisciplinarity
(1) disagree	0.059***	0.058***
	(0.008)	(0.020)
(2) neutral	0.012***	0.011***
	(0.002)	(0.004)
(3) agree	-0.071***	-0.070***
	(0.010)	(0.024)

Panel C. critical thinking	(1) school-level interdisciplinarity	(2) field-level interdisciplinarity
(1) disagree	0.007	-0.009
	(0.005)	(0.006)
(2) neutral	0.004	-0.005
	(0.003)	(0.004)
(3) agree	-0.011	0.015
	(0.008)	(0.010)

Panel D. social justice	(1) school-level interdisciplinarity	(2) field-level interdisciplinarity
(1) disagree	0.025*	0.021***
	(0.013)	(0.007)
(2) neutral	0.009*	0.008***
	(0.005)	(0.003)
(3) agree	-0.034*	-0.029***
	(0.018)	(0.010)

Panel E. self-discipline	(1) school-level interdisciplinarity	(2) field-level interdisciplinarity
(1) disagree	0.012**	0.005
	(0.005)	(0.005)
(2) neutral	0.008**	0.003
	(0.003)	(0.004)
(3) agree	-0.019**	-0.008
	(0.009)	(0.009)

Notes: This table reports the semielasticity (d(y)/d(lnx)) of our indices of interdisciplinary learning on five outcome variables. We estimated the marginal effect of the extent of interdisciplinary learning by holding all other covariates fixed at their sample means. Separate models were estimated for each skill development outcome and two models were generated for each outcome based on (1) our school-level measure and (2) field-level measure of interdisciplinary learning. Standard errors are in parentheses. * $p < 0.1$, **$p < 0.05$, ***$p<0.01$.

Full regression results are presented in Table B1 in B.1. Moving on now to discuss the evidence of control variables, as expected, skill development outcomes display a consistent and positive relationship with having strong external motivation, a high high-school rank, admission via recommendation and screening or star program, spending more time participating in part-time jobs while at university, and living in six special municipalities. While the admission method for the recommendation and screening or star programme only positively affects critical-thinking skills and living in six special municipalities before they entered the university only influences self-reported social-related abilities. By contrast, knowledge-related outcomes display a negative relationship with hours of participating in the student club at university and fathers' years of schooling. Regarding students' schools, Humanities and Social Sciences students (the reference group) tend to feel possessing higher social-related abilities and can use discipline-specific knowledge in a flexible way than other school students. While they feel less they acquire less deep discipline-specific knowledge during their degree than natural science students. In addition, compared to the cohort 2012, younger cohorts are more likely to have higher self-reported abilities.[7]

3.5.4 Tradeoff between breadth and depth: Too-Much-of-a-Good-Thing effect

In this section, sub-sample regression analyses were carried out to examine whether excessive interdisciplinary learning offsets the gain through interdisciplinary learning (the TMGT effect). To test this perspective, we compared the impact of interdisciplinary learning on individual skill outcomes for students displaying high levels of interdisciplinary learning (those in the highest 10%/25%), against those displaying low levels (those in the lowest 10/25%).

Table 3.7 reports the estimates for eight different sub-sample ordered logistic

[7] We addressed the potential issue of model over-fitting was addressed through two approaches. First, by simplifying the model and removing variables lacking practical significance, the results for the new model remain consistent irrespective of the presence of non-significant controls. Second, an array of regularisation techniques, including lasso, elastic-net, ridge, and adaptive methods, was employed to systematically assess their predictive efficacy in variable selection. The findings suggest the validity of incorporating all pertinent independent variables into the regression models.

regressions. It reports the estimates for our independent variable of interest (i.e. interdisciplinary learning) and log odds ratios. Because the purpose is to examine whether the effect of interdisciplinary learning on skill outcomes is predominantly positive for low-level interdisciplinary students, while negative for those with high engagement in interdisciplinarity, rather than on their magnitude. Estimates for our school-level and field-level interdisciplinary learning metric are reported in Panel A and Panel B, respectively. Column (1) to Column (4) relate to each of our sub-samples including graduates with shares of module credits outside their school or field of discipline: Highest 10%, Highest 25%, Lowest 25% and Lowest 10%.

Focusing on the school-level measure in Panel A of Table 3.7, the estimates in Column (1) show negative coefficients across outcomes for the highest 10% sub-sample and statistically significant estimates for social justice and self-discipline. In contrast, those at the lowest 10% interdisciplinary learning display a large and positive coefficient across all skill development outcomes, and significance for coefficients associated with discipline knowledge, knowledge usage and critical thinking. The results from our field-level analysis in Panel B reveal a similar pattern, but are less significant. The effects only appear to be statistically significant and positive for discipline knowledge among those with low levels of exposure to interdisciplinary learning, and negatively significant for knowledge usage among high-level interdisciplinary learners. A plausible explanation for the disparity from the outcomes of the school-level measure could lie in the observation that students generally engaged in fewer instances of field-level interdisciplinary learning. This observation is reflected in Figure 3.2 and Figure 3.3, wherein the extent of field-level interdisciplinary learning gravitates between 0.05 to 0.2, while the corresponding extent for school-level interdisciplinary learning spans from 0.5 to 0.55. Thus, for students whose extent of field-level interdisciplinary learning falls within the Highest 10/25% bracket, their exposure to interdisciplinary learning remains notably lower than that of their counterparts whose engagement lies in the Highest 10/25% range within the school-level context. It is noteworthy that students categorised within the Highest 10% of field-level interdisciplinary learners may still undergo a moderate degree of interdisciplinary learning. Hence, they might be less prone to the adverse effects of the "Too-Much-of-a-Good-Thing" phenomenon compared to students with the highest 10% extent of school-level interdisciplinary learning.[8]

[8]We also introduced a squared term of the extent of interdisciplinary learning in both Equation 3.1 and Equation 3.2 to examine an inverse U-shaped relationship between interdisciplinary learning and skill development outcomes. The findings show that the majority of regression coefficients related to the squared term tend towards the positive direction and lack statistical significance, and the coefficients of the linear term demonstrate a negative trend. It is evident

Table 3.7: Sub-sample comparison.

Panel A. Main Independent Variable: School-level Interdisciplinarity				
	(1)	(2)	(3)	(4)
	Highest 10%	Highest 25%	Lowest 25%	Lowest 10%
discipline knowledge	1.900	0.871	2.857	15.833***
knowledge usage	-2.650	0.035	-0.573	9.172**
critical thinking	-0.094	-1.599	7.898**	18.005**
social justice	-3.268*	-0.690	5.111	11.404
self-discipline	-3.796*	-0.589	0.771	17.926
N	523	1291	1177	416

Panel B. Main Independent Variable: Field-level Interdisciplinarity				
	(1)	(2)	(3)	(4)
	Highest 10%	Highest 25%	Lowest 25%	Lowest 10%
discipline knowledge	0.204	1.032	16.058**	14.299*
knowledge usage	-4.291*	-2.017	-1.155	0.999
critical thinking	3.712	2.930	-0.958	14.132
social justice	0.330	-0.856	4.246	-3.003
self-discipline	-4.472	-1.516	-3.670	1.096
N	494	1255	1234	467

Notes: This table reports the estimates for eight different sub-sample ordered logistic regressions. It reports the estimates for our independent variable of interest (i.e. interdisciplinary learning) and log odds ratios. Column (1) to Column (4) relate to each of our sub-samples including graduates with shares of module credits outside their school or field of discipline: Highest 10%, Highest 25%, Lowest 25% and Lowest 10%. Standard errors are in parentheses. * $p < 0.1$, **$p < 0.05$, ***$p<0.01$.

These results suggest a positive effect of interdisciplinary learning on these abilities for individuals with relatively low levels of exposure to interdisciplinary learning, whereas a negative effect for those with high levels of interdisciplinary learning. Taken together, our results from sub-sample regression analyses support that the TMGT effect exists in interdisciplinary learning.

3.6 Discussion and Conclusion

The development of the knowledge-based economy has broken traditional disciplinary borders leading to a growing interest in interdisciplinary learning. Universities are actively developing ways of providing greater opportunities for interdisciplinary learning. Yet empirical evidence is limited. Prior work has focused on examining the effect of recently implemented interdisciplinary programmes. Yet, flexible module-based interdisciplinary learning in traditional disciplinary programmes is easier to implement but evidence on the impacts of this type of

that the relationship between interdisciplinary learning and skill development may not conform to a purely inverted U-shaped pattern.

programme on students' skills outcomes remains lacking. To this end, this paper proposes two indicators calculating the proportion of credits outside students' schools or from the different field to measure the extent of interdisciplinary learning in traditional disciplinary programmes, and it assesses the potential positive and negative effects of interdisciplinary learning on students' skill development outcomes.

Our findings revealed that, in traditional disciplinary programmes, higher levels of interdisciplinary learning may have a negative impact on student development outcomes. We presented evidence of increases in interdisciplinary learning at the school-level measure leading to diminished students' ability to use discipline-specific knowledge flexibly, the ability of concerns about social justice and well-being, and self-discipline and reflection. Compared to the school-level measure of interdisciplinary learning, no negative impact is found on students' self-discipline and reflection at the field-level measure. Increasing involvement in different-field credits required more time management than in similar-field credits and thus, offset the potential decrease in self-discipline and reflection capacity.

The observed negative relationship between interdisciplinary learning and students' skill developments in this study is contrary to previous studies which have suggested that interdisciplinary learning promotes students' skill development. There are several possible explanations for this counter-intuitive negative effect. First, effective learning depends on the connection between new and past knowledge (Lattuca et al., 2004). Providing students with the opportunity to choose flexibly in traditional disciplinary programmes may lead to lack effective integration between chosen modules in different fields, and thus may not leverage on existing knowledge (Graham and Gareth, 2014; Jones, 2010; Richter and Paretti, 2009). Second, studying from the different field may lead to experiencing difficulties in understanding and communication (Brassler and Dettmers, 2017). Miscommunication and frustration may thus weaken the skill development and achievement through interdisciplinary learning (Taylor, 2018).

Third, the TMGT effect represents an additional source of explanation and our sub-sample regression results support the view (Grant and Schwartz, 2011; Knifsend and Graham, 2012; Langfred, 2004). We showed that getting too much interdisciplinary learning may diminish students' confidence in acquiring deep discipline-specific knowledge, using discipline-specific knowledge in a flexible way, and their critical thinking skills. Students who stretch to learn across too many different fields and too distant from one another may diminish their knowledge capacity absorption. These findings expand existing evidence developing the conceptual links between interdisciplinary learning and skill development outcomes. We showed that interdisciplinary learning makes students learn more from a range of disciplines at the cost of learning less of a specific field (Costa et al., 2019; Hart, 2019; Ivanitskaya et al., 2002).

Our results have important implications for higher education and more specifically for the development of interdisciplinary learning in traditional disciplinary programmes. Providing free choice to students in traditional disciplinary programmes to select modules from other disciplines and learn interdisciplinarily seems to undermine their skill development outcomes and the potential benefits from interdisciplinary learning. Higher education institutions may need to assist students in their module selection with appropriate supporting infrastructure. An option could be to develop interdisciplinary study pathways with relevant modules outside students' primary discipline, or only include modules that have a high-degree of relevance to students' primary discipline. Ensuring some level of discipline-specific knowledge should probably also be a key objective of interdisciplinary learning. Identifying the optimum extent of interdisciplinary learning is an open question. Future research should explore the existence of tipping points; that is the point from taking credits to increase the level of interdisciplinary learning results in worse individual skill development outcomes. We focused on evaluating students' subjective self-reported skill development outcomes. Yet, based on existing research, we know that individual subjective responses tend to underestimate or overestimate their ability in systematic ways (Dunning, 2011). Future research could expand our analysis and assess the impact of interdisciplinary learning on skill development outcomes based on objective measures. The advantages of learning interdisciplinarily may be realised in the future. Future research should thus also extend our analysis investigating the long-term effect of interdisciplinary learning on future labour market outcomes later in life.

4

An Elon Musk Generalist or a Specialist? The Impacts of Interdisciplinary Learning on Post-Graduation Outcomes

The content of this chapter was published in the Studies in Higher Education.

Interdisciplinary education has become increasingly prominent as a core instrument to prepare the next generation workforce. Yet, little is known about the impacts of interdisciplinary education on post-graduation student outcomes. This paper aims to investigate the influence of interdisciplinary learning on graduates' post-graduation plan choices and labour market outcomes using unique administrative micro-data from National Tsing Hua University, Taiwan. Interdisciplinary learning is measured as the share of module credits outside a student's school or field of study. Our results indicate that higher levels of engagement in interdisciplinary learning increase the probability to pursue future study and employment in a field that differs from a graduate's college degree. Higher levels of engagement in interdisciplinary learning are also associated with a higher probability to enter the workforce, rather than pursuing further studies. Yet, this positive association between interdisciplinary learning and the probability to enter the workforce is specific to graduates from traditional disciplinary programmes. Graduates from specialised interdisciplinary programmes with higher levels of engagement in interdisciplinary learning are associated with a reduction in the probability to enter the workforce immediately after graduation. Additionally, we reveal that higher levels of interdisciplinary learning often lead to a general pattern of steady rise in salary and full-time employment over time. Yet these outcomes differ widely

across fields of study. Interdisciplinarity is associated with consistently greater average salaries for Materials Science and Engineering and Computer Science graduates, but lower levels for Life Science graduates. These findings suggest that the impact of interdisciplinary education on post-graduation outcomes is overall beneficial but varies across degree fields. Further research should investigate the reasons for the conditions contributing to unexpectedly negative post-graduate labour market outcomes in particular fields.

4.1 Introduction

As globalisation and the complexity of labour markets increase, interdisciplinary learning is becoming a pivotal instrument to enhance graduates' employability. Often understood as learning knowledge and skills across different disciplines, interdisciplinary learning is argued to benefit learners in developing skills, such as critical thinking, communication, and integrating knowledge effectively to solve complex problems (Hains-Wesson and Ji, 2020; Ivanitskaya et al., 2002; Lattuca et al., 2004). Interdisciplinary learning is described as adding to the list of desirable college experiences that current employers require from newly graduated college students. This is in addition to studying abroad and learning communities, all of which have been shown to positively affect students' post-graduation career outcomes (Miller et al., 2018; Oswald-Egg and Renold, 2021; Partlo and Ampaw, 2018).

In view of the potential benefits from interdisciplinary learning, Higher Education Institutions (HEIs) have designed undergraduate programmes to offer an interdisciplinary learning experience. These programmes can be broadly classified into two types of programmes: *traditional disciplinary* and *specialised interdisciplinary* degree programmes. Specialised interdisciplinary degree programmes are newly designed programmes which allow students to select dual specialities from traditional disciplinary degree programmes. In addition to the opportunity for interdisciplinary learning in specialised interdisciplinary degree programmes, traditional disciplinary degree programmes have gradually loosened the restrictions against modules chosen to provide traditional disciplinary students with the opportunity to learn interdisciplinarity. Traditionally, the core educational idea of traditional disciplinary programmes is to train professional leaders. Under the backdrop, module credits that students can choose are limited to their own discipline. Recent trends in interdisciplinary learning have propelled traditional disciplinary programmes to introduce more options on modules chosen and allow students to select module credits of their own interests in other fields of study. Yet the majority of credits remain in the field of study of their registered programme.

Existing research recognises the critical role played by interdisciplinary learning in undergraduate academic performance and skills (Hains-Wesson and Ji, 2020; Khandakar et al., 2020; Lattuca et al., 2017). However, this work has been restricted in three key ways. First, most research on interdisciplinary learning often treats students in specialised interdisciplinary programmes as the only interdisciplinary learners. Yet, students in traditional disciplinary programmes can also be exposed to interdisciplinary learning by registering modules offered outside their disciplines. Research of interdisciplinary learning in traditional disciplinary programmes is needed to inform the design of effective interdisciplinary education programmes. Second, evidence of interdisciplinary learning has been restricted to academic performance and skills during the period of study at HEIs, such as grade point average (Khandakar et al., 2020) and critical thinking (Lattuca et al., 2017). Empirical evidence on the impact of interdisciplinary learning on a wider range of student post-graduation educational and labour market outcomes is lacking. This is despite the fact that a key argument for the design of interdisciplinary education is to enhance graduate employability (Costa et al., 2019; Lattuca et al., 2004; Med, 2006). Third, there has been little discussion about how the effects of interdisciplinary learning on student post-graduation outcomes may vary across academic fields. Chapter 2 revealed that significant variations in skill development outcomes exist during the period of graduates' study. Less is known about how these differentiated impacts evolve post-graduations as to whether they amplify, with interdisciplinary learning providing a competitive advantage in the labour market.

To address these limitations, we aim to examine the influence of interdisciplinary learning on individual post-graduation plan choices and early labour market outcomes. To this end, we explore the impact of interdisciplinary learning on the post-graduation study plan choices and labour market outcomes of graduates from traditional disciplinary and specialised interdisciplinary degree programmes. We use a two-stage analysis. Drawing on unique administrative and survey data from the Taiwanese National Tsing Hua University (NTHU), we first use a set of logistic regression models to assess the effect of the two structures of interdisciplinary learning (i.e. traditional disciplinary and specialised interdisciplinary degree programmes) on post-graduation plan choices. Secondly, we combine individual records with programme-level career-tracking data from the Taiwanese Ministry of Education (MoE), and examine the impact of interdisciplinary learning on programme-mean salary and employment rate over time and across programmes using a set of cross-classified multilevel models.

The remainder of this paper is as follows. The next section reviews previous conceptual work discussing the positive benefits of interdisciplinary learning on graduates' future plan choices and early labour market outcomes. Section 4.3 offers a description of our study context and describes the data used for this study. Section 4.4 describes the methodology used for estimating the short and long-term effects of interdisciplinary learning before presenting our empirical results in Section 4.5. Section 4.6 discusses our main findings and their implications.

4.2 Background

4.2.1 Conceptual links between interdisciplinary learning and post-graduation plan choices and labour market outcomes

Multiple theories and perspectives can be used to understand and hypothesise about the associations between interdisciplinary learning and post-graduation plan choices and labour market outcomes. We build on these theories and perspectives, including (1) the perspective that interdisciplinarity may increase students' employability, (2) the perspective that interdisciplinary learning exposes learners to a wide range of disciplines, (3) signalling theory that interdisciplinary experience may be served as a signal of new graduates' productivity, and (4) human capital theory that interdisciplinary learning contributes to learners' human capital. In this section, we elaborate on the associations between these theories and interdisciplinary learning and develop four main hypotheses about these associations.

First, interdisciplinary learning is believed to have a positive effect on students' employability skills such as critical thinking skills (Hains-Wesson and Ji, 2020; Hart, 2019; Knight et al., 2013). Graduates who are confident in demonstrating employability skills, tend to be confident about applying for a job immediately after graduation (Miller et al., 2018; Oswald-Egg and Renold, 2021; Park, 2015). Conversely, graduates who may perceive themselves as less prepared for workforce engagement might opt for an extended transition period to secure employment or exhibit a heightened inclination towards pursuing further studies in pursuit of a deeper knowledge foundation. Research on high-impact practices reveals that participation in high-impact practices, such as internships, capstones, or service learning, makes a positive contribution to students' employability skills (Miller et al., 2018; Park, 2015; Silva et al., 2018) and has a positive effect on students' plans to seek employment after graduation (Miller et al., 2018). Similarly, interdisciplinary experience, which has been shown to equip students with employability skills, may also have a positive association with students' intention to seek employment immediately after graduation. We therefore hypothesise that: graduates learning through interdisciplinary training are more likely to seek employment immediately after graduation
Hypothesis 1.

Second, interdisciplinary learning exposes learners to a wide range of disciplines and people from different backgrounds. Acquiring knowledge in a much

wider pool of subjects empowers students to acquire knowledge not only from their primary discipline but also from diverse fields of study. This expands the scope of learners' knowledge, enhancing their versatility when making career choices. Research on diversity suggests that diversity may benefit organisations in improving organisational flexibility (Milem, 2003). Similarly, diversity of disciplinary knowledge may increase learners' flexibility in career choices and the possibility to choose further studies or a job in a field that differs from their college degree. Engaging with people from different backgrounds is associated with greater openness to diversity and challenge (Milem, 2003). Interacting with diverse peers in the learning environment during college shapes the way students think about their competencies in working with different types of people and how to work effectively with others (Milem, 2003; Umbach and Kuh, 2006). Such experience enables learners to have a greater openness to diversity and challenge after college, encouraging learners to experience a wide range of things away from their comfort zone (Milem, 2003; Umbach and Kuh, 2006). Similarly, exposure to diverse peers in the interdisciplinary learning context may make graduates confident in embracing a diverse working field. We therefore hypothesise that: graduates learning through interdisciplinary training are more likely to pursue a further degree/job that is unrelated to their college degree
Hypothesis 2.

Third, human capital theory leads to the expectation that graduates with interdisciplinary experience have a higher probability to find a job immediately after graduation and higher starting salaries than those without interdisciplinary experience. According to human capital theory, there are two types of human capital – generic and specific human capital (Becker, 1962). Generic human capital refers to skills, knowledge, and abilities that are broadly transferable and not specific to a particular job or industry. Specific human capital, on the other hand, refers to skills, knowledge, and experience that are specific to a particular job, industry, or company. A broader interpretation of specific human capital suggests that a particular configuration of general skills also constitutes a form of specific human capital (Lazear, 2009). Organisations place considerable value on specific human capital, often demonstrating willingness to remunerate employees with elevated levels of such expertise (Slaughter et al., 2007). Interdisciplinary learning facilitates the acquisition of knowledge from diverse academic domains, thereby augmenting the likelihood of individuals possessing the specific human capital sought after by organisations. As interdisciplinary experience serves as an indicator of specific human capital, employers may use it as a screening device by looking at new graduates' academic transcripts or degree certificates.

Consequently, employers demonstrate keen interest in recruiting and providing elevated compensation to individuals with a background in interdisciplinary education. We thus hypothesise that: graduates learning through interdisciplinary training are more likely to achieve higher starting salaries and the likelihood of securing a job immediately after graduation

Hypothesis 3.

Fourth, human capital theory also predicts that interdisciplinary learning experience is associated with higher labour market outcomes such as salaries, but the influence may not appear immediately after graduation (Tomaszewski et al., 2021). Existing literature has documented the effects of interdisciplinary learning on mastering a series of skills, such as critical thinking, communication, and integrating knowledge effectively to solve complex problems (Hains-Wesson and Ji, 2020; Ivanitskaya et al., 2002; Lattuca et al., 2004). According to human capital theory, these enhancements in generic human capital are usually compensated in the labour market through higher earnings (Becker, 2009). Yet, human capital is an intangible asset embodied in individuals and unable to observe at first glance. Thus, new graduates' productivity may gain the recognition of employers and be rewarded in salaries gradually after they contribute to a company's productivity. We thus hypothesise that: the predicted benefits of interdisciplinary learning in labour market outcomes will grow over time

Hypothesis 4.

4.2.2 Empirical evidence on interdisciplinary learning and labour market outcomes

The accumulated evidence in interdisciplinary education has shown a positive association between interdisciplinary learning and student skills development while studying (Burkholder et al., 2017; Lattuca et al., 2017; Mansilla et al., 2009). Mansilla et al. (2009), for instance, showed that the mean integration and critical awareness scores for senior students in an interdisciplinary programme were significantly higher than students in traditional disciplinary programmes. Burkholder et al. (2017) investigated the impact of a three-course curriculum that combined environmental science, ethics, and integrative course on students' skills. The pre- and post-comparison suggested that the interdisciplinary curriculum improved students' interdisciplinary thinking, self-confidence, and public speaking skills. Existing studies have also assessed the impact of interdisciplinary learning on student academic performance (Khandakar et al., 2020; Yilmaz et al., 2019). The accumulated evidence indicates that interdisciplinary learning leads to higher average grades. For example, Khandakar et al. (2020) found that students in an interdisciplinary two-course project had higher average grades than students in an independent course. Similarly, Yilmaz et al. (2019) showed that the third- and fifth-year grades were significantly higher in an interdisciplinary course than in a single-discipline-based course.

While there is some evidence assessing the impact of interdisciplinary learning on student skills development and academic performance, little is known about the effects of interdisciplinary learning on post-graduation plan choices and labour market outcomes. Previous research on graduates' labour market outcomes has particularly focused on the effect of high-impact practices, such as internships, learning communities, study abroad, and research with faculty on labour market outcomes. It has been demonstrated that high-impact practice participation enhances employability and leads to higher wages and reduced job search time (Miller et al., 2018; Park, 2015; Silva et al., 2018). These high-impact practice experiences provide students with an opportunity to apply theoretical knowledge in a real-world setting, develop skills to approach complex circumstances, and build a professional network of contacts (Miller et al., 2018). This accumulation of these skills, knowledge, and connections aligns with the concept of general human capital, which refers to skills, knowledge, and competencies that possess broad applicability, transcending the confines of any particular occupation or industry (Becker, 1962). Learning interdisciplinarily is argued to gain similar benefits in general human capital as participating in high-impact practices but seems to take less extra time. Students can gain interdisciplinary experience by being enrolled in a specialised interdisciplinary degree programme or taking module credits outside their own traditional degree programmes.

Beyond the acquisition of general human capital, learning interdisciplinarily holds the potential to foster the accumulation of specific human capital. Drawing from human capital theory, the concept of human capital encompasses two distinct categories: generic and specific human capital (Becker, 1962). Specific human capital entails proficiency, insights, and practical familiarity tailored to particular job roles, industries, or enterprises. A more encompassing interpretation of specific human capital extends to the notion that a unique amalgamation of general skills constitutes a form of specific human capital (Lazear, 2009). By enabling the integration of knowledge from diverse academic domains, interdisciplinary learning enhances the likelihood of individuals acquiring the specific human capital that organisations actively seek. Employers exhibit a notable inclination towards recruiting individuals possessing specific human capital tailored to their respective companies. Consequently, they often display a greater willingness to offer remuneration for these specialised skills (Slaughter et al., 2007). The exploration of these relationships serves not only to enrich our understanding of the value of interdisciplinary learning but also to inform educational institutions, policymakers, and students about the potential advantages and strategies for career success in an evolving job market.

Little is also known as to whether the effect of interdisciplinary learning on labour market outcomes varies across academic disciplines. In Chapter 2, this thesis found that the association between interdisciplinary degree programmes and student educational outcomes while at university varied across academic disciplines. For example, specialised interdisciplinary graduates from the Humanities and Social Sciences displayed higher chances of having profound discipline-specific knowledge than traditional disciplinary graduates from the same school. By contrast, there was no statistically significant difference in the effect of interdisciplinary learning on profound discipline-specific knowledge between specialised interdisciplinary and traditional disciplinary graduates for other study fields such as science. In relation to labour market outcomes, what has been established is academic discipline is a determinant impact on earnings and has interactive effects with student background (Arcidiacono et al., 2012; Park, 2015; Rumberger and Thomas, 1993). Park (2015) found interactive effects between socioeconomic status and academic disciplines on graduates' income. The income disparity between graduates from middle-income families and low-income families from liberal arts backgrounds was more severe in comparison with graduates in science background programmes. There is still uncertainty, however, whether a particular discipline benefits more significantly in labour market outcomes than others from interdisciplinary learning.

Moreover, the evidence discussed above on the positive relationship between interdisciplinary education and skill development is limited to short-term interdisciplinary projects (Burkholder et al., 2017; Khandakar et al., 2020) or specialised interdisciplinary degree programmes (Lattuca et al., 2017; Mansilla et al., 2009). The impact of interdisciplinary learning on graduates from traditional disciplinary degree programmes is limited. For example, Lattuca et al. (2017) used data from various interdisciplinary and traditional disciplinary degree programmes from 17 institutions. They treated students in traditional disciplinary degree programmes as non-interdisciplinary learners and thus compared the learning outcomes of students majoring in interdisciplinary degree programmes and those of students in traditional disciplinary degree programmes. The recent trend in interdisciplinarity also makes module choices flexible gradually in traditional disciplinary degree programmes. Traditional disciplinary students can be exposed to interdisciplinary learning by registering for modules offered outside their disciplines.

Collectively, existing research recognises the critical role played by interdisciplinary learning in academic performance and skills while studying. Yet, there has been no quantitative analysis of interdisciplinary learning in post-graduation plan choices and labour market outcomes. This paper seeks to examine the effect of interdisciplinary learning on post-graduation plan choices and labour market outcomes. We consider graduates from both traditional disciplinary and specialised interdisciplinary degree programmes, and explore whether the effects of interdisciplinary learning on labour market outcomes vary across study fields and over time.

4.3 Case Study and Data

4.3.1 Case study

The National Tsing Hua University represents our case study. As one of the premier universities in Taiwan, NTHU is ranked 177 in QS World University Rankings 2023, and 34 in Asia University Rankings. It offers a full range of degree programmes in Science, Engineering, Management, Humanities and Social Sciences, with around 8,628 undergraduates and 8,289 postgraduates in 2021. The hierarchical structure of NTHU Bachelor degree programmes and the graduation requirement of credits for each programme in 2017 are shown in Table 4.1.[1] Each undergraduate requires to take a total of 128-132 credits, which is made up of university credits, school credits, programme credits, elective credits and free elective credits. University credits are credits that are required to register for all undergraduates, including Chinese, English, general education, and physical education. The difference in the graduation requirement of credits between programmes appears principally in school credits, programme credits and elective credits. Broadly, these 24 Bachelor degree programmes can be categorised into two types of programmes – 7 specialised interdisciplinary degree programmes and 17 traditional disciplinary degree programmes.

[1] The hierarchical structure has been adjusted since NTHU merged with the National Hsinchu University of Education in 2016. In this study, we target 24 Bachelor degree programmes across 7 schools that are present at NTHU in our whole sample period.

Table 4.1: The structure and requirement of NTHU Bachelor degree programmes.

Seven Schools	Twenty Four Programmes	Total Required Credits	University Credits	School Credits	Programme Credits		Elective Credits	Free Elective Credits
					First Speciality	Second Speciality		
Science (SCI)	Interdisciplinary programme of Sciences (IPSCI)	128	28	18-26	29-36	27-33		12-20
	Department of Chemistry (CHEM)	128	28		67		12	21
	Department of Mathematics (MATH)							
	applied mathematics division	128	28		57			43
	pure mathematics division	128	28		54			46
	Department of Physics (PHYS)							
	physics division	128	28		60		12	28
	astronomical physics division	128	28		68		5	27
	photoelectric division	128	28		71		6	23
Engineering (ENGI)	Interdisciplinary programme of Engineering (IPE)	128	28	26	33-38	26-33		3-15
	Department of Chemical Engineering (CHE)	128	28		88			12
	Department of Industrial Engineering and Engineering Management (IEEM)	130	28		72		21	9
	Department of Materials Science and Engineering (MS)	130	28		84		9	9
	Department of Power Mechanical Engineering (PME)	129	28		67		15	19
Humanities and Social Sciences (HSS)	Interdisciplinary programme of Humanities and Social Sciences (IPHSS)	128	28	30	30	18		22
	Department of Chinese Literature (CL)	128	32		54		24	18
	Department of Foreign Languages and Literature (FL)	128	28		67		12	21
Life Science (LS)	Interdisciplinary programme of Life Science (LSIP)	128	28	27	28	27-33		11-17
	Department of Life Science (DLS)	128	28		68		12	20
	Department of Medical Science (DMS)	128	28		68		12	20
Nuclear Science (NS)	Interdisciplinary programme of Nuclear Science (IPNS)	128	28	31	36-37	26-33		0-7
	Department of Engineering and System Science (ESS)	128	28		58-60		30	10-12
	Department of Biomedical Engineering and Environmental Science (BMES)	128	28		58		30	12
Technology Management (CTM)	Interdisciplinary programme of Management and Technology (IPMT)	132	28	38	27-33	27-33		0-12
	Department of Quantitative Finance (QF)	128	28	24	59			17
	Department of Economics (ECON)	130	28	24	24		30	24
Electrical Engineering and Computer Science (EECS)	Interdisciplinary programme of Electrical Engineering and Computer Science (IPEECS)	128			38	30	18	14
	Department of Computer Science (CS)	128	28		52		36	12
	Department of Electrical Engineering (EE)	128	28		53		33	14

Notes: At NTHU, "college" is the term used to refer to what would be a "school" in countries like the Australia, Canada and UK". The formal name of "Interdisciplinary programme of Management and Technology" is "Department of Double Specialty programme of Management and Technology". The requirement of credits for each programme is the regulation in the academic year 2017.

The first group comprises 7 specialised interdisciplinary degree programmes that were established between 2006 and 2009 to facilitate interdisciplinary education. In 2006, the first two interdisciplinary degree programmes were established in the School of Science and the School of Technology Management. Within four years, the seven schools of NTHU established school-level interdisciplinary degree programmes. The key feature of interdisciplinary degree programmes is that original programme credits are divided into two specialities and school credits are added to the graduation requirement of credits (as shown in Table 4.1). Students enrolled in interdisciplinary degree programmes need to take a general knowledge of their registered school during the first two years. After, students can choose one speciality in their school and choose a second speciality at any other school.

The second group consists of 17 traditional disciplinary programmes. Traditionally, the educational goal of HEIs in Taiwan is to help students acquire a single, professional disciplinary knowledge. Students enrolled in a disciplinary programme are required to register for most of the module credits within their programmes. Because of the advocacy of interdisciplinary learning in recent years, NTHU provides students in traditional disciplinary programmes with an opportunity to learn interdisciplinarily by allowing them to register for module credits from different schools-fields. Free elective credits allow students to choose modules that suit their own interests, rather than those required by their main disciplinary programme.

The application methods for high-school students to enrol in a specialised interdisciplinary degree programme or a traditional disciplinary programme are the same. High-school students can apply to university degree programmes through two main routes – (1) application and recommendation or (2) examination and placement. Under the examination and placement route, high-school students are required to take the Advanced Subjects Test (AST). After obtaining their test results, students reference the average exam scores accepted by universities in the previous year and submit a list of preferred university programmes, with a maximum of 100 selections, ranked by preference. Subsequently, the College Entrance Examination Center allocates students to specific university programmes based on their AST scores and preference list. This process underscores that students are not able to secure enrolment in specific programmes based solely on their preferences.

The theoretical maximum extent of interdisciplinary exposure for interdisciplinary degree students (representing as First Speciality and Second Speciality in Table 4.1) may arguably be well-defined and more than those for traditional disciplinary students (representing as Free Selective Credits in Table 4.1). Comparing the effect of interdisciplinary learning of graduates from traditional disciplinary and specialised interdisciplinary programmes therefore may be inappropriate. As such, we conduct analyses on graduates from traditional disciplinary programmes and graduates from specialised interdisciplinary degree programmes separately. To examine the effect on labour market outcomes, we include an interaction term identifying the type of graduate programme and the extent of interdisciplinary learning (which is defined as the proportion of credits that were offered by other schools or by a different field). This helps distinguish graduates from the two types of programmes. The detailed methodology is described in Section 4.4.

4.3.2 Data sources

We used data from three sources: (1) NTHU administrative data, (2) NTHU Graduation Survey (GS) data, and (3) career-tracking data integrated by the Taiwanese Ministry of Education. Administrative data from different sections across NTHU provides information on students' backgrounds including programme of study, school, gender, and admission methods, and module profiles, such as module departments, credits, and module GPA. The Center for Institutional Research of NTHU distributes a Graduation Survey to collect information about students' learning experiences during their studies. This survey has been running annually since 2012 and collects data on students' individual and family background information and graduation plans. The response rate is high providing a return rate of, for example, 98.2% in 2015.

The MoE integrates career-tracking data for policy purposes, in particular enhancing the quality of career guidance, reducing job-educational mismatch, and improving the efficiency of educational resource allocation. MoE collaborates with the Ministry of Labor to construct the national graduates' career-tracking system. Graduates' background information is combined with salary data from the Ministry of Finance, travel records from the Ministry of the Interior, military insurance data from the Ministry of National Defense, as well as other relevant employment insurance records. This career-tracking data collects post-graduation records, such as monthly salary, employment status and further education of all graduates in Taiwan since 2010 and tracks them annually up to five years after graduation. However, Taiwanese privacy and personal data protection laws prevented us from obtaining individual records for our analysis. We only had access to programme-level career-tracking data. While this constrains our analysis to examine programme-level aggregate labour market outcomes, such analysis still provides a valuable insight into the relationship between interdisciplinary learning and labour market outcomes.

To analyse the influence of interdisciplinary learning on post-graduation plan choices, we used individual-level data. We linked the university administrative data and GS data to construct an individual-level data set, comprising a total of 7,712 individuals who graduated between 2012 and 2017. We excluded 549 students who have changed their programmes because affiliating to two different programmes makes the identification of module credits taken in other schools difficult and affects our measurement of interdisciplinary learning. We further removed 1,241 observations with missing values, resulting in a final dataset of 5,922 observations, with 14.51% of graduates enrolled in specialised interdisciplinary degree programmes.

To examine the influence of interdisciplinary learning on postgraduate labour market outcomes, we used programme-level data. Given the lack of individual information on labour markets, we transformed our individual-level data set into a programme level and assembled it with the programme-level career-tracking data to capture labour market outcomes. This programme-level data set comprises a total of 720 programme records from 2012 to 2017, including 24 programmes, six cohorts, and one to five years after graduation.

4.3.3 Variables description

4.3.3.1 Outcome variables

To assess the influence of interdisciplinary learning on post-graduation plan choices, we considered four outcomes: (1) planning to continue studies, (2) planning to enter the workforce, (3) the degree of alignment between a graduate's Bachelor degree field and planned future field of study, and (4) the degree of alignment between a graduate's Bachelor degree field and planned future field of job. Data were obtained from the GS. Table 4.2 lists and describes the data to measure these outcomes. A question "career plans after graduation" was used to capture the first two outcomes: planning to continue studies and planning to enter the workforce. Out of 5,922 graduates, 65.35% of respondents indicated that they plan on continuing studies, 16.06% on military service, 11.75% on employment, 3.44% on test preparation, 2.48% not plan yet, and 0.91% others. Given this distribution of responses, the largest shares were the "continuing studies", "military service", and "employment" categories. "Military service" in Taiwan is mandatory and would not be used for analysis. We therefore only used "continuing studies" and "employment" categories in subsequent analyses. Two separate binary variables were created: planning to continue studies or not; and planning to enter the workforce or not after graduation. We also consider the degree of alignment between a graduate's college degree and future fields of study/job. We used information from the following questions: "The academic field you chose for your post-graduate study is closely associated with your college degree at NTHU" and "Your expected job duties are closely related to what you have learned in school". We built two separately categorical variables with three categories (disagree, neutral and agree) to capture the degree of alignment between a graduate's Bachelor degree field and planned future field of study/job.

To assess programme-level labour market outcomes, we used career-tracking data. In particular we used information on: (1) the average monthly nominal salary and (2) the employment rate. In the career tracking data, graduate destinations are categorised into four groups: (1) individuals who have left Taiwan for at least three months, (2) those fulfilling their military service, (3) those pursuing further studies, and (4) the work-eligible population. The average monthly nominal salary specifically refers to the average salary of graduates who belong to the work-eligible population, are enrolled in Employment Insurance, and have an insured salary that meets or exceeds the minimum wage threshold. In our analysis, the average monthly nominal salary was transformed into the real value to adjust for inflation. This was achieved by dividing the nominal salary by the Consumer Price Index (CPI) and multiplying it by 100.[2] The employment rate is the percentage of employed graduates in relation to the total graduates in each programme. Because of the lack of individual information on labour markets, individual-level data were aggregated into programme-level data. A description of programme-level labour market outcomes is provided in Table 4.3.

Table 4.2: Description of individual post-graduation plan choices.

Variables	Description of Variables			
		No	Yes	
continue studies	1 for pursuing advanced study after graduation	34.65%	65.35%	
enter the workforce	1 for entering the workforce or job search after graduation	88.25%	11.75%	
		Disagree	Neutral	Agree
similar-field study	the degree of alignment between a graduate's Bachelor degree field and planned future field of study	14.70%	3.39%	81.91%
similar-field job	the degree of alignment between a graduate's Bachelor degree field and planned future field of job	15.60%	5.10%	79.30%

4.3.3.2 Defining interdisciplinary learning

The term "Interdisciplinary Learning" in this context is used literally to mean the process of learning knowledge and skills from different disciplines (Karlqvist, 1999). In this scenario, the essence of "Interdisciplinary Learning" manifests through the acquisition of knowledge and skills spanning multiple disciplines. We used two metrics to quantify the extent of interdisciplinary learning – a school-level and a discipline-field-level metric developed in Chapter 3. The first captures

[2]The reference base period, in which the CPI is defined as 100, is the year 2016. The CPI data used in this calculation were obtained from the Taiwanese National Statistics. Available from: https://eng.stat.gov.tw/.

Table 4.3: Description of programme-level labour market outcomes

		years after graduation				
	Mean	1	2	3	4	5
real salary	41,142	31,342	37,251	42,084	48,116	51,999
	(11025)	(6135)	(7262)	(7698)	(10705)	(11897)
employment rate	0.644	0.480	0.576	0.729	0.790	0.782
	(0.236)	(0.259)	(0.120)	(0.179)	(0.151)	(0.162)

Notes: The currency used for real salary is New Taiwan Dollars. The exchange rate applied is 1 Great British Pound to 36.770 New Taiwan Dollars, based on the average exchange rate in 2022. Standard deviations are in parentheses.

the share of module credits taken outside a student's school of enrolment. The second refers to the share of module credits taken in a disciplinary field that differs from the field of a student's school of enrolment. Equations 4.1 and 4.2 represent the mathematical form of these measures. To more easily understand these Equations, Figure 4.1 displays the generic structure of a student's module profile. Broadly, total credits registered by a student can be divided into three categories with module credits offered by: (1) their own programme, (2) other programmes in their own school, and (3) other schools. The latter can be further divided into three subgroups with module credits: (1) within the same disciplinary field, (2) from a similar field, and (3) from a different field.

$$\textit{school-level interdisciplinarity}_i = \frac{\textit{sum (credits student i took from other schools)}}{\textit{total credits student i took}} \tag{4.1}$$

$$\textit{field-level interdisciplinarity}_i = \frac{\textit{sum (credits student i took from different field)}}{\textit{total credits student i took}} \tag{4.2}$$

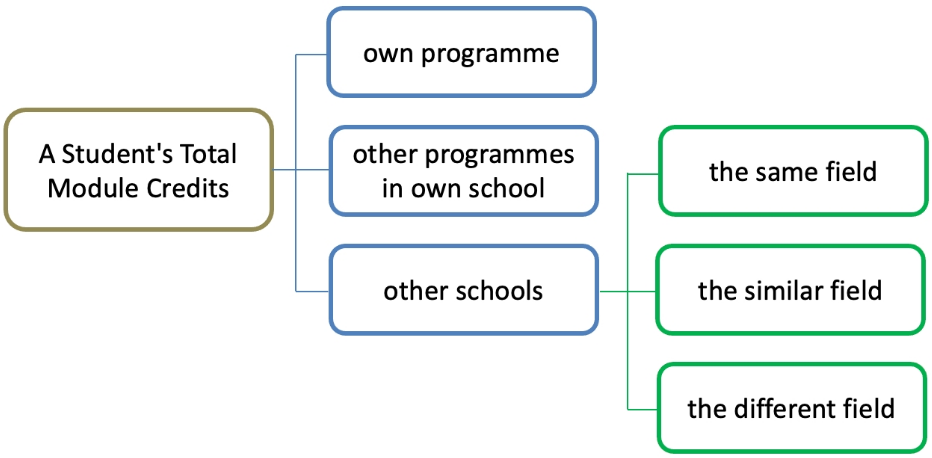

Figure 4.1: The structure of a student module credits.

We categorised module credits offered by other schools into three subgroups in two steps. First, we classified the seven schools at NTHU into three disciplinary fields: humanity, society, and technology according to the Taiwanese Ministry of Education's disciplinary classification. The school of Humanities and Social Sciences (HSS) belongs to the humanity field, School of Technology Management (CTM) belongs to the society field, and other five schools, including Science (SCI), Life Science (LS), Nuclear Science (NS), Electrical Engineering and Computer Science (EECS) and Engineering (ENGI), belong to the technology field. Next, we compared the similarity between the three fields based on Biglan's taxonomy of academic disciplines (Biglan, 1973; Kolb, 1981). According to Biglan's taxonomy of academic disciplines, humanity (consisting of Chinese Literature and Foreign Languages at NTHU) and society fields (consisting of Economics and Finance) are more similar to each other than any of these fields with technology fields (consisting of Science and Engineering). On the other hand, technology fields are more similar to society fields than to humanity fields. Therefore, if a humanity-field student took module credits offered in a technology field, the module credits would be classified as module credits offered by a different field. The extent of interdisciplinary learning can thus be captured by the share of module credits registered and completed at different schools or disciplinary fields over the duration of an undergraduate programme.

4.3.3.3 Control variables

To isolate the relationship between interdisciplinary learning and post-graduate plan choices and labour market outcomes, we controlled for individual and household attributes which are known to influence these choices and outcomes (Miller et al., 2018; Oswald-Egg and Renold, 2021; Tomaszewski et al., 2021). Gender, admission methods, experiences in overseas volunteer and exchanging, cohorts, schools, parents' occupations, family income status, and living areas were included as dummy variables to account for variations in students' plan choices and labour market outcomes. Continuous variables were included to capture post-graduation plan choices and labour market outcomes differentials according to motivation to undertake university study, university entrance grades, hours of participating in clubs and part-time jobs per week, average GPA, and parents' years of education. We also included academic rank in high school in the form of an ordinal variable to control variations in post-graduation outcomes attributing to intelligence.

For the analysis of labour market outcomes, in addition to individual and household attributes, we also considered two macroeconomic factors – GDP deflators and unemployment rates – to capture potential employment differentials

Table 4.4: Description of independent variables.

Variables	Description of Variables	Mean	Std. Dev.
Main Independent Variables			
school-level interdisciplinarity	the proportion of credits offered by different schools	0.263	0.122
field-level interdisciplinarity	the proportion of credits offered by different fields	0.135	0.064
Other Control Variables			
Student-related variables			
male	1 for male and 0 for female	0.664	0.472
high-school rank	rank in high school, 1 is bottom 20%, 5 is top 20%	2.003	1.226
motivation to undertake university study			
external	the external motivation such as employment requirement	-0.011	0.903
internal	the internal motivation such as self-exploration	0.003	0.839
admission methods			
exam	1 for Examination and Placement	0.526	0.499
application	1 for Recommendation and Screening or Star programme	0.469	0.499
others	1 for other programmes	0.005	0.071
entrance scores	the total score in General Scholastic Ability Test	66.123	4.194
club hours	hours of participating in student clubs per week	4.190	3.385
part-time hours	hours of participating in part-time job per week	2.913	3.296
volunteer overseas	1 for having worked as a volunteer overseas	0.080	0.271
exchange student	1 for being an exchange student in a foreign university	0.110	0.313
final GPA	average GPA in university	79.959	6.484
Cohorts			
cohort2012	graduated in 2012	0.161	0.367
cohort2013	graduated in 2013	0.163	0.370
cohort2014	graduated in 2014	0.179	0.384
cohort2015	graduated in 2015	0.190	0.392
cohort2016	graduated in 2016	0.192	0.394
cohort2017	graduated in 2017	0.115	0.319
Schools			
Humanities & Social Sciences	1 for the Humanities and Social Sciences	0.095	0.293
Technology Management	1 for the Technology Management	0.143	0.350
Electrical Engineering & Computer Science	1 for the Electrical Engineering and Computer Science	0.191	0.393
Engineering	1 for the Engineering	0.245	0.430
Nuclear Science	1 for the Nuclear Science	0.119	0.324
Life Science	1 for the Life Science	0.061	0.239
Science	1 for the Science	0.146	0.353
Household characteristic variables			
father's occupation			
white-collar	1 for a white-collar worker	0.769	0.421
blue-collar	1 for a blue-collar worker	0.154	0.361
other-collar	1 for a other-collar worker	0.077	0.266
mother's occupation			
white-collar	1 for a white-collar worker	0.633	0.482
blue-collar	1 for a blue-collar worker	0.049	0.215
other-collar	1 for a other-collar worker	0.318	0.466
father's yos	father's years of education	15.057	3.431
mother's yos	mother's years of education	14.216	3.024
lowincome family	1 for belonging to low-income households as defined in Article 4 of the Taiwanese Public Assistance Act[a]	0.021	0.143
municipality	1 for living in six special municipalities (Taipei, New Taipei, Taoyuan, Taichung, Tainan, and Kaohsiung)[b]	0.759	0.428
Macroeconomic variables			
unemployment rate	the unemployment rate in Taiwan in 2012 to 2017	4.193	0.151
GDP deflator	the GDP deflator in Taiwan in 2012 to 2017	98.285	1.856

[a] According to Article 4 of the Taiwanese Public Assistance Act, the low-income households described in this Act shall qualify under the following conditions: they are approved by their local municipality competent authority via application; their average divided monthly income among each person in the household falls below the lowest living index; and their total household assets do not exceed the specific amount announced by the central and municipality competent authorities in the year of application.

[b] According to Article 4 of the Taiwanese Local Government Act, regions with population of not less than one million and two hundred fifty thousand and have special requirements in their political, economic, cultural, and metropolitan developments may establish special municipalities.

during business cycles. Prior research has noted that labour market outcomes post-graduation tend to be systematically worse during periods of economic slowdowns with long-lasting effects on graduates' outcomes (Andrews et al., 2020; McQuaid, 2017; Oreopoulos et al., 2012). Table 4.4 describes the variables used in our analysis and provides their summary statistics across our sample.

4.4 Methodology

Two different types of models were employed. We first used a series of logistic regression models to assess the relationship between interdisciplinary learning and individual post-graduation plan choices. Then, we used multilevel modelling to examine the effect of interdisciplinary learning on programme-level labour market outcomes and capture variability in these outcomes across programmes and over time.

4.4.1 Post-graduation plan choice modelling

We adopted two types of logistic regression models to analyse the influence of interdisciplinary learning on individual post-graduation plan choices. Binary logistic regression models (as shown in Equation 4.3) were used to analyse two dichotomous choices; that is, (1) the plan to continue studies, and (2) the plan to enter the workforce after graduation. Ordered logistic regression models (as shown in Equation 4.4) were used to examine ordinal outcomes; that is, (1) the degree of alignment between a graduate's Bachelor degree field and planned future field of study, and (2) a graduate's Bachelor degree field and planned future field of job.

We accounted for potential correlated plan choices from students within the same school. Students from the same schools may be more likely to make similar choices. To account for this potential effect, we added school dummy variables to control for school-level fixed effects and also clustered standard errors by schools to allow for systematic heteroskedasticity across clusters of observations.

Formally, for binary outcomes – the plan to continue studies and to enter the workforce after graduation, the binary logistic regression model is as follows:

$$\begin{aligned} y_{1i}^* &= \alpha + \gamma Index_i + \sum_s \delta_s \cdot school_{si} + x_i'\beta + \varepsilon_i, \\ y_{1i} &= 1 \text{ if } y_{1i}^* > 0; \end{aligned} \tag{4.3}$$

where y_{1i} represents one of our two binary post-graduation plans for student i, i.e., continuing studies or entering the workforce. $Index_i$ is one of the indices measuring interdisciplinary learning, i.e., *school-level interdisciplinarity* or *field-level interdisciplinarity.* $school_{si}$ is a school-dummy variable indicating student i belonging to school s; x_i' is a vector of control variables including the variables listed in Table 4.4; α, γ, δ, and β represent parameters to be estimated. γ is the parameter of interest, which measures the effects of interdisciplinary learning. ε_i is the error term. The distribution of ε_i was assumed to follow a logistic distribution. Separate models were estimated for each of our two binary outcome variables.

For ordinal outcomes – the degree of alignment between a graduate's Bachelor degree field and planned future field of study, and planned future field of job, we used ordered logistic regression models:

$$\begin{aligned} y_{2i}^* &= \alpha + \gamma Index_i + \sum_s \delta_s \cdot school_{si} + x_i'\beta + \varepsilon_i, \\ y_{2i} &= m \text{ if } \tau_{m-1} < y_{2i}^* < \tau_m \text{ for m=1 to 3,} \end{aligned} \tag{4.4}$$

where y_{2i} represents one of two ordinal outcomes. m is the ordinal scale representing disagree, neutral and agree.

The sample was split into two sub-groups, graduates from traditional disciplinary degree programmes and graduates from specialised interdisciplinary degree programmes, because of the difference in programme design. As shown in Table 4.1, the structure of required credits varies across the two types of programmes. Besides, the potential variance in content between traditional disciplinary and specialised interdisciplinary programmes may potentially introduce disparate effects of other independent variables on students' outcomes across these distinct programme categories. Embracing the sample split approach facilitates the introduction of coefficients that can vary across groups while maintaining a coherent analytical framework. Therefore, we performed separate regression models for the two sub-groups to investigate the impact of interdisciplinary learning on individual post-graduation plans.[3]

[3] We have undertaken a Chow test to examine whether the two programmes had significantly different regression coefficients of each independent variable. Our findings reveal significant disparities in the relationships between outcomes and variables such as cohorts, schools, gender,

4.4.2 Labour market outcome modelling

To estimate the impact of interdisciplinary learning on programme-level labour market outcomes and capture potential time-variant and programme-variant effects, cross-classified multilevel models were employed. We used random intercepts and slopes to capture variations in labour market outcomes across programmes and over the span of years subsequent to graduation. Particular disciplines are believed to benefit more significantly than others from interdisciplinary learning. The benefits of interdisciplinary learning are also expected to change over time; though the shape of these effects is unclear — whether they stabilise after an initial positive impact or accumulate over time. Figure 4.2 offers a visual representation of the cross-classified structure of our programme-level data. In our cross-classified multilevel structure, level 1 refers to programme-cohort observations. Level 2 comprises programme-level observations and years after graduation. We used varying intercepts to capture variations across programmes and the span of years subsequent to graduation, and varying slopes to capture the variability in the effect of interdisciplinary learning on labour market outcomes.

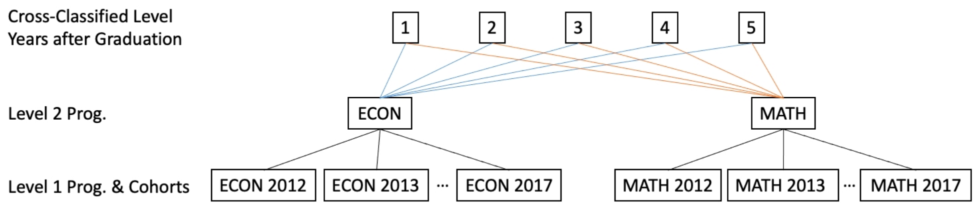

Figure 4.2: Cross-classified multilevel structure of the data.

The estimated cross-classified multilevel model can be represented as follows:

$$\begin{aligned} Y_{ij} = \alpha + \beta_1 interdis\_prog_i + \beta_2 avg\_Index_i + \beta_3 interdis\_prog_i \times avg\_Index_i + x_i'\gamma \\ + u_{0ij} + u_{0prog(ij)} + u_{1prog(ij)} avg\_Index_i + u_{0t(ij)} + u_{1t(ij)} avg\_Index_i + \varepsilon_{ij}, \end{aligned} \tag{4.5}$$

where Y_{ij} is the continuous labour market outcome of programme i in cohort j: (1) the log of average monthly real salary or (2) the employment rate. The fixed part of Equation 4.5 is $\alpha + \beta_1 interdis\_prog_i + \beta_2 avg\_Index_i + \beta_3 interdis\_prog_i * avg\_Index_i + x_i'\gamma$ with fixed part parameters α, β_1, β_2, β_3, and γ. $interdis\_prog_i$ is a binary variable, with 1 for a specialised interdisciplinary degree programme and 0 for a traditional disciplinary degree programme. avg_Index_i is one of the programme-average indices of interdisciplinary learning: *school-level interdisciplinarity* or *field-level interdisciplinarity*. The interaction term $interdis\_prog_i * avg\_Index_i$ is added to control potential variations from the difference in programme de-

and family background, discernible across these two programme categories. The test results support our initial conjectures, providing evidence in favour of the sample split approach.

sign between specialised interdisciplinary and traditional disciplinary degree programmes. x_i' is a vector of control variables including student-related variables, cohorts, household characteristics, and macroeconomic variables (Table 4.4), but all are transformed into programme average. β_2 and β_3 are the fixed part parameters of interest, which measure the effects of interdisciplinary learning and the difference of these effects across specialised interdisciplinary and traditional disciplinary degree programmes. ε_{ij} is the random error term.

The random part of Equation 4.5 is $u_{0ij} + u_{0prog(ij)} + u_{1prog(ij)} avg\_Index_i + u_{0t(ij)} + u_{1t(ij)} avg\_Index_i$. u_{0ij}, $u_{0prog(ij)}$ and $u_{0t(ij)}$ represent a programme-cohort-, programme- and years-after-graduation-level random components which allow the intercept to vary randomly across the programme-cohort, programme, and years after graduation. $u_{1prog(ij)}$ and $u_{1t(ij)}$ are random slope terms that are used to allow the effects of interdisciplinary learning to vary randomly across programmes and years after graduation.

4.5 Results

4.5.1 Differences in post-graduation study choices and labour market outcomes

Figure 4.3 shows the share of graduates planning to continue further studies, transition into the workforce, and study or work in a field aligned with their field of studies post-graduation by type of study programmes. Figure 4.4 shows the average salary and employment rate. As shown in Figure 4.3, overall, most graduates seek to pursue further education after graduation and plan to study or work in a field that is aligned with their Bachelor degree. On average only around 15% of graduates intend to enter the workforce and less than 20% of graduates plan to study or work in a field that differs from their Bachelor degree.

In terms of labour market outcomes, Figure 4.4 reveals a general pattern of steady rise over time. Specifically, it displays a consistent increase in the log of average monthly real salary and employment rate in the five years following graduation. Though increases tend to be larger in the first few years, particularly for employment.

Small differences exist between graduates from traditional disciplinary and specialised interdisciplinary degree programmes. Figure 4.3 reveals that graduates from specialised interdisciplinary degree programmes are less likely to continue to engage in further studies and more likely to transition into the workforce after graduation, compared to graduates from traditional disciplinary programmes. Figure 4.4 indicates that salary tends to be slightly higher for tra-

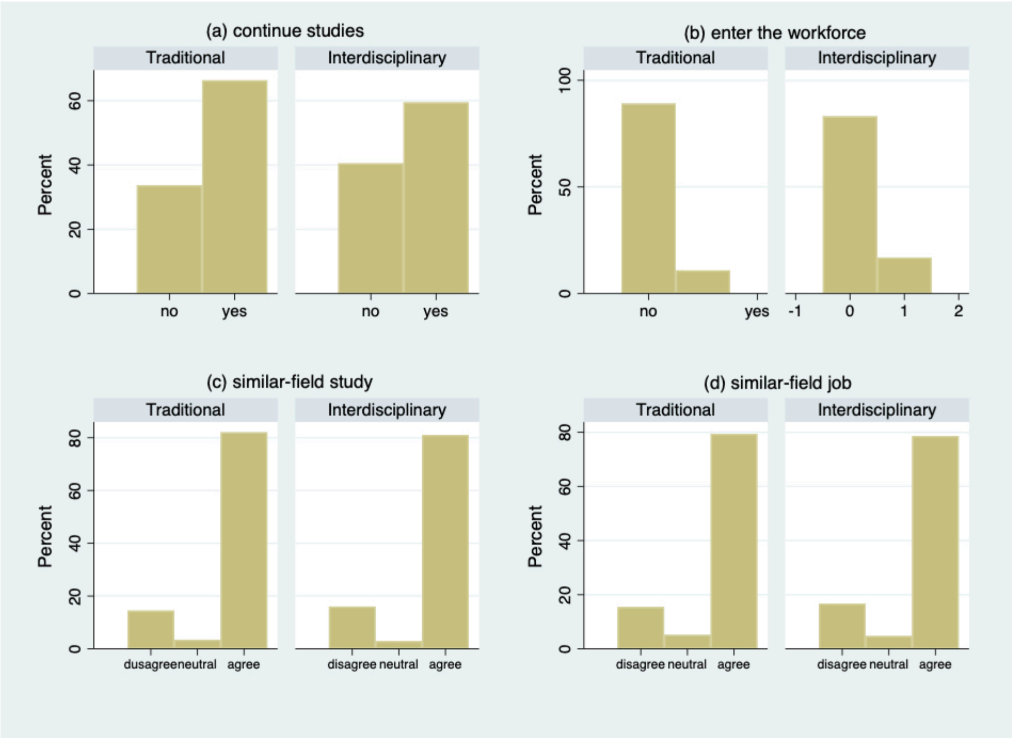

Figure 4.3: The share of individual post-graduation study plan choices by types of programmes.

Figure 4.4: The average programme-level labour market outcomes by types of programmes and years after graduation.

ditional disciplinary graduates than for those from specialised interdisciplinary degree programmes, but these differences are statistically insignificant.

4.5.2 No systematic difference in individual attributes between traditional disciplinary and specialised interdisciplinary graduates

We investigate the issue of self-selection into interdisciplinary degree programmes. Table 4.5 presents mean differences of students' attributes that may affect graduates' choices of enrolling in a traditional disciplinary degree programme or a specialised interdisciplinary degree programme. The reported scores are calculated by taking the mean difference between traditional disciplinary graduates and specialised interdisciplinary graduates. The first column displays the mean difference between traditional disciplinary and specialised interdisciplinary graduates in the total sample. The other seven columns show the mean difference from each graduating school.

Table 4.5 column (1) reveals that, overall, most individual attributes do not show significant differences between traditional disciplinary and specialised interdisciplinary graduates. Regarding the variation across seven schools (see column (2) – column (8)), there are no systematic patterns in individual attributes between traditional disciplinary and specialised interdisciplinary graduates across schools. For example, in terms of gender, the HSS traditional disciplinary programmes had 17% fewer male graduates than the HSS specialised interdisciplinary programme. On the contrary, 9% more male graduates are observed for the ENGI traditional disciplinary programmes than in the ENGI specialised interdisciplinary programme. The descriptive evidence reveals that there is no apparent combination of individual traits that may affect students' choices between traditional disciplinary and specialised interdisciplinary programmes.

4.5.3 Varying effects of interdisciplinary learning on post-graduation plan choices

Table 4.6 presents the results of our binary and ordered logistic regression analysis modelling the plan of graduates' post-graduation choices. Specifically, it reports the marginal effect between our two measures of interdisciplinary learning (school-level measure and field-level measure) and four post-graduation plan choices holding all other covariates fixed at their sample means. The results of ordered logistic regression analysis in Panel C and Panel D are shown for each of the three categories of our outcome variables (i.e. disagree, neutral and agree).

Table 4.5: Mean differences of individual attributes between traditional disciplinary and specialised interdisciplinary graduates.

	ALL	*Seven Schools*						
		HSS	CTM	EECS	ENGI	LS	NS	SCI
male	0.130***	-0.170***	0.008	0.005	0.090**	-0.012	-0.068	0.017
Admission methods								
application	0.022	0.024	-0.357***	0.119**	-0.001	0.153***	0.086*	-0.060
exam	-0.021	-0.025	0.357***	-0.123***	0.020	-0.153***	-0.086*	0.058
others	-0.001	0.000	0.000	0.005	-0.018**	0.000	0.000	0.002
high-school rank	0.043	-0.068	0.174**	0.137	0.078	0.072	0.117	-0.012
entrance scores	0.626***	-0.392	-1.570***	-1.81***	-0.664*	0.228	-0.542	-1.100***
Father's occupation								
white-collar	-0.006	0.026	-0.022	0.010	-0.089**	-0.019	-0.028	-0.035
blue-collar	-0.003	-0.014	-0.005	0.009	0.049	0.007	0.000	-0.017
other-collar	0.009	-0.012	0.027	-0.019	0.041*	0.011	0.028	0.053**
Mother's occupation								
white-collar	-0.020	0.032	-0.063*	-0.059	0.006	-0.024	-0.070	0.011
blue-collar	-0.008	-0.013	-0.031**	-0.001	-0.021	0.001	0.037	0.012
other-collar	0.028*	-0.020	0.093***	0.060	0.015	0.023	0.034	-0.024
father's yos	0.004	0.021*	0.003	0.006	0.005	0.032*	0.020	-0.017
mother's yos	0.120	0.080	-0.226	-0.064	0.416	-0.256	-0.068	0.352
lowincome family	-0.072	-0.026	-0.429**	-0.178	0.084	0.195	-0.198	0.102
municipality	0.005	-0.027	-0.007	0.017	-0.019	0.070*	-0.034	-0.002

Notes: The corresponding schools are as below: HSS: Humanities and Social Sciences; CTM: Technology Management; EECS: Electrical Engineering and Computer Science; ENGI: Engineering; LS: Life Science; NS: Nuclear Science; SCI: Science. The numerical values are calculated by the variable means of traditional disciplinary graduates minus the variable means of specialised interdisciplinary graduates. * $p < 0.1$, ** $p < 0.05$, *** $p<0.01$.

Separate logistic regression models were estimated for traditional disciplinary graduates and specialised interdisciplinary graduates.[4]

Panel A Table 4.6 shows the estimates for the probability to engage in further studies post-graduation. For graduates from traditional disciplinary programmes, results indicate that getting one more percent credits outside the school of their Bachelor degree reduced the probability of seeking to continue studies by 0.409%. Consistently, Panel B shows that traditional disciplinary graduates were 0.079% more likely to be willing to enter the workforce after graduation given one percent increase in school-level interdisciplinary learning. Together, these results suggest that traditional disciplinary graduates with a higher extent of interdisciplinary learning across schools tend to seek employment immediately after graduation. No significant estimates are observed for our field-level models, indicating graduates taking credits from a different field while studying did not affect their intention to study further or seek employment.

By contrast, for graduates from specialised interdisciplinary programmes, a negative association was estimated between the extent of interdisciplinary learning and the likelihood of planning a transition into the workforce. A one percent increase in the number of credits from other schools and outside their degree field seem to drop the average probability of planned transition into the workforce by 0.148% and 0.123%. Specialised interdisciplinary graduates with a higher extent

[4] The full set of regression estimates are reported in Table C1 in C.1.

Table 4.6: Marginal effects of individual post-graduation plan choices.

Panel A. continue studies	(1) school-level interdisciplinarity	(2) field-level interdisciplinarity
Traditional	-0.409***	-0.486
	(0.077)	(0.297)
Interdisciplinary	0.424	0.699
	(0.344)	(0.495)

Panel B. enter the workforce	(1) school-level interdisciplinarity	(2) field-level interdisciplinarity
Traditional	0.079***	0.102
	(0.029)	(0.078)
Interdisciplinary	-0.148***	-0.123***
	(0.035)	(0.041)

Panel C. similar-field study	(1) school-level interdisciplinarity	(2) field-level interdisciplinarity
Traditional		
(1) disagree	0.548***	0.458***
	(0.038)	(0.073)
(2) neutral	0.136***	0.109***
	(0.010)	(0.019)
(3) agree	-0.684***	-0.567***
	(0.044)	(0.090)
Interdisciplinary		
(1) disagree	0.142**	0.031
	(0.058)	(0.065)
(2) neutral	0.028	0.006
	(0.018)	(0.014)
(3) agree	-0.170**	-0.037
	(0.075)	(0.079)

Panel D. similar-field job	(1) school-level interdisciplinarity	(2) field-level interdisciplinarity
Traditional		
(1) disagree	0.437***	0.425***
	(0.095)	(0.082)
(2) neutral	0.139***	0.133***
	(0.028)	(0.030)
(3) agree	-0.575***	-0.558***
	(0.121)	(0.110)
Interdisciplinary		
(1) disagree	0.155**	-0.079
	(0.068)	(0.048)
(2) neutral	0.044**	-0.022
	(0.018)	(0.014)
(3) agree	-0.200**	0.102
	(0.084)	(0.062)

Notes: This table reports the marginal effects between our two measures of interdisciplinary learning and four post-graduation plan choices holding all other covariates fixed at their sample means. In Row "Traditional", we present the effect of interdisciplinary learning for graduates from traditional disciplinary programs, whereas in Row "Interdisciplinary," we present the results for specialised interdisciplinary graduates. Column (1) and (2) display the effect of interdisciplinary learning, with the school-level index and the field-level index being used to measure the extent of interdisciplinary learning, respectively. To account for variations in students' plan choices related to individual and household attributes, we included a set of control variables such as gender, cohorts, schools, university entrance grades, and family income status. Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p<0.01$.

of interdisciplinary learning had a lower intention to seek employment immediately after graduation, compared to those with a lower extent of interdisciplinary learning.

Panel C and Panel D in Table 4.6 show the estimates for the degree of alignment between graduates' Bachelor degree field, and their planned future field of study and job. The results indicate that graduates with interdisciplinary learning experience had a lower tendency to take up further studies and jobs related to their college degree whether they graduated from traditional disciplinary or specialised interdisciplinary degree programmes. For example, the coefficient on "agree" of "school-level interdisciplinarity" for traditional disciplinary graduates in Panel C and Panel D indicate that, traditional disciplinary graduates with one more percent credits taken from other schools are associated with a decline of 0.684% and 0.575% in the probability of agreeing to pursue studies or a job aligned with their Bachelor degree field. The results were consistent for our two metrics of interdisciplinary learning. Similarly, for graduates from specialised interdisciplinary programmes, increasing one percent of credits outside their schools decreased 0.170% and 0.200% probability of agreeing that they would pursue studies or a job aligned with their Bachelor degree field. However, no significant effects were found under the field-level measure.

4.5.4 Varying effects of interdisciplinary learning on programme-level labour market outcomes

Table 4.7 presents the results of our multilevel models. Results for two outcome models are reported based on (1) our school-level measure and (2) field-level measure of interdisciplinary learning. Table 4.7 provides a summary of the estimated fixed-effect coefficients relating to interdisciplinary learning.[5] The results indicate no statistically significant relationship between interdisciplinary learning and post-graduation programme-average salary and employment rate. Interdisciplinary learning seems to have no effect on post-graduation labour market outcomes. This relationship appears to be consistent for both graduates from traditional disciplinary and specialised interdisciplinary programmes, and our two metrics of interdisciplinary learning.

These fixed-effect estimates however seem to conceal significant differences across programmes and over time. Figure 4.5 and Figure 4.6 depict estimated random slopes capturing variations in the effect of interdisciplinary learning on labour market outcomes across programmes and over time. It is important to bear in mind that a positive random-effect estimate does not necessarily mean

[5]The full set of fixed-effect results are reported in Table C2 in C.1.

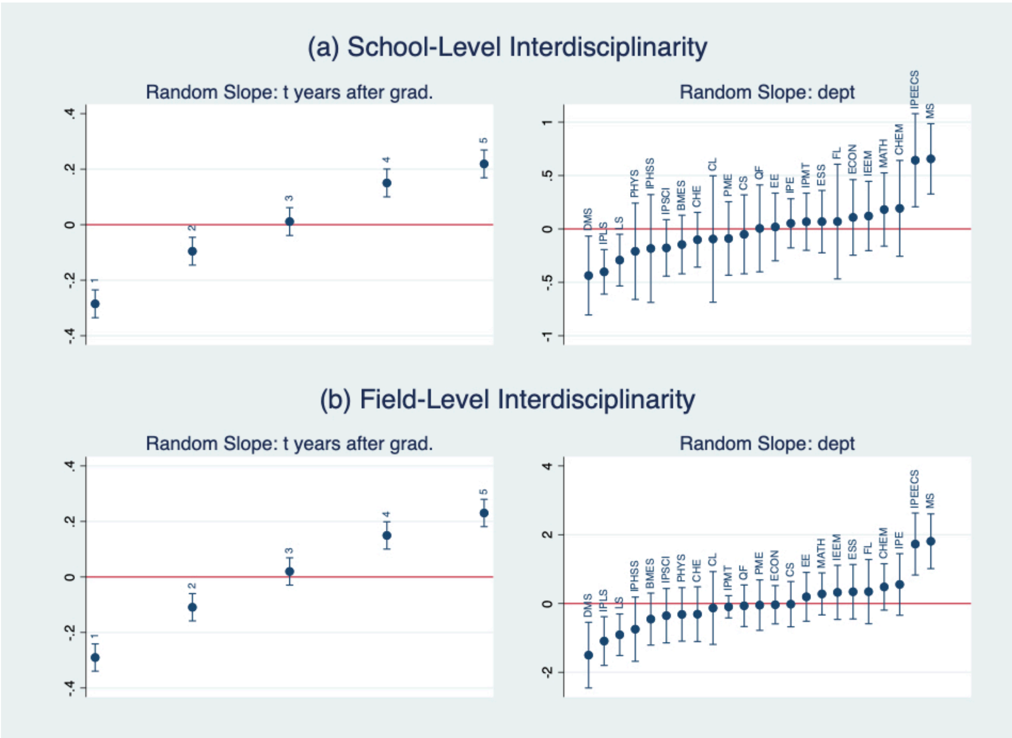

Figure 4.5: Random effects for the log of average monthly real salary. *Notes:* This figure depicts estimated random slopes capturing variations in the effect of interdisciplinary learning on programme-level salary across programmes and over time. Subfigure (a) presents the effects based on utilising the school-level index to measure the extent of interdisciplinary learning, while subfigure (b) displays the results obtained using the field-level index. The level for confidence intervals is 90%. The corresponding programmes are 7 specialised interdisciplinary programmes: Interdisciplinary Programme of Sciences (IPSCI), Engineering (IPE), Humanities and Social Sciences (IPHSS), Nuclear Science (IPNS), Life Science (IPLS), Electrical Engineering and Computer Science (IPEECS), Management and Technology (IPMT) and 17 traditional disciplinary programmes: Chemistry (CHEM), Mathematics (MATH), Physics (PHYS), Chemical Engineering (CHE), Industrial Engineering and Engineering Management (IEEM), Materials Science and Engineering (MS), Power Mechanical Engineering (PME), Chinese Literature (CL), Foreign Languages and Literature (FL), Life Science (LS), Medical Science (DMS), Engineering and System Science (ESS), Biomedical Engineering and Environmental Science (BMES), Quantitative Finance (QF), Economics (ECON), Computer Science (CS), Electrical Engineering (EE).

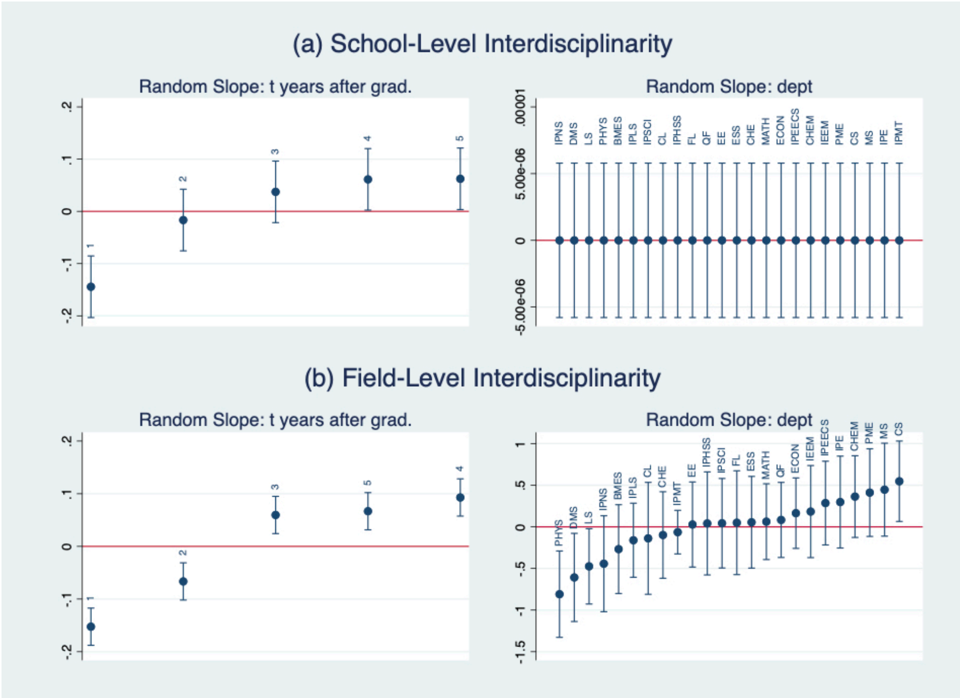

Figure 4.6: Random effects for the employment rate. *Notes:* This figure depicts estimated random slopes capturing variations in the effect of interdisciplinary learning on the employment rate across programmes and over time. Subfigure (a) presents the effects based on utilising the school-level index to measure the extent of interdisciplinary learning, while subfigure (b) displays the results obtained using the field-level index. The level for confidence intervals is 90%. The corresponding programmes are 7 specialised interdisciplinary programmes: Interdisciplinary Programme of Sciences (IPSCI), Engineering (IPE), Humanities and Social Sciences (IPHSS), Nuclear Science (IPNS), Life Science (IPLS), Electrical Engineering and Computer Science (IPEECS), Management and Technology (IPMT) and 17 traditional disciplinary programmes: Chemistry (CHEM), Mathematics (MATH), Physics (PHYS), Chemical Engineering (CHE), Industrial Engineering and Engineering Management (IEEM), Materials Science and Engineering (MS), Power Mechanical Engineering (PME), Chinese Literature (CL), Foreign Languages and Literature (FL), Life Science (LS), Medical Science (DMS), Engineering and System Science (ESS), Biomedical Engineering and Environmental Science (BMES), Quantitative Finance (QF), Economics (ECON), Computer Science (CS), Electrical Engineering (EE).

Table 4.7: Multilevel model: fixed effects of interdisciplinary learning on programme-level early career outcomes.

	ln salary		employment rate	
	(1)	(2)	(1)	(2)
avg. school-level interdisciplinarity	-0.124		-0.172	
	(0.260)		(0.196)	
avg. field-level interdisciplinarity		0.664		0.066
		(0.928)		(0.625)
interdisciplinary prog.	-0.110	0.011	-0.038	-0.114
	(0.096)	(0.165)	(0.086)	(0.107)
interdisciplinary prog.×school-level interdisciplinarity	0.293		0.151	
	(0.369)		(0.247)	
interdisciplinary prog.×field-level interdisciplinarity		-0.331		0.744
		(1.298)		(0.822)
student-related controls	yes	yes	yes	yes
household characteristic controls	yes	yes	yes	yes
macroeconomic controls	yes	yes	yes	yes
intercept	9.670***	9.581***	1.111	1.070
	(1.135)	(1.170)	(1.087)	(1.104)
N	458		561	
AIC	-369.2	-370.6	-259.9	-262.4
Log likelihood	209.6	209.3	154.9	155.2

Notes: This table presents the results of the estimated fixed-effect coefficients related to interdisciplinary learning in our multilevel models. Column (1) and (2) display the effect of interdisciplinary learning, with the school-level index and the field-level index being used to measure the extent of interdisciplinary learning, respectively. Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p<0.01$.

a positive relationship between interdisciplinary learning and labour market outcomes. A positive random effect in a particular programme indicates that the effect of interdisciplinary learning is greater in size for the programme – compared to the university average. The overall effects of interdisciplinary learning in each programme should combine the fixed and random effects estimates. We present the overall effects in Figures C1 - C4 in C.1.

Figure 4.5 shows that interdisciplinary learning has a negative impact on programme-level salary within one and two years after graduation – compared to the average across all years (deviations from the fixed effect estimate). However, the impact of interdisciplinary learning turns positive on salary four years after graduation. An increase of one percent in credits outside a graduate's school is associated with a rise in programme-level salary in the fourth year after graduation by around 0.16% (as shown in the top left figure of Figure 4.5). Our results indicate that the potential benefits of interdisciplinary learning on salary might appear after graduation for four years.

Turning to variations in the impact of interdisciplinary learning on salary across programmes, Figure 4.5 reveals significant variability in the relationship between interdisciplinary learning and salary across programmes. The plot shows that the effects of interdisciplinary learning on five out of 24 programmes differ significantly from the average effects of interdisciplinary learning in university.

Among 24 programmes, the association between interdisciplinary learning and salary is the highest at MS, followed by IPEECS. The overall effects of interdisciplinary learning on salary at MS and IPEECS are also positive and indicate that interdisciplinarity benefits MS and IPEECS graduates in salary (as shown in Figure C1 and Figure C2 in C.1). In contrast, the effect of interdisciplinary learning on salary is the poorest at the School of Life Science, including DMS, LS, and IPLS. The overall effects of interdisciplinary learning on salary are also consistently negative at the School of Life Science and indicate that interdisciplinary learning may have a negative effect on salary at that school (as shown in Figure C1 and Figure C2 in C.1).

Figure 4.6 presents the random-effect estimates for the employment rate. The results indicate a negative relationship between interdisciplinary learning and the employment rate within the first and second year after graduation. This relationship is reversed to a positive correlation in the third to fifth years after graduation. This result is similar to the time variation in the effects of interdisciplinary learning on salary and indicates that the potential benefits of interdisciplinary learning on employment might appear after graduation for three years.

Figure 4.6 also displays variations in the impact of field-level interdisciplinary learning across programmes, whereas there is no variation across programmes in the impact of school-level interdisciplinary learning. The apparent absence of programme-level variation in the effect of the school-level interdisciplinary index on employment rates may be attributed to the nuances of how the extent of interdisciplinary learning is measured. The field-level interdisciplinary index could conceivably offer a more precise gauge of interdisciplinary learning compared to the school-level interdisciplinary index, mainly due to its consideration of the extent of divergence between students' disciplinary field and the field of the registered modules.

Our results show that four out of 24 programmes had statistically significant differences in the effect of field-level interdisciplinary learning from the university average. The Department of Computer Science is the only programme whose correlation between field-level interdisciplinarity and the employment rate is significantly higher than the university average. Interdisciplinary learning seems to enhance the employment possibility of CS graduates. On the contrary, the effect of interdisciplinary learning on the employment rate is the poorest at PHYS, followed by DMS and LS. Learning interdisciplinarity seems to reduce the employment possibility of PHYS, DMS, and LS graduates.

4.6 Discussion and Conclusion

Interdisciplinary learning is increasingly recognised as a critical instrument to prepare the future workforce. As such, HEIs have established interdisciplinary programmes and loosened restrictions against module selection to allow students to be exposed to areas of knowledge outside their field of study. Yet, the effects of interdisciplinary learning have not been closely examined. This paper sought to empirically assess the impact of interdisciplinary learning on graduates' post-graduation plan choices (continuing studies, entering the workforce, the degree of alignment between a graduate's Bachelor degree field and planned future field of study/job) and programme-level labour market outcomes (salary and the employment rate) under traditional disciplinary and specialised interdisciplinary degree programmes drawing unique individual data from NTHU, Taiwan.

We tested four hypotheses. First, we hypothesised that *graduates learning through interdisciplinary training are more likely to seek employment immediately after graduation*. Our evidence is mixed and indicates that the effects of interdisciplinary learning on seeking employment immediately after graduation vary across traditional disciplinary and specialised interdisciplinary graduates. Our results revealed that interdisciplinary learning increased the probability of the intention to seek employment for traditional disciplinary graduates, which is consistent with our hypothesis. However, the effects of interdisciplinary learning on specialised interdisciplinary degree graduates are opposite to those on traditional disciplinary graduates and inconsistent with our hypothesis. This result may be explained by the fact that specialised interdisciplinary graduates on average have higher levels of interdisciplinarity than traditional disciplinary graduates and thus may encounter the trade-off between breadth of general knowledge and depth in specialist content gained through interdisciplinary learning (Costa et al., 2019; Hart, 2019; Ivanitskaya et al., 2002). Generally, students with higher levels of interdisciplinary learning engagement stretch their time across multiple disciplines to gain a breadth of knowledge. They may gain an overview of the respective disciplines but lack a depth of discipline-specific knowledge. As a result, students with higher levels of interdisciplinarity may feel less prepared for the workforce and seek to pursue further study to gain sufficient discipline-specific knowledge. At NTHU, the theoretical maximum extent of interdisciplinary exposure for interdisciplinary degree students is more than those for traditional disciplinary students because of the design of the total required credits. The majority of credits in traditional disciplinary degree programmes are within the field of study of students' registered programmes, while those in specialised interdisciplinary degree programmes are split into two specialities. Therefore, specialised interdisciplinary graduates may have greater difficulties in acquiring specific knowledge and have a higher intention to pursue further study.

A second hypothesis concerns the idea that *graduates learning through interdisciplinary training are more likely to pursue a further degree/job that is unrelated to their college degree.* We posit that interdisciplinary learning can contribute to learners' increased flexibility in selecting career paths. Consistent with this statement, our results revealed that interdisciplinary learning increases the transition to study fields and jobs which differ from their college degree. This evidence is consistent across both traditional disciplinary and specialised interdisciplinary graduates, though the degree of association differs, with the probability of transitioning to a different field being smaller for the latter. Such difference may be due to the design of specialised interdisciplinary degree programmes. Graduates from specialised interdisciplinary degree programmes can choose two specialities (two study fields) across disciplines, while those from traditional disciplinary degree programmes specialise in a single discipline. Thus, specialised interdisciplinary graduates with two study fields are more likely to pursue a further job that is related to their college degree than traditional disciplinary graduates.

We also presented evidence in relation to two hypotheses relating to early labour market outcomes. We hypothesised that *graduates learning through interdisciplinary training are more likely to achieve higher starting salaries and the likelihood of securing a job immediately after graduation* (Hypothesis 3), and that *the predicted benefits of interdisciplinary learning in labour market outcomes will grow over time* (Hypothesis 4). Our evidence did not support Hypothesis 3. We found that interdisciplinary learning is negatively associated with programme-level monthly salary and employment rate in the first and second years after graduation. A possible explanation is that early career outcomes can quickly change as graduates secure their first full-time jobs and identify career development options. The potential benefits of interdisciplinary learning may be realised later. Also, some graduates seek to pursue further studies after graduation from their undergraduate programme. Normally, it takes two years to get a Master degree in Taiwan and this has become the normal route before transitioning to the labour market. Furthermore, the regulations pertaining to compulsory military enlistment in Taiwan may introduce a gender bias. Specifically, all male citizens between 18 and 36 years old are mandated to fulfil their military service obligations. During our sample period (2012-2017), the typical duration of military service was one year. This tendency contributes to the observation that the majority of those employed within one or two years after graduation are female respondents. Therefore, the salary and employment rate after graduation for three years may provide a more accurate representation of the actual entry-level employment outcomes for graduates. In relation to hypothesis 4, we showed that the effects of interdisciplinary learning on salary and employment rate were positive after graduation for three years growing during the following years. Overall, our results provide support for Hypothesis 3 and Hypothesis 4.

This study has found that generally interdisciplinary learning benefits graduates in preparing for the workforce and gains in salary and employment. Our results offered some support for the impact of interdisciplinary education on post-graduation plan choices and early labour market outcomes. Yet, the specific type of interdisciplinarity does not emerge as the primary determinant influencing the effects of interdisciplinary learning on labour market outcomes. Instead, the crucial factor lies in the extent of interdisciplinary learning, characterised by the proportion of credits originating from other schools or fields. This finding aligns with the findings from Table 2.6 in Chapter 2, where it is demonstrated that graduates from specialised interdisciplinary and traditional disciplinary programmes achieve similar outcomes in terms of knowledge acquired, global perspective, and skills. Furthermore, interdisciplinary education in higher education needs to address the potential trade-off between the breadth and depth of specialist content or the TMGT effect. It is noteworthy that the School of Life Science, which exhibits the highest extent of interdisciplinarity (as shown in Figure 3.2 in Chapter 3), concurrently reports the least favourable labour market outcomes. The poorest labour market outcomes observed for the school with the highest degree of interdisciplinarity corresponds with the findings of the TMGT effects presented in Chapter 3. Consequently, greater efforts are needed to ensure students engage and acquire a "deep" degree of specialist knowledge. Providing an overview understanding of a subject will probably not be enough to consolidate knowledge in an area.

This study examined data capturing graduate labour market outcomes over the first five years immediately after graduation from their undergraduate programme. Our study thus provided evidence on the immediate, short-term effects of interdisciplinary learning on career outcomes. Future research should expand this work by analysing the medium- and long-term impacts of interdisciplinary learning analysing the extent to which short-term differences between graduates from traditional disciplinary and specialised interdisciplinary degree programmes are exacerbated and reduced as graduates gain working experience.

Our results revealed wide variations in salary and employment outcomes associated with interdisciplinary learning across study programmes. Evidence showed significantly higher salary for graduates from the Department of Materials Science and Interdisciplinary Programme of Electrical Engineering and Computer Science, and employment rates for computer science graduates; yet, these are the lowest level for Life Science and Physics graduates. Future work should seek to understand the causes of such large differences. It should aim to study the extent to which differences in labour market outcomes are due to the benefits from interdisciplinary learning. Some degrees may benefit little from acquiring knowledge from other disciplines, particularly if they required applied technical knowledge. Differences may also be because of deficiencies in the design of programmes in certain fields at NTHU, or macro-economic conditions impacting starting graduates in specific sectors during the period of our analysis. Understanding the causes of differences in graduate labour market outcomes have the potential to improve the design and labour market value of interdisciplinary learning education.

5

Conclusion

5.1 Introduction

The transition from an industrial-based economy to a knowledge-based economy has arguably been accompanied by growing complexity in labour market tasks. Problems in an interconnected global marketplace usually extend beyond the scope of single disciplines. Work increasingly requires collaboration across fields (Graham and Gareth, 2014). Such a trend has altered the demand for skills in labour markets and called the future workforce to be equipped with knowledge that enables them to collaborate in interdisciplinary teams to understand highly complex problems and produce novel solutions. In response, HEIs have turned to develop programmes to deliver interdisciplinary education and form the workforce of the future.

Previous studies have sought to understand the effects of interdisciplinary education on students' skill development outcomes (Burkholder et al., 2017; Hains-Wesson and Ji, 2020; Mansilla et al., 2009). However, most quantitative work has focused on short-term interdisciplinary modules (Orillion, 2009; Taylor, 2018) and collaborative projects (Costa et al., 2019; Khandakar et al., 2020). Few studies have paid attention to specialised interdisciplinary Bachelor degree programmes and interdisciplinary learning opportunities within traditional disciplinary programmes. Broadly, there are four types of interdisciplinary programmes in universities, i.e., interdisciplinary modules, collaborative projects, specialised interdisciplinary degree programmes, and flexible module-based interdisciplinary learning in traditional disciplinary programmes. Interdisciplinary modules and collaborative projects are short-term interdisciplinary learning mechanisms which are usually on a semester basis. Specialised interdisciplinary degree programmes and flexible module-based interdisciplinary learning in traditional disciplinary programmes are different. They offer long-term interdisciplinary opportunities and are designed within or as Bachelor degree programmes. Specialised interdisciplinary degree programmes are usually created by a group of faculty occupying lines in different traditional disciplinary programmes in the same school. Students from specialised interdisciplinary degree programmes are allowed to select two specialities from two different disciplines. Flexible module-based interdisciplinary learning in traditional disciplinary programmes is an interdisciplinary learning opportunity that is designed for traditional disciplinary students to learn interdisciplinarily by loosening rigid module-choice restrictions to some degree.

Additionally, most work has been limited to a particular field of study (Lattuca et al., 2017; Mansilla et al., 2009). Yet, students' educational outcomes may vary across fields due to differences in pedagogic practices and learning styles (Badcock et al., 2010; Walsh and Hardy, 1999). Moreover, no studies have empirically explored the impact of interdisciplinary learning on post-graduation outcomes. This lack of attention is unfortunate because enhancing employability to prepare for the workforce is a key argument to develop interdisciplinary educational options (Freedman, 2013; INOMICS Team, 2015). Overall, the impact of interdisciplinary education on students' skill outcomes and post-graduation outcomes remains understudied. A comprehensive study of the effects of interdisciplinary education on educational outcomes and post-graduation outcomes would provide HEIs with practical suggestions on designing and delivering interdisciplinary programmes to develop interdisciplinary education effectively.

This thesis sought to contribute to filling these gaps by drawing on a unique combination dataset from three sources from the National Tsing Hua University in Taiwan: (1) administrative records of students' backgrounds and module profiles, (2) a Graduation Survey, and (3) career tracking data. First, this thesis investigated the educational achievements of specialised interdisciplinary degree programmes across seven fields of study. Second, this thesis provided the first investigation into the effects of interdisciplinary learning on individual skill development for graduates from traditional disciplinary programmes. Third, this thesis expanded research on the skill development outcomes of students during their study years to the labour market outcomes of graduates, to determine whether interdisciplinary learning enhances graduate employability.

This chapter first summarises the main findings of the three analytical chapters – Chapter 2, Chapter 3, and Chapter 4. Section 5.3 then discusses the key contributions and implications of our findings for policy and research. The final Section discusses the key limitations of this thesis and highlights avenues for further research.

5.2 Summary of the main findings

To better understand the effect of interdisciplinary learning in higher education, this thesis sought to address three specific aims. This section re-states each of these aims and discusses the associated findings from the analyses.

5.2.1 The educational outcomes of specialised interdisciplinary Bachelor degree programmes

The first thesis objective is addressed in Chapter 2 and seeks to understand the effect of specialised interdisciplinary Bachelor degree programmes on student educational outcomes – knowledge acquired, global perspective, and skills improvement. Two key findings emerged from the analysis.

The first key finding established that specialised interdisciplinary degree programmes do not necessarily lead to better student educational outcomes. We found a positive association between interdisciplinary learning and educational outcomes for graduates from specialised interdisciplinary degree programmes of the School of Humanities and Social Sciences, School of Engineering, School of Electrical Engineering and Computer Science and School of Science. Yet, our results also revealed a significantly negative association between objective skills and specialised graduates from the School of Technology Management and the School of Life Science. Specialised interdisciplinary graduates from the School of Technology Management had a lower probability to possess critical thinking skills than traditional disciplinary graduates in their schools. Specialised interdisciplinary graduates from the School of Life Science were less likely to possess interpersonal interaction skills than graduates from traditional disciplinary programmes in their schools.

The second key finding pointed to significant differences in educational outcomes between specialised interdisciplinary programmes across fields of study. The specialised interdisciplinary degree programme of the School of Humanities and Social Sciences outperformed specialised interdisciplinary degree programmes in other study fields, especially in relation to the use of discipline-specific knowledge in a flexible way and 'soft' abilities (critical thinking, social justice, and self-discipline). By contrast, specialised interdisciplinary degree programmes in the School of Life Science, School of Technology Management, and School of Science had the worst educational outcomes, especially in terms of acquisition of profound discipline-specific knowledge, the use of discipline-specific knowledge in a flexible way, and skills of critical thinking and self-discipline. The observed discrepancy across fields of study might be explained by the design of specialised interdisciplinary programmes, learning environments, pedagogic practices, and the Too-Much-of-a-Good-Thing effects (TMGT effect) (Grant and Schwartz, 2011; Knifsend and Graham, 2012; Langfred, 2004). The specialised interdisciplinary programme of Humanities and Social Sciences is the only specialised interdisciplinary programme at NTHU whose faculty members were all appointed within the programme. Having dedicated hosting faculty members within a specialised interdisciplinary programme enables a programme to integrate disciplines effectively and form its menus of modules within the programme, and raise the degree of cohesion among faculty and students. Learning environments promoting disciplinary integration and cohesion among faculty and students tend to yield better student outcomes (Beachboard et al., 2011; Monson and Kenyon, 2018). In addition, Humanities and Social Sciences, classified as soft pure disciplines, place greater importance on broad general knowledge and are more likely to deal with more realistic problems than hard disciplines such as physics (Braxton, 1995; Liu and Shi, 2015; Neumann, 2001). Involvement in real-world problems requires the use of reflective judgement and promotes the application of knowledge and 'soft' abilities (Kay and Young, 1986; Lattuca et al., 2004). Furthermore, it is noteworthy that the School of Humanities and Social Sciences, which demonstrated the most favourable educational outcomes, exhibits the lowest extent of interdisciplinarity (as shown in Figure 3.2 in Chapter 3). Conversely, the School of Life Science, which exhibited the least favourable educational outcomes, showcases the highest extent of interdisciplinarity. This scenario aligns with the TMGT effects and implies that students with greater engagement in interdisciplinary learning might experience diminishing or even negative returns from such an approach, potentially due to their relative lack of discipline-specific knowledge.

5.2.2 The effect of interdisciplinary learning within traditional disciplinary degree programmes

The second thesis objective presented in Chapter 3 investigated whether graduates from traditional disciplinary programmes gain a quantifiable level of skill development from learning interdisciplinarily. Skill development outcomes in this Chapter comprise profound discipline-specific knowledge, use of the discipline-specific knowledge flexibly, critical-thinking skills, concerns about social justice and well-being, and self-discipline and reflection. There are two main findings from the analysis.

First, regression modelling results revealed a negative association between interdisciplinary learning delivered in traditional disciplinary programmes and students' skill development. In traditional disciplinary programmes, graduates with higher school-level interdisciplinarity were less likely to possess the ability to use discipline-specific knowledge flexibly, concerns about social justice and well-being, as well as having self-discipline and reflection. The results from field-level interdisciplinarity displayed a similar negative pattern to the school-level measure, except for a statistically insignificant effect on self-discipline and reflection. These differences can be explained by the degree of divergence between the field of students' discipline and the field of the module they registered. Students who registered credits from different fields require more time management than students who only registered credits from the same and similar fields because they must make more efforts on integrating different kinds of knowledge. Extra efforts for students who registered credits from different fields may offset the observed negative effect of interdisciplinary learning on self-discipline and reflection.

Second, evidence revealed that in traditional disciplinary programmes, graduates with a moderate degree of engagement with interdisciplinary learning may gain a clear advantage from learning interdisciplinarily. By contrast, graduates may experience negative returns if their levels of interdisciplinary learning engagement are too high. The findings in this thesis showed a positive relationship between interdisciplinary learning and skill development outcomes for graduates at the lowest 10% extent of interdisciplinary learning. Conversely, a negative association was found for graduates at the highest 10% extent of interdisciplinary learning. A possible explanation for these results may be the theory of TMGT effect (Grant and Schwartz, 2011; Knifsend and Graham, 2012; Langfred, 2004). Getting too much of a good thing (higher levels of interdisciplinary learning) may diminish the possible advantage of interdisciplinary learning. Students stretching their time across multiple disciplines are less likely to internalise knowledge in that discipline than those highly committed individuals and thus suppress the potential benefits of interdisciplinary learning.

5.2.3 The long-run effect of interdisciplinary learning on post-graduation outcomes

Chapter 4 addresses the third thesis objective seeking to determine the association between outcomes post-graduation and interdisciplinary experience in traditional disciplinary and specialised interdisciplinary Bachelor degree programmes. Four key findings emerged from the analyses. The first two findings relate to post-graduation plan choices and the last two identify the impacts of interdisciplinary learning on labour market outcomes.

First, regression modelling estimates suggested that the effects of interdisciplinary learning on post-graduation plan choices vary across traditional disciplinary and specialised interdisciplinary graduates. Evidence indicated that interdisciplinary learning may increase the chances of transitioning into the labour market for traditional disciplinary graduates, whereas high levels of interdisciplinary education could act to reduce the chances of making a transition to the labour market for specialised interdisciplinary graduates. Instead, they would be more likely to continue in education. In this thesis it was hypothesised that *graduates learning through interdisciplinary training are more likely to seek employment immediately after graduation* because interdisciplinary learning is believed to contribute to students' employability skills (Hains-Wesson and Ji, 2020; Hart, 2019; Knight et al., 2013). Graduates with confidence in demonstrating employability skills tend to be confident about applying for a job immediately after graduation (Miller et al., 2018; Oswald-Egg and Renold, 2021; Park, 2015). However, the result for graduates from specialised interdisciplinary degree programmes is contrary to this hypothesis. This inconsistency may be related to the TMGT effect (Grant and Schwartz, 2011; Knifsend and Graham, 2012; Langfred, 2004). Because of the programme design, specialised interdisciplinary graduates on average have higher levels of interdisciplinarity than traditional disciplinary graduates. As evidenced in Chapter 3, graduates with higher levels of interdisciplinary learning tend to encounter the TMGT effect which suppresses the potential benefits of interdisciplinary learning. Therefore, specialised interdisciplinary graduates are more likely to acquire fewer employability skills than traditional disciplinary graduates and seek to pursue further study to gain sufficient employability skills.

Second, evidence suggested that graduates with interdisciplinary training tend to pursue a further degree/job that is unrelated to their college degree, regardless of the type of programme. This finding is consistent with the hypothesis in this thesis that *graduates learning through interdisciplinary training are more likely to pursue a further degree/job that is unrelated to their college degree*. Interdisciplinary learning exposes learners to a wide range of disciplines and people from different backgrounds. Diversity of disciplinary knowledge and engaging with people from different backgrounds may increase learners' openness to diversity and challenge, and enhance flexibility in career choices (Milem, 2003; Umbach and Kuh, 2006).

Third, findings also showed that higher interdisciplinarity tends to lead to a greater average salary and higher chances of full-time employment over time after graduation. This relationship appears to be consistent for both traditional disciplinary and specialised interdisciplinary graduates. This evidence supports the hypothesis in this thesis that *the predicted benefits of interdisciplinary learning in labour market outcomes will grow over time*. The positive association between interdisciplinary learning and students' skill development outcomes enhances their productivity in the labour market (Hains-Wesson and Ji, 2020; Hart, 2019; Knight et al., 2013). These enhancements in new graduates' productivity may be rewarded in salaries gradually after they contribute to a company's productivity (Becker, 2009).

Fourth, there is a noticeable variation in salary and employment outcomes associated with interdisciplinary learning across degree programmes. Evidence indicated that the association between interdisciplinary learning and salary is the highest for graduates from the Department of Materials Science, but the poorest for graduates from the School of Life Science. On the other hand, evidence showed a significantly higher employment rate in the effect of field-level interdisciplinary learning for graduates from the Department of Computer Science than the university average; yet, these are the lowest level for graduates from the Department of Physics and the School of Life Science. Learning interdisciplinarity seems to reduce the employment possibility of graduates from the Department of Physics and the School of Life Science. The observed variation among different fields of study could potentially be explained by the TMGT effect in the context of interdisciplinarity, as demonstrated in Chapter 3. The School of Life Science, which concurrently presents the least favourable labour market outcomes, exhibits the highest extent of interdisciplinarity (as shown in Figure 3.2 in Chapter 3). The correlation between the poorest labour market outcomes and the highest level of interdisciplinarity within this school aligns with the findings on the TMGT effects detailed in Chapter 3.

5.3 Contributions and implications

In addressing the research objectives, this thesis has made key contributions with implications on the design of interdisciplinary education in three distinct domains: evidence and knowledge, theory, and education policy.

Evidence and knowledge

In terms of the evidence and knowledge domain, this thesis is one of the few studies that provide evidence on two forms of interdisciplinary education – specialised interdisciplinary degree programmes and flexible module-based interdisciplinary learning in traditional disciplinary programmes, and demonstrate how the effects of interdisciplinary learning vary across study fields. The first substantive contribution of this thesis is to provide the first comprehensive understanding of the educational outcomes of specialised interdisciplinary degree programmes in a wide range of study fields. Previous studies have primarily focused on short-term interdisciplinary modules and collaborative projects (Borrego et al., 2000; Hains-Wesson and Ji, 2020; Khandakar et al., 2020). The evidence on specialised interdisciplinary Bachelor degree programmes relates to a few quantitative studies and is limited to particular study fields (Lattuca et al., 2017; Mansilla et al., 2009). This thesis focused on understanding long-term specialised interdisciplinary degree programmes and revealed that they do not necessarily lead to better student educational outcomes. Specialised interdisciplinary graduates from the School of Technology Management and the School of Life Science had a lower probability to possess critical thinking skills and interpersonal interaction skills than their counterparts from traditional disciplinary programmes. This thesis also showed that specialised interdisciplinary graduates from the Humanities and Social Sciences outperformed graduates from the other specialised interdisciplinary programmes. The evidence in this thesis thus suggests that other specialised interdisciplinary programmes should adjust supporting measures from the experience of interdisciplinary degree programmes at the School of Humanities and Social Sciences.

The second substantive contribution is to conceptualise interdisciplinary learning in traditional disciplinary programmes. Generally, students from traditional disciplinary programmes were viewed as non-interdisciplinary learners (Khandakar et al., 2020; Lattuca et al., 2017; Mansilla et al., 2009). Interdisciplinary learning within traditional disciplinary programmes has often been ignored. This thesis recognised that students in traditional disciplinary programmes can have an interdisciplinary learning experience by acquiring module credits outside their field of study. This thesis thus proposed *school-level interdisciplinarity* calculating the proportion of one's module credits that were offered by other schools to measure the extent of interdisciplinary learning of graduates from traditional disciplinary programmes. It also considered the degree of divergence between the field of students' discipline and the field of the module they registered may result in different learning performances because taking a module from a different field may need to make more efforts on integrating knowledge. We therefore also measured *field-level interdisciplinarity* as the proportion of one's module credits that were offered by a different field. This thesis developed simple yet robust indicators to measure the extent of interdisciplinary learning in traditional disciplinary programmes.

The third substantive contribution is to bring the concept of the "Too-Much-of-a-Good-Thing effect" into interdisciplinary learning. The TMGT effect has been applied and explored in various fields, such as psychology, management and education (Grant and Schwartz, 2011; Knifsend and Graham, 2012; Langfred, 2004). The TMGT effect predicts that getting too much of a good thing may diminish the possible advantage of product or good being consumed. Yet, it has not been applied in interdisciplinary education. The perspective of the TMGT effect can be used to complement the debate on the trade-off between breadth and depth of knowledge in interdisciplinary learning. Students who stretch to learn across too many different fields (get too much interdisciplinary learning) may diminish their knowledge capacity absorption and end up with negative skill development (suppress the potential benefits of interdisciplinary learning). Our findings support the standpoint of the TMGT effect and show that graduates with the lowest 10% extent of interdisciplinary learning had a positive association with skill development outcomes. In contrast, graduates with the highest 10% extent of interdisciplinary learning were negatively associated with skill development outcomes. The evidence suggests that there may be a certain critical level of discipline-specific knowledge. Beyond that point there seems to be little benefits from studying interdisciplinarily. It also indicates that students need a substantive grounding in some discipline-specific knowledge before engaging in interdisciplinary learning.

The fourth substantive contribution is to provide evidence on the effects of interdisciplinary education on post-graduation outcomes. Enhancing employability is a key argument for the design of interdisciplinary education. Yet, much uncertainty still exists about the association between interdisciplinary education and post-graduation outcomes. Existing research primarily focused on examining the effects of interdisciplinary learning on skills during learners' study periods (Burkholder et al., 2017; Khandakar et al., 2020; Lattuca et al., 2017). This thesis established the association between interdisciplinary learning and post-graduation outcomes and indicated that interdisciplinary learning during undergraduate studies is overall beneficial to post-graduation outcomes. It is essential to underscore that the predominant determinant influencing the impacts of interdisciplinary learning resides in the extent of interdisciplinary learning, rather than the particular type of interdisciplinarity. Evidence indicated that a higher extent of interdisciplinary learning tends to increase the chances of transitioning into the labour market, encourage graduates to pursue a further degree/job that is unrelated to their college degree, and lead to a greater average salary and higher chances of full-time employment over time after graduation.

Theoretical contributions

In terms of theory, this thesis contributes towards expanding conceptual links between interdisciplinary learning and skill development outcomes. Previous research proposed that the pedagogic strategies and learning environments which are commonly adopted in interdisciplinary education are the key to promoting learning, such as raising questions involving complex, real-world problems and interactivity sessions (Brassler and Dettmers, 2017; Lattuca et al., 2004; Rienties and Héliot, 2018). They provide theoretical support to the links between interdisciplinary learning and student skill outcomes without taking account of the variations in pedagogic practices and learning methods across study fields (Brassler and Dettmers, 2017; Lattuca et al., 2004; Rienties and Héliot, 2018). Their perspectives therefore imply that the links between interdisciplinary learning and student skill outcomes are the same across fields of study. This thesis evidenced that the effects of interdisciplinary learning on student skill development and labour market outcomes varied across fields of study. Our findings suggest that the conceptual links between interdisciplinary learning and student outcomes need to reflect the variation in pedagogic practices and learning methods across study fields. Interdisciplinary learning is not necessary to benefit all academic fields. The determinant factor in the effects of interdisciplinary learning may be the use of pedagogic practices and learning methods.

This thesis also contributes to theory by modifying a positive monotonic relationship between interdisciplinary learning and student skill outcomes to a non-monotonic relationship. Traditional theories tend to be static by proposing that interdisciplinary learning has a positive monotonic effect on student outcomes. This thesis employed sub-sample analyses and found that the effect of interdisciplinary learning on student outcomes relies on the extent of interdisciplinary learning. We found a positive effect of interdisciplinary learning on student skill outcomes for individuals with relatively low levels of exposure to interdisciplinary learning, whereas a negative effect was shown for those with high levels of interdisciplinary learning. This thesis evidenced that the relationship between interdisciplinary learning and student skill outcomes is non-monotonic. Higher education institutions should guide students to engage in interdisciplinary learning with a moderate degree to avoid the potential negative effects from over-interdisciplinarity.

Education policy

Ultimately, the significance of this thesis lies in its contribution to education policy. The findings of this thesis are envisaged to have three key policy implications. First, this thesis demonstrates that interdisciplinary education on its own is not necessarily a reliable way to enhance learners' employability and prepare them for the labour market, calling for supporting measures of higher education institutions in interdisciplinary education. Rather than simply providing the chance for interdisciplinary learning, higher education institutions should evaluate student outcomes across programmes regularly and adjust supporting measures from the experience of successful interdisciplinary degree programmes. The evidence in this thesis suggests that organising faculty teams in a specialised interdisciplinary degree programme may be a potential option to enhance the benefits of interdisciplinary education. The belongingness and connectedness between faculty and students may be a key aspect to enhance students' learning outcomes (Knight et al., 2013; Monson and Kenyon, 2018).

Second, this thesis demonstrates that interdisciplinary learning faces the TMGT effect – interdisciplinary learning contributes to students' breadth of knowledge at the expense of depth of knowledge. Findings in Chapter 3 indicate that graduates with a lower extent of interdisciplinary learning have a positive association between interdisciplinary learning and skill development, while those with high levels of exposure display a negative association. Therefore, higher education institutions need to ensure students get the optimal degree of discipline-specific knowledge before exposing them to interdisciplinary learning, or to develop interdisciplinary study pathways with relevant modules outside students' primary discipline.

Third, given resource constraints, loosening module choice restrictions in traditional disciplinary programmes seems to be a valuable option for higher education institutions to develop interdisciplinary education. We studied the effects of these programmes on student skills outcomes. Our findings indicated that there were no apparent differences in the association between interdisciplinary learning and student post-graduation outcomes between graduates from specialised interdisciplinary degree programmes and traditional disciplinary degree programmes. Implementing interdisciplinary education in traditional disciplinary programmes by allowing students freely choosing modules outside their disciplines is more easily implemented than establishing a new specialised interdisciplinary degree programme. Therefore, this thesis suggests that it is valuable to develop interdisciplinary education by loosening module choice restrictions to allow traditional disciplinary students freely choosing their modules with certain degrees.

5.4 Limitations

A major limitation of this study relates to data availability. First, the Taiwanese career-tracking data which collects post-graduation records only tracks graduates annually up to five years after graduation. As a result, the analysis could only study the early career labour market outcomes of graduates at the cohort level. Yet, we know that early career outcomes can quickly change as graduates secure their first full-time jobs and identify career development options. Though, we also know that graduates who transition into long periods of unemployment tend to experience unstable professional career pathways with cycles of unemployment and out of the workforce (Andrews et al., 2020; McQuaid, 2017; Rowe et al., 2017). The potential benefits of interdisciplinary learning may be realised later and may grow as graduates gain more work experience. The availability of career-tracking data for a longer period after graduation would enable a more comprehensive understanding of the long-term effects of interdisciplinary learning on graduate labour markets and may provide valuable insights to shape graduate employment policies.

Second, the unavailability of individual-level labour market outcomes constrained the analysis at an aggregate level. Because of Taiwanese privacy and personal data protection laws, we only had access to programme-level career tracking data. Programme average conceals within-programme student variation in the level of interdisciplinary learning and in labour market outcomes. Averages may also conceal the potential effects of interdisciplinary learning on labour market outcomes. Programme-level data limited our ability to better understand the relationship between individual interdisciplinary learning and individual labour market outcomes.

5.5 Future research

The findings presented in this thesis suggest three avenues for future research. Firstly, the reason why interdisciplinary learning in certain fields of study tends to lead to poorer outcomes needs further investigation. Evidence in Chapter 2 and Chapter 4 indicates that the associations between interdisciplinary learning and student outcomes vary across study fields. Such association might be positive for some programmes, while some are negative. A possible explanation for unexpected negative results might be that interdisciplinary education in such programmes lacks sufficient support, such as the lack of dedicated hosting faculty members. There are, however, many possible reasons that may lead to negative impacts from learning interdisciplinarily in a particular study field. Learning environments and pedagogical practices, learning styles, and student attributes in a particular discipline may account for variations in learning outcomes across disciplines. Learning environments and pedagogical practices in different disciplines, for example, may mould student learning styles into a particular discipline and thus result in different learning outcomes. Besides, differential learning outcomes may reflect general differences in the group of students who are attracted to each discipline area. On the other hand, the nature of work in different disciplines might be a possible factor influencing the negative effects of interdisciplinary learning on labour market outcomes. In some fields, employers may value and look for employees with knowledge and expertise in a single disciplinary field. The precise reason is not yet clear. Investigation of the factors driving the negative effects of interdisciplinary learning in a particular field can help higher education institutions to find the right remedy and thus lead to desired outcomes. Further work needs to be done to examine the potential causes of the unexpected negative effects of interdisciplinary learning on students skills development and labour market outcomes.

Secondly, further research is required to identify the optimum extent of interdisciplinary learning. Results in Chapter 3 demonstrate that graduates with moderate engagement in interdisciplinary learning may gain an advantage in terms of skill development while graduates with high levels of exposure may experience negative returns on skill development. What is less clear is the optimum extent of interdisciplinary learning. Understanding the optimum extent of interdisciplinary learning can help higher education institutions to set up a tipping point which ensures students a positive return on interdisciplinary learning.

Finally, the methodological framework to measure the extent of interdisciplinary learning and to assess the effects of interdisciplinary learning on skill development outcomes and post-graduation outcomes can be extended to other geographic settings. This thesis is the first study of interdisciplinary learning within traditional disciplinary degree programmes and on post-graduation outcomes. The evidence in this thesis indicates that the effects of interdisciplinary learning varied across fields of study. Understanding the role of culture and methods of learning across countries in explaining the effects of interdisciplinary learning is of key importance to have a more comprehensive perception of interdisciplinary learning.

Appendices

A

Chapter 2 Appendix

A.1 Marginal effects of specialised interdisciplinary degree programmes at university level

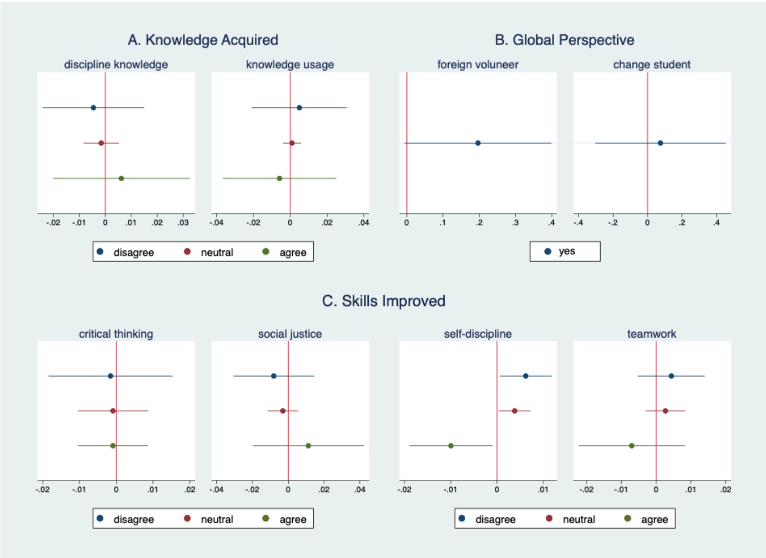

Figure A1: Marginal effects of specialised interdisciplinary degree programmes on its educational objectives at university level. *Notes:* The levels for confidence intervals is 90%.

A.2 Marginal effects of specialised interdisciplinary degree programmes by schools

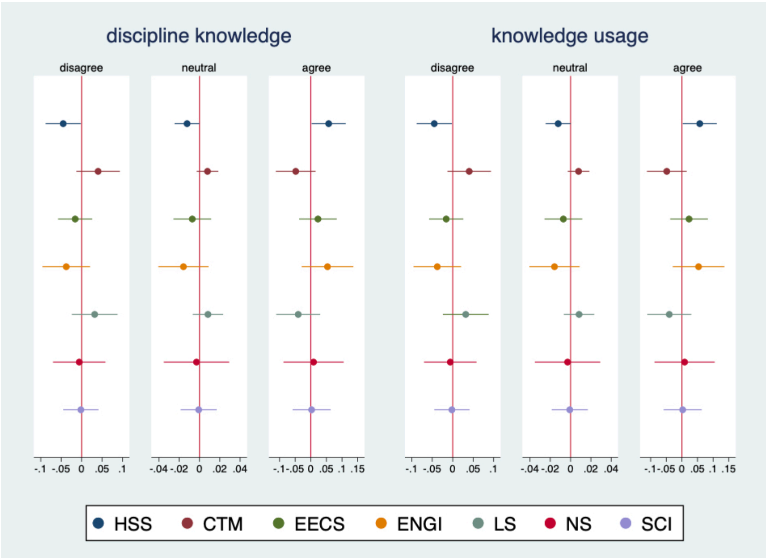

Figure A2: Marginal effects of specialised interdisciplinary degree programmes on knowledge acquired in each school. *Notes:* The levels for confidence intervals is 90%.

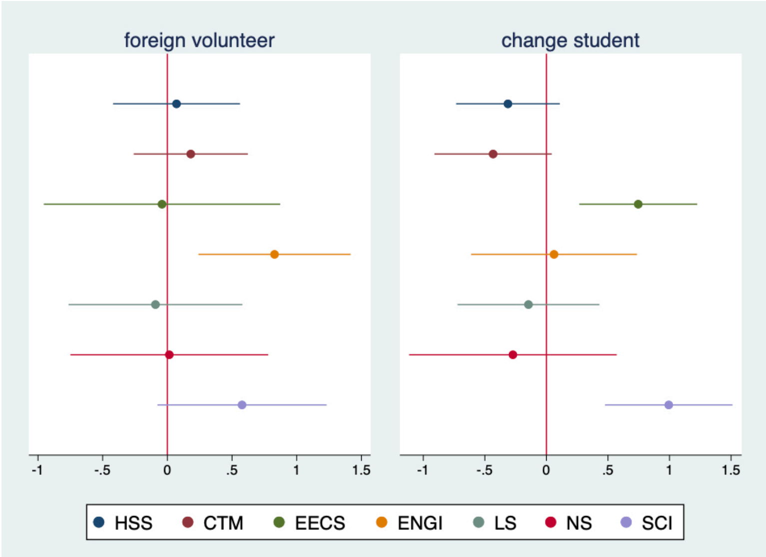

Figure A3: Marginal effects of specialised interdisciplinary degree programmes on global perspective in each school. *Notes:* The levels for confidence intervals is 90%.

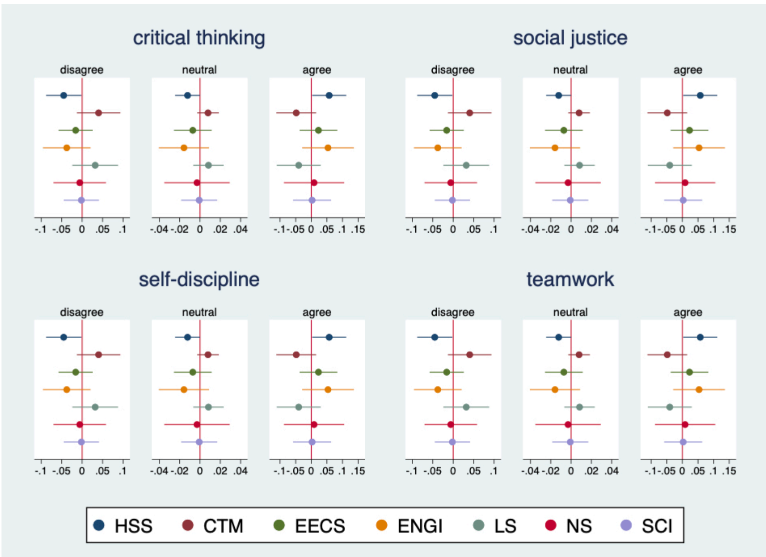

Figure A4: Marginal effects of specialised interdisciplinary degree programmes on skills improved in each school. *Notes:* The levels for confidence intervals is 90%.

A.3 Comparison of the outcomes of interdisciplinary degree programmes between seven schools

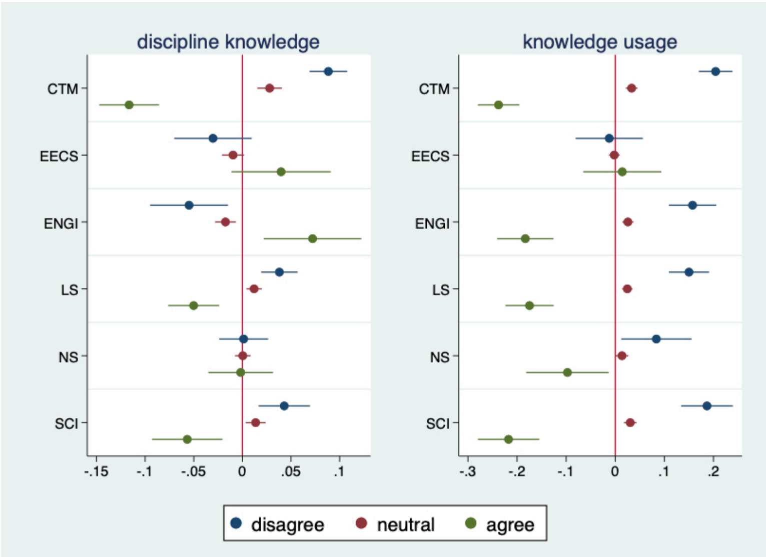

Figure A5: Comparison between seven specialised interdisciplinary degree programmes: marginal effects on knowledge acquired. *Notes:* The reference group is HSS. The levels for confidence intervals is 90%.

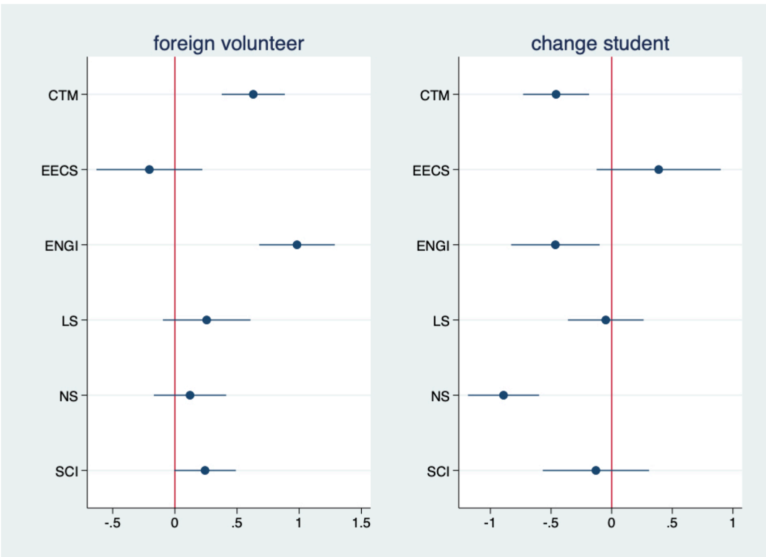

Figure A6: Comparison between seven specialised interdisciplinary degree programmes: marginal effects on global perspective. *Notes:* The reference group is HSS. The levels for confidence intervals is 90%.

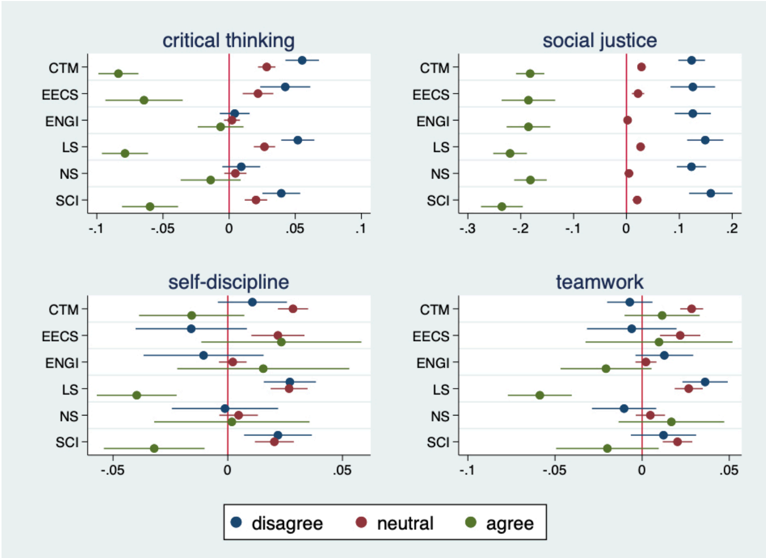

Figure A7: Comparison between seven specialised interdisciplinary degree programmes: marginal effects on skills improved. *Notes:* The reference group is HSS. The levels for confidence intervals is 90%.

A.4 Sensitivity Analyses

In Section 2.3.1, we raised the concern regarding potential bias introduced by the deletion process of missing data. The missing values in our dataset stem from parents' years of education and entrance scores. To check the robustness of our results based on simply deleting missing values, we conducted the conditional mean imputation method to substitute missing values and reproduced the regression results in Section 2.5.

The conditional mean imputation method involved selecting graduates with complete information and regressing the three problematic variables (parents' years of education and entrance scores) individually against all other independent variables. Subsequently, we utilised the estimated equations to predict the missing values for the three problematic variables. We then repeated the regression model in Section 2.4 with the imputed values replacing the missing ones. The new results, presented in Table A1 and Table A2, reveal the most notable discrepancy lies in the comparison of outcomes among interdisciplinary degree programmes across seven schools, namely Section 2.5.4. The primary distinction between the imputed results (Table A2) and the results obtained by simply deleting missing values (Table 2.8) lies in the findings for interdisciplinary HSS graduates, who demonstrated less confidence in their interaction skills compared to interdisciplinary CTM, EECS, ENGI, NUCL, and SCI graduates. However, the other results remain consistent with the main findings in Table 2.8.

In light of these analyses, it became evident that while the deletion process may have introduced some bias, it is not of a significant magnitude.

Table A1: Log-odds estimates for interdisciplinary educational objectives by schools under the conditional mean imputation method.

	Knowledge Acquired		Global Perspective		Skills Improved			
	discipline knowledge	knowledge usage	volunteer overseas	foreign exchange	critical thinking	social justice	self-discipline	interaction
All	-0.039	-0.091	0.131	0.235*	0.023	0.061	-0.108	-0.098
	(0.097)	(0.090)	(0.240)	(0.139)	(0.219)	(0.141)	(0.099)	(0.133)
HSS	0.208	0.291	0.260	-0.238	0.446	1.325***	-0.114	-0.122
	(0.201)	(0.201)	(0.247)	(0.219)	(0.364)	(0.396)	(0.301)	(0.257)
CTM	-0.283	-0.136	0.150	-0.323	-0.719***	-0.342	-0.362	0.064
	(0.185)	(0.177)	(0.250)	(0.246)	(0.269)	(0.254)	(0.289)	(0.300)
EECS	0.047	0.055	-0.081	1.102***	-0.298	0.208	-0.193	-0.150
	(0.320)	(0.272)	(0.545)	(0.259)	(0.344)	(0.292)	(0.331)	(0.390)
ENGI	0.517	-0.378	0.987***	-0.043	0.890	0.136	0.240	-0.112
	(0.406)	(0.245)	(0.290)	(0.370)	(0.544)	(0.344)	(0.471)	(0.425)
LS	-0.322	-0.026	-0.179	-0.094	0.047	-0.095	-0.433	-0.857**
	(0.299)	(0.243)	(0.401)	(0.325)	(0.339)	(0.293)	(0.383)	(0.356)
NS	-0.115	-0.444	0.048	0.034	0.143	-0.082	0.020	0.041
	(0.386)	(0.318)	(0.436)	(0.423)	(0.643)	(0.428)	(0.600)	(0.696)
SCI	-0.059	-0.196	0.598	0.994***	0.274	-0.130	0.084	0.338
	(0.239)	(0.199)	(0.372)	(0.304)	(0.311)	(0.218)	(0.267)	(0.288)

Notes: Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p<0.01$.

Table A2: Log-odds estimates: comparison of specialised interdisciplinary degree programmes in seven schools under the conditional mean imputation method.

	Knowledge Acquired		Global Perspective		Skills Improved			
	discipline knowledge	knowledge usage	volunteer overseas	foreign exchange	critical thinking	social justice	self-discipline	interaction
CTM	-0.763***	-1.188***	0.432***	-0.394**	-1.503***	-1.960***	-0.204	0.452***
	(0.117)	(0.135)	(0.107)	(0.157)	(0.118)	(0.187)	(0.165)	(0.107)
EECS	0.448*	0.073	-0.479*	0.631*	-1.118***	-1.754***	0.314	0.412*
	(0.252)	(0.283)	(0.268)	(0.341)	(0.345)	(0.325)	(0.263)	(0.220)
ENGI	1.021***	-0.790***	0.888***	-0.669***	-0.119	-1.779***	0.478*	0.393**
	(0.188)	(0.241)	(0.158)	(0.155)	(0.221)	(0.285)	(0.255)	(0.153)
LSCO	-0.191**	-0.871***	-0.096	-0.133	-1.371***	-2.234***	-0.356**	-0.451***
	(0.093)	(0.173)	(0.188)	(0.212)	(0.208)	(0.211)	(0.141)	(0.115)
NUCL	-0.016	-0.784***	-0.011	-0.702***	-0.420	-1.697***	0.331	0.910***
	(0.150)	(0.278)	(0.177)	(0.161)	(0.293)	(0.216)	(0.219)	(0.142)
SCI	-0.204	-1.024***	0.146	-0.157	-0.981***	-2.361***	-0.298*	0.098
	(0.156)	(0.220)	(0.170)	(0.296)	(0.271)	(0.248)	(0.162)	(0.168)
N	1021	1021	1021	1021	1021	1021	1021	1021
R-sq	0.081	0.075	0.084	0.077	0.156	0.144	0.103	0.141

Notes: The reference group is HSS. Standard errors are in parentheses. * $p < 0.1$, **$p < 0.05$, ***$p<0.01$.

B

Chapter 3 Appendix

B.1 Ordered logistic regression results

Table B1: Ordered logistic regression results.

	Individual Knowledge				Social Outcomes					
	discipline knowledge		knowledge usage		independent thinking		social justice		self-discipline	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
school-level interdisciplinarity	-0.589		-1.383***		-0.581		-1.028*		-1.053**	
	(0.789)		(0.196)		(0.403)		(0.557)		(0.488)	
field-level interdisciplinarity		-0.990		-2.617***		1.419		-1.690***		-0.835
		(0.913)		(0.917)		(0.975)		(0.579)		(0.937)
Student-related variables										
male	0.102	0.098	0.403***	0.386***	0.017	0.049	-0.282***	-0.290***	-0.402***	-0.395***
	(0.087)	(0.091)	(0.057)	(0.072)	(0.152)	(0.160)	(0.105)	(0.101)	(0.126)	(0.130)
Motivation to undertake university study										
external	0.619***	0.618***	0.619***	0.616***	0.697***	0.700***	0.672***	0.670***	0.712***	0.712***
	(0.069)	(0.068)	(0.055)	(0.055)	(0.076)	(0.077)	(0.032)	(0.032)	(0.053)	(0.054)
internal	-0.062	-0.062	-0.032	-0.029	0.035	0.032	-0.030	-0.029	0.069	0.068
	(0.058)	(0.058)	(0.054)	(0.054)	(0.069)	(0.070)	(0.090)	(0.089)	(0.052)	(0.051)
Admission methods										
exam	0.029	0.024	-0.075	-0.090*	0.058	0.053	0.026	0.013	0.170	0.156
	(0.075)	(0.073)	(0.048)	(0.051)	(0.066)	(0.064)	(0.081)	(0.076)	(0.155)	(0.155)
application	0.340	0.363	0.110	0.169	1.331***	1.325***	-0.294	-0.259	-0.103	-0.084
	(0.387)	(0.388)	(0.304)	(0.297)	(0.436)	(0.425)	(0.483)	(0.466)	(0.611)	(0.602)
high-school rank	0.046***	0.045***	0.013	0.010	0.011	0.012	0.051*	0.049*	0.125***	0.123***
	(0.012)	(0.013)	(0.031)	(0.032)	(0.047)	(0.046)	(0.027)	(0.028)	(0.047)	(0.047)
entrance scores	0.026	0.025	0.014	0.012	0.011	0.009	-0.024*	-0.025*	-0.005	-0.007
	(0.017)	(0.017)	(0.012)	(0.012)	(0.021)	(0.020)	(0.013)	(0.013)	(0.018)	(0.018)
club hours	-0.023**	-0.023**	-0.021*	-0.021*	0.009	0.010	0.011	0.011	0.001	0.001
	(0.011)	(0.011)	(0.011)	(0.011)	(0.018)	(0.017)	(0.011)	(0.011)	(0.011)	(0.011)
part-time hours	0.003	0.003	0.021***	0.021***	0.026**	0.026*	0.035***	0.035***	0.036***	0.035***
	(0.014)	(0.014)	(0.006)	(0.006)	(0.013)	(0.013)	(0.009)	(0.009)	(0.012)	(0.012)

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continued

	Individual Knowledge				Social Outcomes					
	discipline knowledge		knowledge usage		independent thinking		social justice		self-discipline	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Schools										
Technology Management	-0.139	-0.138**	-0.661***	-0.631***	-0.389***	-0.595***	-0.160**	-0.158***	0.005	-0.075
	(0.137)	(0.067)	(0.046)	(0.098)	(0.045)	(0.114)	(0.078)	(0.037)	(0.125)	(0.108)
Electrical Engineering	0.409**	0.367***	0.115	0.041	-0.598***	-0.784***	-0.239*	-0.312***	0.059	-0.075
& Computer Science	(0.189)	(0.065)	(0.095)	(0.124)	(0.093)	(0.154)	(0.126)	(0.071)	(0.205)	(0.163)
Engineering	0.474**	0.394***	-0.180**	-0.352***	-0.626***	-0.805***	-0.213	-0.352***	0.125	-0.059
	(0.209)	(0.059)	(0.091)	(0.106)	(0.085)	(0.134)	(0.135)	(0.070)	(0.216)	(0.157)
Nuclear Science	0.354	0.246***	-0.431***	-0.655***	-0.989***	-1.284***	-0.401**	-0.590***	-0.140	-0.412***
	(0.294)	(0.069)	(0.094)	(0.135)	(0.088)	(0.151)	(0.204)	(0.067)	(0.233)	(0.136)
Life Science	0.306	0.199***	-0.034	-0.271***	-0.385***	-0.578***	-0.122	-0.310***	-0.033	-0.263**
	(0.227)	(0.045)	(0.079)	(0.088)	(0.086)	(0.112)	(0.139)	(0.053)	(0.199)	(0.122)
Science	0.071	0.068	-0.539***	-0.523***	-0.806***	-0.957***	-0.584***	-0.589***	-0.534***	-0.599***
	(0.124)	(0.049)	(0.077)	(0.111)	(0.090)	(0.144)	(0.092)	(0.066)	(0.163)	(0.141)
Cohorts										
cohort2013	0.629***	0.624***	0.312***	0.299***	0.948***	0.960***	0.653***	0.644***	1.033***	1.029***
	(0.139)	(0.135)	(0.106)	(0.102)	(0.200)	(0.199)	(0.184)	(0.183)	(0.225)	(0.223)
cohort2014	0.734***	0.730***	0.064	0.050	1.314***	1.330***	0.835***	0.824***	1.228***	1.222***
	(0.170)	(0.165)	(0.150)	(0.140)	(0.108)	(0.114)	(0.138)	(0.140)	(0.129)	(0.130)
cohort2015	0.671***	0.664***	0.870***	0.850***	0.866***	0.887***	1.389***	1.375***	1.685***	1.677***
	(0.201)	(0.199)	(0.112)	(0.107)	(0.154)	(0.153)	(0.133)	(0.132)	(0.247)	(0.250)
cohort2016	0.769***	0.766***	0.362***	0.351***	1.987***	2.006***	1.373***	1.364***	1.708***	1.704***
	(0.080)	(0.073)	(0.062)	(0.055)	(0.153)	(0.153)	(0.148)	(0.152)	(0.132)	(0.137)
cohort2017	0.757***	0.748***	0.375***	0.350***	1.313***	1.353***	1.047***	1.032***	1.462***	1.462***
	(0.172)	(0.169)	(0.127)	(0.120)	(0.103)	(0.099)	(0.220)	(0.228)	(0.116)	(0.113)
Household characteristic variables										
Father's occupation										
blue-collar	-0.139***	-0.138***	-0.130	-0.127	0.264*	0.264*	-0.021	-0.019	0.112	0.113
	(0.049)	(0.051)	(0.081)	(0.080)	(0.139)	(0.139)	(0.079)	(0.079)	(0.076)	(0.076)
other-collar	-0.202*	-0.202*	0.049	0.050	0.018	0.006	0.001	0.002	-0.029	-0.031

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continued

	Individual Knowledge				Social Outcomes					
	discipline knowledge		knowledge usage		independent thinking		social justice		self-discipline	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
	(0.110)	(0.110)	(0.072)	(0.072)	(0.127)	(0.130)	(0.083)	(0.085)	(0.114)	(0.115)
Mother's occupation										
blue-collar	-0.043	-0.037	-0.160	-0.142	0.222	0.207	-0.157	-0.141	-0.053	-0.047
	(0.171)	(0.167)	(0.152)	(0.146)	(0.140)	(0.145)	(0.158)	(0.154)	(0.172)	(0.173)
other-collar	0.060	0.057	0.003	-0.002	-0.032	-0.031	-0.009	-0.012	-0.093	-0.095
	(0.120)	(0.122)	(0.071)	(0.070)	(0.086)	(0.086)	(0.070)	(0.070)	(0.078)	(0.078)
lowincome family	0.042	0.051	0.257	0.273	-0.219	-0.197	-0.010	0.001	-0.115	-0.098
	(0.297)	(0.297)	(0.214)	(0.223)	(0.239)	(0.237)	(0.111)	(0.117)	(0.170)	(0.176)
father's yos	-0.028**	-0.028**	0.003	0.004	0.009	0.008	-0.023	-0.022	0.024	0.024
	(0.012)	(0.012)	(0.010)	(0.010)	(0.022)	(0.022)	(0.021)	(0.021)	(0.024)	(0.023)
mother's yos	0.018	0.018	0.005	0.006	0.031	0.032	0.006	0.006	0.006	0.007
	(0.011)	(0.011)	(0.009)	(0.009)	(0.024)	(0.023)	(0.026)	(0.026)	(0.026)	(0.026)
municipality	0.043	0.046	-0.095	-0.088	0.157**	0.158**	0.090	0.095	0.234**	0.238**
	(0.105)	(0.106)	(0.106)	(0.108)	(0.079)	(0.080)	(0.060)	(0.060)	(0.106)	(0.109)
cut1	0.136	0.061	-0.391	-0.602	-0.941	-0.872	-3.648***	-3.801***	-2.194*	-2.306*
intercept	(1.089)	(1.027)	(0.782)	(0.819)	(1.392)	(1.371)	(0.933)	(0.904)	(1.273)	(1.233)
cut2	0.558	0.482	-0.031	-0.242	-0.410	-0.341	-3.225***	-3.378***	-1.626	-1.738
intercept	(1.099)	(1.034)	(0.789)	(0.823)	(1.419)	(1.397)	(0.943)	(0.915)	(1.304)	(1.264)
N					5,063					

Notes: Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p<0.01$.

C

Chapter 4 Appendix

C.1 Full results

Table C1: Logistic regression results of individual post-graduation plan choices.

	continue studies				enter the workforce			
	Traditional		Interdisciplinary		Traditional		Interdisciplinary	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
school-level	-1.945***		1.798		1.775***		-2.409***	
interdisciplinarity	(0.373)		(1.464)		(0.651)		(0.535)	
field-level		-2.312		2.965		2.279		-1.959**
interdisciplinarity		(1.415)		(2.107)		(1.818)		(0.847)
Student-related variables								
male	-0.322***	-0.329***	0.176	0.179	-2.147***	-2.143***	-2.763***	-2.702***
	(0.053)	(0.060)	(0.229)	(0.230)	(0.081)	(0.090)	(0.465)	(0.444)
high-school rank	-0.020	-0.022	0.001	-0.006	-0.031	-0.031	0.071	0.078
	(0.018)	(0.019)	(0.084)	(0.081)	(0.054)	(0.055)	(0.122)	(0.121)
final GPA	0.127***	0.125***	0.118***	0.119***	-0.125***	-0.124***	-0.112***	-0.109***
	(0.008)	(0.007)	(0.016)	(0.016)	(0.017)	(0.017)	(0.025)	(0.027)
volunteer overseas	0.045	0.035	0.581***	0.586***	-0.111	-0.107	-0.776***	-0.811***
	(0.145)	(0.145)	(0.198)	(0.178)	(0.302)	(0.301)	(0.100)	(0.112)
exchange student	-0.338***	-0.336***	-0.116	-0.108	0.293**	0.284**	0.171	0.170
	(0.108)	(0.113)	(0.251)	(0.248)	(0.130)	(0.129)	(0.297)	(0.281)
Motivation to undertake university study								
external	0.215***	0.215***	0.231***	0.196***	-0.023	-0.024	-0.152	-0.098
	(0.036)	(0.037)	(0.050)	(0.044)	(0.032)	(0.032)	(0.098)	(0.102)
internal	-0.021	-0.022	-0.202***	-0.161***	0.067	0.071	0.125*	0.075
	(0.041)	(0.039)	(0.052)	(0.058)	(0.065)	(0.062)	(0.071)	(0.099)
Admission methods								
exam	-0.075	-0.089	-0.130	-0.166	-0.094	-0.086	-0.307**	-0.336***
	(0.182)	(0.170)	(0.201)	(0.173)	(0.154)	(0.154)	(0.141)	(0.084)

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continued

	continue studies				enter the workforce			
	Traditional		Interdisciplinary		Traditional		Interdisciplinary	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
others	-0.961***	-0.894***	-1.020	-1.005	1.089**	1.024*	-1.106	-1.120
	(0.286)	(0.305)	(1.255)	(1.261)	(0.522)	(0.555)	(0.808)	(0.813)
entrance scores	-0.009	-0.011	-0.025	-0.034	-0.018	-0.017	-0.013	-0.013
	(0.019)	(0.018)	(0.024)	(0.024)	(0.021)	(0.020)	(0.038)	(0.035)
club hours	0.029***	0.029***	0.060***	0.061***	-0.010	-0.009	-0.023	-0.025
	(0.007)	(0.007)	(0.023)	(0.023)	(0.024)	(0.023)	(0.023)	(0.022)
part-time hours	-0.030**	-0.030**	-0.024	-0.023	0.069***	0.069***	0.005	0.003
	(0.014)	(0.014)	(0.028)	(0.027)	(0.015)	(0.015)	(0.037)	(0.035)
Cohorts								
cohort2013	0.134	0.126	-0.464	-0.437	-0.051	-0.046	0.975	0.907
	(0.177)	(0.169)	(0.362)	(0.369)	(0.199)	(0.207)	(0.830)	(0.866)
cohort2014	-0.097	-0.099	-0.692**	-0.710**	0.346***	0.332***	1.044**	1.074**
	(0.143)	(0.133)	(0.272)	(0.292)	(0.104)	(0.100)	(0.433)	(0.488)
cohort2015	-0.071	-0.080	-0.636	-0.630	0.529***	0.532**	1.071	1.091
	(0.162)	(0.156)	(0.409)	(0.426)	(0.201)	(0.215)	(0.728)	(0.745)
cohort2016	-0.364**	-0.360**	-0.443**	-0.430*	0.642**	0.621**	0.798***	0.773**
	(0.168)	(0.175)	(0.222)	(0.237)	(0.294)	(0.313)	(0.279)	(0.330)
cohort2017	-0.415***	-0.421***	-0.845**	-0.787**	0.844***	0.843***	0.879	0.829
	(0.113)	(0.125)	(0.335)	(0.334)	(0.265)	(0.281)	(0.802)	(0.839)
Schools								
Technology Management	0.634***	0.552***	0.349	0.090	-0.485***	-0.421***	0.065	-0.041
	(0.076)	(0.110)	(0.306)	(0.452)	(0.116)	(0.163)	(0.139)	(0.177)
Electrical Engineering	2.767***	2.561***	1.856***	1.982***	-2.044***	-1.866***	-1.467***	-1.685***
& Computer Science	(0.150)	(0.112)	(0.223)	(0.232)	(0.133)	(0.137)	(0.154)	(0.148)
Engineering	2.671***	2.363***	1.121**	1.729***	-1.994***	-1.722***	-0.447**	-1.257***
	(0.154)	(0.100)	(0.486)	(0.172)	(0.160)	(0.107)	(0.218)	(0.141)
Life Science	2.698***	2.262***	0.850	1.466***	-2.520***	-2.148***	-0.602***	-1.501***
	(0.179)	(0.132)	(0.636)	(0.163)	(0.239)	(0.181)	(0.191)	(0.176)
Nuclear Science	2.898***	2.502***	1.220**	1.885***	-2.569***	-2.211***	-2.073***	-2.938***

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continued

	continue studies				enter the workforce			
	Traditional		Interdisciplinary		Traditional		Interdisciplinary	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
	(0.172)	(0.104)	(0.586)	(0.179)	(0.200)	(0.128)	(0.224)	(0.098)
Science	2.432***	2.348***	1.397***	1.785***	-1.959***	-1.896***	-1.528***	-2.138***
	(0.116)	(0.114)	(0.311)	(0.168)	(0.128)	(0.190)	(0.224)	(0.200)
Household characteristic variables								
Father's occupation								
blue-collar	-0.124**	-0.119**	-0.140	-0.172	0.409***	0.400***	-0.117	-0.126
	(0.059)	(0.059)	(0.315)	(0.293)	(0.125)	(0.123)	(0.236)	(0.239)
other-collar	-0.279**	-0.283**	-0.135	-0.136	0.190	0.190	-0.870**	-0.884**
	(0.123)	(0.123)	(0.291)	(0.291)	(0.190)	(0.195)	(0.373)	(0.377)
Mother's occupation								
blue-collar	-0.193*	-0.180*	-0.310	-0.269	-0.239**	-0.236**	0.747	0.693
	(0.116)	(0.108)	(0.351)	(0.335)	(0.117)	(0.107)	(0.570)	(0.588)
other-collar	0.078	0.072	-0.161	-0.134	-0.110**	-0.103**	0.042	0.043
	(0.075)	(0.074)	(0.283)	(0.288)	(0.048)	(0.052)	(0.207)	(0.190)
father's yos	0.026*	0.026*	0.028	0.031	-0.033**	-0.033**	-0.096***	-0.107***
	(0.016)	(0.015)	(0.034)	(0.037)	(0.016)	(0.015)	(0.034)	(0.031)
mother's yos	-0.022**	-0.020**	-0.015	-0.016	0.014	0.011	0.067	0.068
	(0.010)	(0.010)	(0.023)	(0.023)	(0.022)	(0.022)	(0.052)	(0.053)
lowincome family	0.133	0.165	0.878	0.757	-0.157	-0.204	-0.452	-0.297
	(0.124)	(0.121)	(0.603)	(0.542)	(0.256)	(0.246)	(0.672)	(0.668)
municipality	0.019	0.024	-0.264**	-0.242**	-0.133	-0.139	0.061	0.033
	(0.096)	(0.090)	(0.124)	(0.117)	(0.150)	(0.148)	(0.181)	(0.179)
intercept	-10.108***	-9.814***	-8.279***	-7.916***	10.900***	10.687***	9.932***	9.675***
	(1.564)	(1.375)	(2.589)	(2.413)	(2.375)	(2.232)	(3.071)	(3.048)
N		5,063		859		5,063		859
pseudo R-sq	0.181	0.180	0.156	0.158	0.300	0.300	0.317	0.311

Notes: Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p<0.01$.

Table C2: Fixed effects of interdisciplinary learning on labour market outcomes

	ln salary		employment rate	
	(1)	(2)	(1)	(2)
school-level interdisciplinarity	-0.124		-0.172	
	(0.260)		(0.196)	
field-level interdisciplinarity		0.664		0.066
		(0.928)		(0.625)
interdisciplinary prog.	-0.110	0.011	-0.038	-0.114
	(0.096)	(0.165)	(0.086)	(0.107)
interdisciplinary prog.×school-level interdisciplinarity	0.293		0.151	
	(0.369)		(0.247)	
interdisciplinary prog.×field-level interdisciplinarity		-0.331		0.744
		(1.298)		(0.822)
Student-related variables				
male	0.153	0.121	-0.087	-0.073
	(0.099)	(0.099)	(0.072)	(0.068)
final GPA	0.018**	0.017*	0.002	0.002
	(0.009)	(0.010)	(0.007)	(0.007)
volunteer overseas	0.276	0.245	0.201	0.157
	(0.202)	(0.197)	(0.155)	(0.154)
exchange student	0.111	0.152	0.060	0.077
	(0.185)	(0.182)	(0.114)	(0.111)
club hours	0.017	0.019	0.012	0.014
	(0.016)	(0.015)	(0.012)	(0.011)
part-time hours	-0.036**	-0.024	0.020	0.027**
	(0.018)	(0.017)	(0.013)	(0.013)
cohort2012	0.023	0.019	0.188***	0.175***
	(0.064)	(0.064)	(0.062)	(0.062)
cohort2013	0.025	0.025	0.146***	0.140**
	(0.059)	(0.060)	(0.054)	(0.055)
cohort2014	-0.017	-0.024	0.135***	0.128***
	(0.049)	(0.049)	(0.045)	(0.045)
cohort2015	0.002	-0.003	0.075*	0.070*
	(0.046)	(0.045)	(0.040)	(0.040)
cohort2016	-0.012	-0.013	0.020	0.016
	(0.045)	(0.044)	(0.039)	(0.039)
Household characteristic variables				
father's yos	0.014	0.015	-0.003	-0.007
	(0.019)	(0.020)	(0.013)	(0.013)
lowincome family	-0.191	-0.054	0.219	0.258
	(0.502)	(0.492)	(0.407)	(0.399)
municipality	-0.006	0.017	0.272**	0.223*
	(0.168)	(0.169)	(0.119)	(0.118)
unemployment rate	-0.043	-0.044	-0.127	-0.122
	(0.099)	(0.099)	(0.119)	(0.120)
GDP deflator	-0.006	-0.006	-0.004	-0.004
	(0.005)	(0.005)	(0.006)	(0.006)
intercept	9.670***	9.581***	1.111	1.070
	(1.135)	(1.170)	(1.087)	(1.104)
N	458		561	

Notes: Variables were transformed into the programme average, except for the unemployment rate and GDP deflator. Standard errors are in parentheses.
*p < 0.1, **p < 0.05, ***p<0.01.

Figure C1: Overall effects of interdisciplinary learning on the log of average monthly real salary based on the school-level interdisciplinarity. *Notes:* The corresponding schools are as below: HSS: Humanities and Social Sciences; CTM: Technology Management; EECS: Electrical Engineering and Computer Science; ENGI: Engineering; LS: Life Science; NS: Nuclear Science; SCI: Science.

Figure C2: Overall effects of interdisciplinary learning on the log of average monthly real salary based on the field-level interdisciplinarity. *Notes:* The corresponding schools are as below: HSS: Humanities and Social Sciences; CTM: Technology Management; EECS: Electrical Engineering and Computer Science; ENGI: Engineering; LS: Life Science; NS: Nuclear Science; SCI: Science.

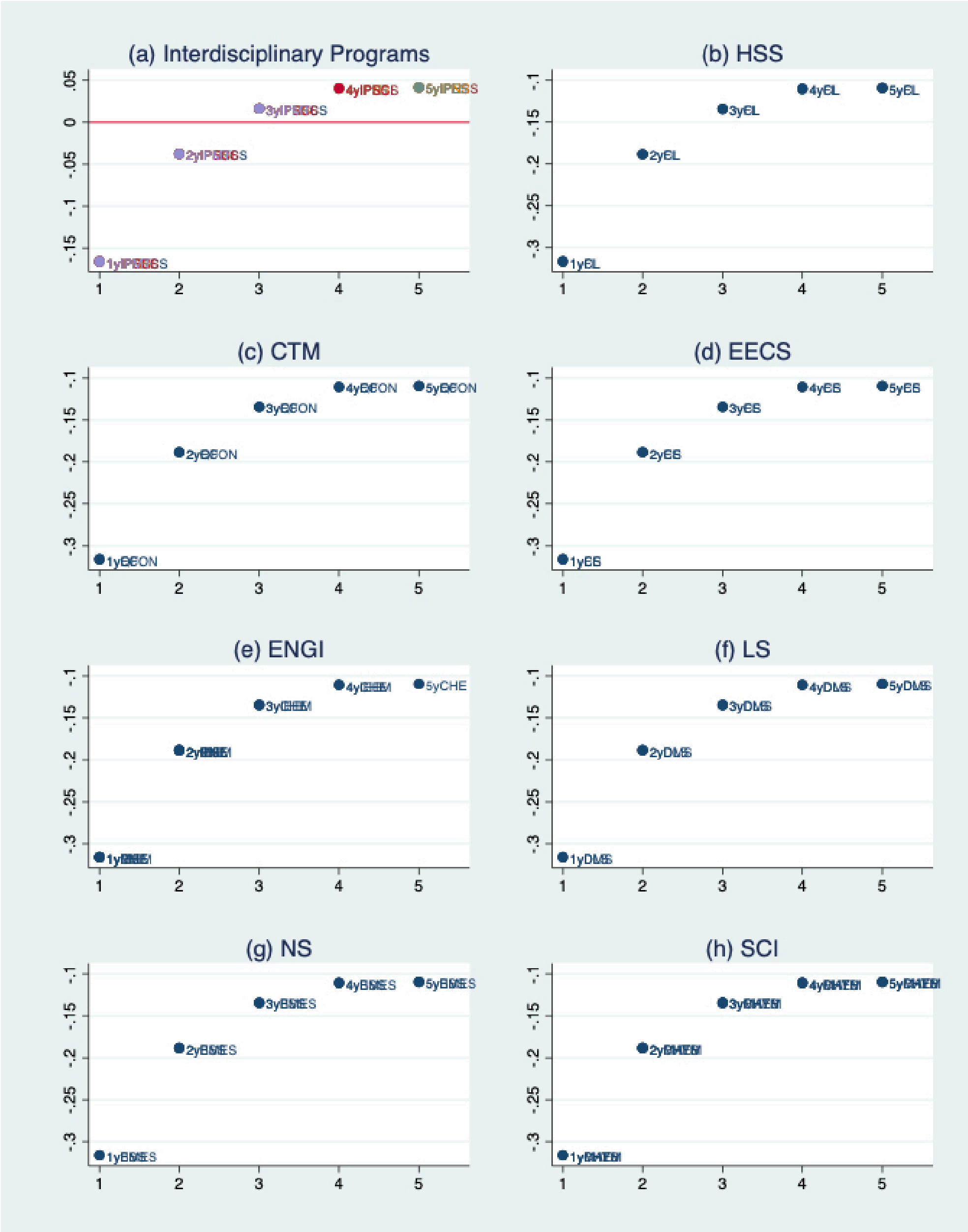

Figure C3: Overall effects of interdisciplinary learning on the employment rate based on the school-level interdisciplinarity. *Notes:* The corresponding schools are as below: HSS: Humanities and Social Sciences; CTM: Technology Management; EECS: Electrical Engineering and Computer Science; ENGI: Engineering; LS: Life Science; NS: Nuclear Science; SCI: Science.

Figure C4: Overall effects of interdisciplinary learning on the employment rate based on the field-level interdisciplinarity. *Notes:* The corresponding schools are as below: HSS: Humanities and Social Sciences; CTM: Technology Management; EECS: Electrical Engineering and Computer Science; ENGI: Engineering; LS: Life Science; NS: Nuclear Science; SCI: Science.

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