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THE ALIGNMENT OF CURRICULUM COMPONENTS OF CAMBRIDGE
IGCSE INTERNATIONAL MATHEMATICS

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Mathematics

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GRADUATE SCHOOL OF EDUCATION

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September 2025

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ABSTRACT

The Alignment of Curriculum Components of Cambridge IGCSE International

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MA in Curriculum and Instruction

Advisor: Prof. Dr. Alipaşa Ayas

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This thesis investigates the alignment among the Cambridge IGCSE International Mathematics 0607 Extended syllabus, a widely used textbook, and past examination papers. The focus is placed on the topic of functions, which constitutes a central component of the curriculum. A systematic item to learning objective mapping was first conducted to examine the extent to which textbook and assessment items reflect the official syllabus learning objectives. Items were then categorized by cognitive demand using the framework of Stein and Smith (1998). To quantify alignment between the textbook and assessments, Porter's Alignment Index (PAI) (Porter, 2002) was applied, with Kazemi's (2022) extension used to capture categories of misalignment. The analysis revealed notable discrepancies in coverage and emphasis. Several textbook items could not be mapped to any learning objective, often requiring skills or transformations not explicitly included in the curriculum. Assessments, in contrast, concentrated heavily on a limited set of learning objectives, particularly those related to function notation, and graphical calculator skills, while paying less attention to others. The application of PAI provided a numerical measure of alignment between the textbook and assessments, while Kazemi's (2022) framework further highlighted patterns of misalignment, such as overrepresentation of specific objectives and cognitive demands. These findings underscore the importance of careful textbook selection, teacher preparation, and curriculum monitoring to ensure that instruction, materials, and assessments work together to promote coherent student learning.

Keywords: Curriculum alignment, IGCSE, Functions, Porter's Alignment Index

ÖZET

Cambridge IGCSE Uluslararası Matematik Öğretim Programı Bileşenlerinin Uyum

Ada Elif Mutlu

Eğitim Programları ve Öğretim Yüksek Lisans Programı

Danışmanı: Prof. Dr. Alipaşa Ayas

Eylül 2025

Bu tez, Cambridge IGCSE Uluslararası Matematik 0607 Genişletilmiş ders programı, yaygın olarak kullanılan bir ders kitabı ve geçmiş sınav kağıtları arasındaki uyumu araştırmaktadır. Odak noktası, öğretim programının merkezi bir bileşeni olan fonksiyonlar konusudur. Ders kitabı ve değerlendirme öğelerinin resmi öğretim programı öğrenme hedeflerini ne ölçüde yansıttığını incelemek için ilk önce sistematik öğe ve öğrenme hedefi eşlemesi yapılmıştır. Öğeler daha sonra Stein ve Smith (1998) tarafından geliştirilen bir çerçeve kullanılarak bilişsel talebe göre kategorize edilmiştir. Ders kitabı ve değerlendirmeler arasındaki uyumu nicel olarak ölçmek için Porter'ın Uyum Endeksi (PAI) (Porter, 2002) uygulanmış olup uyumsuzluk kategorilerini belirlemek için ise Kazemi'nin (2022) uzantısı kullanılmıştır. Analiz, kapsam ve vurgu açısından dikkate değer birtakım tutarsızlıklar ortaya koymuştur. Birkaç ders kitabı ögesi, çoğu zaman öğrenim programında açıkça yer almayan beceri veya dönüşümleri gerektiren herhangi bir öğrenme hedefine eşleştirilememiştir. Buna karşılık değerlendirmeler, özellikle fonksiyon gösterimi ve grafik hesap makinesi becerileriyle ilgili sınırlı bir öğrenme hedef kümesine yoğunlaşırken, diğerlerine daha az yoğunlaşmıştır. PAI uygulaması ders kitabı ile değerlendirmeler arasında sayısal bir uyum ölçüsü verirken Kazemi'nin (2022) çerçevesi, belirli hedeflerin ve bilişsel taleplerin uyumsuzluk kalıplarının altını daha da çizmiştir. Bu bulgular, öğretim, materyaller ve sınavların uyum içinde çalışarak tutarlı bir öğrenci öğrenimini desteklemesini sağlamak için dikkatli ders kitabı seçiminin, öğretmen hazırlığının ve öğretim programı takibinin önemini vurgulamaktadır.

Anahtar kelimeler: Öğretim programı uyumu, IGCSE, Fonksiyonlar, Porter'ın Uyum

İndeksi

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CHAPTER 1: INTRODUCTION

Introduction

Life is not always fair. While some of us gain opportunities to broaden our horizons at earlier stages of life, others encounter them later or not at all. Türkiye, like many other countries, has been striving to adopt strategies that promote equity in education across the nation. Despite the Ministry of National Education's (MoNE) ongoing efforts and the existence of a unified national curriculum, the quality of education unfortunately still varies greatly from one region to another, even within the same city. I am a firm believer that every child deserves access to high-quality education, regardless of their socio-economic background. In light of these disparities, it is understandable that there has been increasing interest in integrating international curricula alongside the national curriculum in Türkiye. I feel privileged to have received a strong international education in high school, an experience that inspired me to become a teacher and support students with similar aspirations. As a current teacher of international curricula, I am committed to reflecting on the challenges they present and contributing to their continuous improvement.

International education is a broad term that encompasses many aspects, such as international mindedness, global citizenship, and multiculturalism (Metli & Lane, 2020; Singh & Qi, 2013). It is a growing trend globally and also in Türkiye. My experiences as both a student and a teacher in the international education system in Türkiye have raised questions about the coherence of curriculum materials. This study investigates the alignment and potential misalignment across the syllabus, the assessments, and a widely used textbook of the Cambridge International General

Certificate of Secondary Education (IGCSE) International Mathematics 0607

Extended subject. This chapter presents the background of the study, outlines the problem and its purpose, states the research questions, highlights the significance of the study, and provides definitions of key terms.

Background

In Türkiye, schooling is nationally centralised under the MoNE. With formal authorisation, selected schools may implement international programmes in parallel with the national curriculum. The most common offerings are the International Baccalaureate (PYP, MYP, and DP), IGCSE, A and AS Levels, and Advanced Placement (AP). These programmes provide internationally recognised pathways while remaining subject to national regulations.

This study focuses on the Cambridge IGCSE International Mathematics 0607 Extended subject. Its purpose is to examine the alignment and potential misalignment among three curriculum components: the syllabus, past assessments, and a widely used textbook. The analysis is conducted through document analysis and does not rely on classroom implementation data, local policy practices, or national assessment regimes.

Although the research is situated in Türkiye, the country context is not central to either the design or interpretation of findings. The documents analysed are standardised international materials that are identical across jurisdictions where Cambridge IGCSE International Mathematics is taught. References to Türkiye are therefore limited to providing orientation on how international programmes operate within a centralised national system. The contribution of this study is to evaluate how consistently the syllabus, assessments, and textbook of Cambridge IGCSE International Mathematics align with one another, offering insights that are

applicable in any setting where this curriculum is delivered. Building on this orientation, it is useful to consider briefly how international education has emerged and expanded in Türkiye, providing context for why programmes such as IGCSE are present in the country.

Emergence and Growth of International Education in Türkiye

Studies have shown that the Turkish education system is dominated by high-stakes testing (Aksoy, 2023; Ayas et al., 2013), creating a testing-oriented environment in which exam preparation often replaces classroom teaching and pressures teachers to focus on coaching for exams. This persistent emphasis on examinations helps explain the growing demand for international programmes, where assessments are less focused on placement and more oriented toward holistic learning and skills development.

In Türkiye, international programs cannot be implemented in isolation from the national education system (Ministry of National Education, 2024). According to the regulations set by the MoNE, schools authorized to offer international programs are still required to comply with the national curriculum. This means that students must continue to take compulsory subjects designated by the Turkish curriculum, such as Turkish language, history, and religious culture, regardless of their enrolment in international tracks. As a result, international programs function not as substitutes but as additions to the national framework, creating a dual-curriculum structure in which students fulfil both international and national requirements simultaneously (Ministry of National Education, 2024).

International educational institutions, which have been part of Türkiye's educational landscape for centuries, began with the establishment of Phanar Greek Orthodox College in 1454 (Özel Fener Rum Lisesi, n.d.). Currently, these minority,

foreign, and international institutions constitute a small fraction of the overall schools in Türkiye and primarily cater to international students.

The earliest recognition of the International Baccalaureate (IB) in Türkiye was in 1994, in Koç School (International Baccalaureate Organization [IBO], n.d.). The IB is the most recognized international program in Türkiye, with 123 schools offering one or more of IB's four programs (IBO, n.d.). IB Diploma Programme (IBDP) is the most popular of IB's four programs, with 80 schools in Türkiye, offered to 16 to 19-year-olds, followed by IB Primary Years Programme (IBPYP) with 70 schools, a program offered to 3-11-year-olds. With only 16 schools offering IB Middle Years Programme (IBMYP), offered to 11 to 16-year-olds, there is a need for another international program to prepare students for IBDP. Institutions often turn to alternative international programs to address the absence of the IBMYP in many schools, with the IGCSE being the primary choice. IGCSE is currently offered in 45 schools in Türkiye (Cambridge Assessment International Education [CAIE], n.d.-g).

The Cambridge International General Certificate of Secondary Education

The Cambridge IGCSE is the most popular international program for students aged 14-16, offering qualifications that are recognized and valued worldwide (CAIE, n.d.-b). It was created by the University of Cambridge in September 1986, at the same time as the General Certificate of Secondary Education (GCSE), which is its UK equivalent (CAIE, n.d.-c).

While GCSE is considered the national curriculum in the UK (UK Government, n.d.), IGCSE is typically taught alongside the national curriculum of the country where it is offered. IGCSE includes more than 70 subjects, including 30 languages, and gives schools the flexibility to choose which subjects they offer

(CAIE, n.d.-d). In some subjects, there is an option to choose either the Core subject content or the Extended subject content. The Core subject content is within the ability range of the majority of students, with the maximum mark being a C.

Whereas the Extended subject content is designed for more academically able students; they can achieve grades from A* to E (CAIE, n.d.-d). Compared to GCSE, which has mandatory subjects of English, mathematics, and science; no subject is compulsory under IGCSE guidelines. However, it is common for the IGCSE schools in Türkiye to require students to study IGCSE English, mathematics, and science as the schools see IGCSE as a preparation for other international programs such as IB, AS/A Levels, or AP.

The learner-centred and inquiry-based approach of IGCSE helps with developing skills such as problem-solving and creative thinking, which are helpful for students to prepare for their next step in education. This makes IGCSE compatible with other curricula, making it easier to integrate with the national curriculum of the country.

Cambridge IGCSE International Mathematics 0607

Students are individually assessed in each subject. The topic of this research, Cambridge IGCSE International Mathematics 0607, is assessed based on three different papers. As mentioned above, in some subjects, students are allowed to choose between Core or Extended subject content. For Cambridge IGCSE International Mathematics, students who choose the Core subject content take Papers 1, 3, and 5, whereas the ones who pick the Extended subject content take Papers 2, 4, and 6. In this research, only the Extended subject content is considered.

Paper 2 (worth 40%) is a 90-minute, non-calculator exam that includes structured and unstructured questions. Similarly, Paper 4 (worth 40%) is also a 90-

minute exam with structured and unstructured questions, in which students are allowed to use a graphic display calculator. Paper 6 (worth 20%) is again a 90-minute exam with one investigation section, and one modelling section. All these papers are externally assessed by CAIE.

For this course syllabus, there are two assessment objectives (AOs) which are defined as below by CAIE. Both of these AOs have about ten objectives that explain what candidates should be able to do in regards to these AOs.

AO1: Knowledge and understanding of mathematical techniques

AO2: Analyse, interpret and communicate mathematically

The weighing for AOs is summarized below in Table 1 and Table 2.

Table 1

Assessment Objectives as a Percentage of The Extended Qualification Overall

Assessment Objective	Weighing in IGCSE %
AO1: Knowledge and understanding of mathematical techniques	40–50
AO2: Analyse, interpret and communicate mathematically	50–60
Total	100

Note. Adapted from <https://www.cambridgeinternational.org/Images/662472-2025-2027-syllabus.pdf> (CAIE, 2023)

Table 2*Assessment Objectives as a Percentage of Each Component*

Assessment Objective	Weighing in components %		
	Paper 2	Paper 4	Paper 6
AO1: Knowledge and understanding of mathematical techniques	40–50	40–50	25–35
AO2: Analyse, interpret and communicate mathematically	50–60	50–60	65–75
Total	100	100	100

Note. Adapted from Syllabus Cambridge IGCSE International Mathematics 0607 (CAIE, 2023)

CAIE has five endorsed resources to support teachers and students with Cambridge IGCSE International Mathematics 0607: two books from Cambridge University Press, one book from Hodder Education, one website called Kognity, and lastly one book from Haese Mathematics (CAIE, n.d.-e). Cambridge IGCSE International Mathematics (0607) Extended (3rd edition) by Haese Mathematics will be the textbook of analysis for this thesis.

Problem

Clear alignment among learning objectives, instructional materials, and assessment tasks is considered important for supporting equitable mathematics education and for narrowing the gap between national and international standards (Polikoff, 2012; Webb, 1997). However, it is uncertain whether international mathematics curricula consistently demonstrate such alignment within their own structure. This raises the need to examine how well their components are coordinated to ensure coherent instruction.

In the Cambridge IGCSE International Mathematics 0607 Extended subject, both the syllabus and the examination papers (Papers 2, 4, and 6) are produced by Cambridge International, which provides an inherent degree of consistency between the stated learning objectives and the assessments. By contrast, the Haese Mathematics textbook, while endorsed by Cambridge, functions as the principal instructional resource for many teachers and students without any systematic evidence confirming its alignment beyond the endorsement itself. Preliminary observations indicate that the textbook's coverage and depth of explanation may not always correspond to the emphasis placed in the syllabus or past examinations. Certain learning objectives that hold considerable assessment weight appear to receive only limited attention in the textbook, whereas other learning objectives may be treated more extensively than their representation in assessments suggests. In the absence of a documented analysis of this alignment, educators and curriculum planners lack clear guidance on whether the textbook provides comprehensive preparation for learners. This gap motivates the present study, which examines the degree of alignment among the key curriculum components of the Cambridge IGCSE International Mathematics 0607: the syllabus learning objectives, the Haese textbook, and the past examination papers.

By September 2025, scholars had not yet conducted a systematic investigation into the alignment of curriculum components for any Cambridge IGCSE subject. In particular, there is a complete absence of research examining the three-way alignment among the officially prescribed learning objectives, the instructional content of endorsed textbooks, and the structure and emphasis of the corresponding assessments. This thesis addresses that gap by evaluating how well

these three elements correspond to one another, providing the first comprehensive analysis of their interrelationships in the context of IGCSE mathematics.

Purpose

The purpose of this study is to examine the alignment of curriculum components in the Cambridge IGCSE International Mathematics 0607 course, with a particular focus on the topic of functions, which is a central topic in the curriculum. The study first identifies all function-related learning objectives from the official syllabus and prepares them for analysis. These learning objectives are then examined across past examination papers and the Haese Mathematics textbook to determine how many are covered and how this coverage is distributed.

The research investigates both the frequency with which learning objectives appear and the balance of attention they receive in each component. By comparing these distributions, the study makes it possible to see which learning objectives are consistently emphasized across past examination papers and the Haese textbook, and which learning objectives receive less systematic coverage.

The results of the study revealed areas of both alignment and misalignment in the coverage of functions, which may influence how teachers and students allocate their instructional time and preparation efforts. A key outcome is to clarify the extent to which the syllabus, examinations, and textbook support one another, offering evidence that may guide teachers, curriculum planners, and textbook authors in fostering more coherent preparation for learners.

Research Questions

This thesis aims to answer the following questions:

1. What is the extent and emphasis of coverage in the Haese Mathematics textbook review sets and the Cambridge IGCSE International Mathematics examinations of the syllabus' function topic learning objectives?
2. To what extent do the Haese Mathematics textbook review sets and the Cambridge IGCSE International Mathematics examinations align for function topic learning objectives, as measured by Porter's Alignment Index?
3. Which misalignment types, per Kazemi's misalignment framework, are observed between the Haese review sets and the Cambridge IGCSE International Mathematics examinations for the function topic learning objectives?

Significance

Focusing on the functions topic within the Cambridge IGCSE International Mathematics 0607 programme, this research offers the first empirical analysis of alignment gaps between the Haese International Mathematics textbook, and the official syllabus learning objectives and assessments. By pinpointing specific areas where textbook content either under-represents or over-emphasizes learning objectives, the study provides teachers with clear guidance on where supplemental instruction or alternative resources are needed to fully address curriculum requirements. Curriculum planners and school administrators can use the findings to make informed decisions about textbook adoption and to develop targeted professional development that strengthens alignment in lesson planning and assessment design.

For textbook publishers, the evidence-based insights highlight opportunities to revise content structure, exercise selection, and cognitive challenge to better support intended learning outcomes. Although the study concentrates on functions,

its methodological framework can be extended to other topics or subjects, thus informing broader efforts to ensure coherence within the teaching–learning–assessment triad. Ultimately, the study contributes to the enhancement of instructional quality by fostering a more transparent and systematic relationship among syllabus objectives, textbook materials, and examination demands, thereby supporting more effective

Definition of Key Terms.

Learning Objective (LO): A specific statement in the syllabus that describes the knowledge, skills, or processes that students are expected to acquire.

Syllabus: The official document published by Cambridge Assessment International Education (CAIE) that outlines the aims, assessment objectives, and learning objectives of the IGCSE International Mathematics (0607) course

Textbook: The Cambridge IGCSE International Mathematics (0607) textbook by Haese Mathematics, used as the instructional material under analysis.

Assessment: The past IGCSE International Mathematics (0607) examination papers issued by CAIE, which serve as the official assessments of the syllabus.

Item: An individual question, or part in an assessment paper or textbook exercise that requires a response from the student. Items are used as the unit of analysis in the mapping process.

Mark: The numerical value assigned to an item or part of an item in an assessment. Marks indicate the relative weight of the item in determining student performance.

Alignment: The extent to which two or more curriculum components (syllabus, textbook, assessments) address the same learning objectives with comparable emphasis.

Porter's Alignment Index (PAI): A quantitative measure of alignment that compares the distribution of items across topics and cognitive demand levels in two curriculum components.

Kazemi's Misalignment Framework: An extension of Porter's model that categorizes misalignment into different types, identifying whether gaps arise from missing content, additional content, or differences in emphasis (Kazemi, 2022).

Cognitive Demand Level: The level of thinking required to complete a task, classified in this study using Stein and Smith's (1998) framework: memorization, procedures without connections, procedures with connections, and doing mathematics.

CHAPTER 2: REVIEW OF RELATED LITERATURE

Introduction

This chapter presents a review of the relevant literature that forms the theoretical and conceptual foundation of the thesis. In order to understand the complex interplay between the components of a curriculum, specifically learning objectives (LOs), textbooks, and assessments, the chapter begins by exploring the nature of curriculum and the historical development of curriculum models. It then examines the integration of national and international curricula in different contexts. Subsequent sections address the role of LOs, the significance of textbooks, and the nature of assessments. The chapter concludes with a review of alignment studies concerning these key curriculum components. Given that the empirical focus of this thesis is the functions topic within the Cambridge IGCSE International Mathematics (0607) course, the review opens with the importance of functions in secondary mathematics and their value as an analytic lens for alignment among LOs, textbooks, and assessments.

Importance of Function Topic in Mathematics

Functions are the main topic of this thesis because of its central in secondary mathematics. Functions are one of the first places where students must connect equations, tables, and graphs as different forms of the same idea. Leinhardt et al. (1990) argue that functions and graphs mark an early stage where learners use one representation to make sense of another, for example, linking an algebraic rule, a data table, and a graph. They also describe early graphing work as a critical moment that can enable powerful learning when instruction is well designed. Studying functions, therefore, offers a clear lens on the kinds of translation demands that

curricula and assessments impose, and on whether classroom materials actually prepare students to make those translations.

Recent classroom evidence shows a practical way to support this work. In a high-school functions unit, a Desmos-based sequence produced larger pre- to post-test gains than a comparison class, and students reported that dynamic graphing helped them examine intercepts, turning points, and parameter effects (Chechan et al., 2023). In the context of this thesis, such findings motivate checking whether the textbook review sets and past examinations provide tasks that ask students to move between forms at suitable levels of demand and, where needed, whether technology-supported tasks would strengthen that alignment.

History of Curriculum and Ideologies

Curriculum is a foundational element within educational contexts, broadly defined as a structured framework outlining educational goals, content, teaching strategies, and assessment methods. According to Kelly (2009), curriculum comprises the planning and systematic organization of educational experiences that learners encounter under institutional guidance. It serves not only as a guide for educators to deliver content but also as a means to align instructional practices with desired educational outcomes (Tyler, 1949). A well-designed curriculum clearly articulates the intended LOs, thereby influencing both teacher instruction and student learning experiences.

Historically, the concept of curriculum has evolved significantly. Tyler (1949) introduced a systematic approach emphasizing clearly defined educational objectives, relevant learning experiences, and effective assessment practices to achieve desired learning outcomes. Building upon Tyler's foundational work, Taba (1962) proposed a particularly influential model comprising four interrelated

components: LOs, subject matter, learning experiences, and assessment. This model highlights curriculum as a coherent integration of these critical elements.

Curriculum models have since diversified to reflect a range of theoretical orientations and contextual needs. Ornstein and Hunkins (2017) offer a comprehensive classification of curriculum models, including product-oriented models such as those of Tyler and Taba, which emphasize pre-specified objectives and measurable outcomes. In contrast, process models, as exemplified by Stenhouse, focus on curriculum as a dynamic and evolving set of educational experiences, privileging teacher judgment and classroom interaction. Developmental and learner-centred models, such as those informed by Bruner, Piaget, and Vygotsky, prioritize the cognitive and social growth of learners, emphasizing age-appropriate sequencing, scaffolded learning, and increasing complexity over time.

Furthermore, curriculum encapsulates more than mere content delivery; it reflects educational philosophies, societal values, and pedagogical perspectives, providing direction and coherence across instructional practices (Eisner, 2002). Curriculum ideologies have historically shaped how curricula are designed and implemented, influencing both educational priorities and classroom practices. Understanding these historical developments is vital, as they provide the foundation for how curriculum is conceptualized and enacted in different contexts. Building on this historical perspective, the following section explores how national and international curricula have been integrated across various countries. This discussion helps frame the broader context in which curriculum components such as LOs, textbooks, and assessments are developed and aligned.

Integration of National and International Curricula

The integration of national and international curricula has become an increasingly prominent feature of secondary education, particularly in contexts where schools seek to maintain national compliance while offering students access to globally recognized academic opportunities. Rather than replacing national frameworks, international programs are frequently implemented in parallel, resulting in hybrid curricular models that must balance competing pedagogical and structural demands.

Resnik (2012) offers a theoretical foundation for understanding these developments through the concept of *educational denationalization*, which refers to the process by which global curricular frameworks are incorporated into national systems. According to her analysis, programs such as the IB are commonly layered onto national curricula rather than substituting for them, particularly in elite and internationally oriented schools. This dual implementation model enables institutions to preserve national educational legitimacy while simultaneously enhancing global academic mobility. However, it also introduces institutional and pedagogical tensions, including challenges related to content alignment, assessment design, and teacher workload (Resnik, 2012).

In China, the integration of international curricula, such as Cambridge International and the IB, has become widespread within various schools aiming to cultivate globally competitive students. Yang (2024) systematically reviewed this integration, highlighting significant advancements in the adoption of international educational frameworks and innovative teaching methodologies. Nevertheless, substantial challenges persist, including limited empirical evidence demonstrating the effectiveness of different teaching models, insufficient strategies for localizing

international content, and a lack of clear frameworks for developing students' cross-cultural competencies (Yang, 2024).

Indonesia offers a contrasting approach, exemplified by a case study at Kesatuan Bangsa High School in Yogyakarta. Here, the Indonesian national curriculum (Curriculum 2013) has been systematically integrated with the IGCSE, particularly within mathematics and science disciplines (Zamroni & Haryanto, 2020). Curriculum planning in this context was predominantly driven by subject-specific teacher forums, guided by the support of school administrators. Despite effective local planning and high curriculum overlap, logistical difficulties arose, notably concerning differing assessment schedules and mismatch in subject content (Zamroni & Haryanto, 2020). This illustrates a model where integration is managed at the institutional level, emphasizing flexibility and responsiveness to local educational contexts.

These integration efforts are often underpinned by broader educational goals such as international-mindedness and global citizenship, which have become central to the discourse of international education. International-mindedness reflects a commitment to intercultural understanding, respect for diversity, and global awareness, and is promoted as a core value in widely adopted international frameworks such as the IB and Cambridge programs. Closely related is the notion of global citizenship, which introduces a normative and participatory dimension. As outlined by UNESCO (2015), global citizenship education aims to equip learners with the knowledge, skills, and values required to engage actively with global issues and contribute to a more equitable and sustainable world. In hybrid curricular settings, these ideals often serve as guiding principles, although their realisation is shaped by national policy contexts, institutional resources, and curriculum alignment.

The integration of international programmes into national systems has also taken root in Türkiye, where international education has expanded significantly over the past two decades. Due to national regulatory frameworks, schools in Türkiye are not permitted to offer international programmes independently; instead, such programmes must be implemented alongside the national curriculum prescribed by the MoNE. This legal requirement ensures that all students receive the nationally mandated content while allowing schools to supplement it with international components. While the coexistence of national and international curricula presents particular institutional and pedagogical challenges, it also reflects Türkiye's growing engagement with global educational trends. Situating this within a broader context allows for a more comprehensive understanding of how international education has historically developed in Türkiye and how it continues to evolve in response to global and local forces.

In Türkiye, international education gained popularity starting from the late 1990s, reflecting a broader global trend. The first IB school in Türkiye was Koç School in 1994 with the IB Diploma Programme (IBDP) (IBO, n.d.). The first school to offer IGCSE in Türkiye was Pakistan Embassy International Study Group, starting in 2001 (Pakistan Embassy International Study Group, n.d.). IB Middle Years Programme (IBMYP) which is catered towards the same age group as IGCSE is offered in 15 schools in Türkiye whereas IGCSE is offered in 45 schools (CAIE, n.d.-g ; IBO, n.d.). Out of these 45 schools, 16 schools offer only IBDP, 12 schools offer only A Levels, two schools offer AP, and one school offers IBDP and A Levels for the last two years of high school. The remaining schools do not offer an international program for the last two years of high school.

Recent research, particularly by Çorlu (2015), provides empirical evidence of the effectiveness of IGCSE in preparing students for higher-level international education, specifically the IBDP in the context of mathematics and science subjects. Çorlu's comparative study illustrates that students transitioning from IGCSE demonstrate superior academic readiness and adaptability compared to their counterparts from the IBMYP, particularly due to IGCSE's structured, rigorous, and content-specific pedagogical approach (Çorlu, 2015).

Overall, these findings emphasize that well-structured international curricula such as the IGCSE offer substantial benefits in terms of academic rigor, clear LOs, and better preparation for advanced educational stages. Consequently, they underscore the curriculum's critical role not only as an instructional tool but also as an essential component in shaping educational experiences and outcomes at both national and international levels.

Curriculum Components and Their Alignment

While the integration of national and international curricula highlights the broader structures through which educational systems organise content and standards, understanding how a curriculum functions in practice requires a closer look at its internal components. Understanding the curriculum is crucial, as it directly impacts teaching effectiveness, learner engagement, and ultimately, student achievement (Marsh & Willis, 2007). This calls for an investigation not only into how curricula are adopted or adapted but also into how their core components, such as LOs, textbooks, and assessments, interact within a single curriculum. The sections that follow examine each of these elements in detail and consider how their alignment influences the coherence and effectiveness of the curriculum as a whole.

Learning Objectives and Assessments

Learning objectives (LOs) are an essential part of a curriculum. Orr et al. (2022) defines LOs as “as a statement that communicates the purpose of instruction using an action verb and describes the expected performance and conditions under which the performance should occur” (p.1). This definition is heavily inspired by Robert F. Mager’s book, *Preparing Instructional Objectives*. In his book, Mager (1997) states that objectives must be statements that denote measurable attributes that are observable at the end of a program. He emphasizes that objectives “relate to the evaluation of the degree to which the learner is able to perform in the manner desired” (Mager, 1997, pp. 3-4). With this description of objectives, Mager relates LOs to assessment. He explains that assessments are milestones in the learning process that tell both the teacher and the student the degree to which objectives are successfully achieved. Mager also states that LOs should be written in such a manner that two people who read it should understand the exact same thing, nothing more or nothing less. He lists some verbs that are open to many interpretations and fewer interpretations (Mager, 1997). The verb *understand* in the list *Open to Many Interpretations* interested me, as the verb *understand* is heavily used in many objectives in various mathematics curricula. To give an example from Cambridge IGCSE International Mathematics 0607 (Extended) curriculum, which is the focus of this study, the verb *understand* is used in 16 LOs. For the syllabus LOs, see Appendix A.

Mager (1997) explains that the usage of the verb *understand* as the action verb of the objective is acceptable if and only if the objective describes what the student will be doing when demonstrating that he understands. Mager asks the readers if the statement ‘to understand the rules of logic’ is stated in performance

terms. He later explains that the statement does not say what the student will be doing in order to show that he understands: “Will he be reciting them? Will he be listing them? Will he be solving problems in logic? If so, what kind of problems?” (Mager, 1997, p. 22).

The main focus of this study is Cambridge IGCSE International Mathematics 0607. For this curriculum, the teachers are not offered a curriculum to use as a guide but a syllabus. This syllabus includes comprehensive information about subject content which includes LOs for both Core and Extended, assessment details (list of formulas, command words, mathematical conventions), grade descriptions, and changes from the previous syllabus. In this thesis, I will not be critiquing how well IGCSE International Mathematics 0607 LOs are written. However, it is important to note that some LOs in the syllabus need to be separated into two or more LOs, as explained in Chapter 3. To give an example, the LO E3.3 Functions has three sub-learning objectives, as can be seen in Appendix A. To reflect this more accurately, I split E3.3 into three sub-learning objectives E3.3.1, E3.3.2, and E3.3.3, each corresponding to one of the skills listed in the original syllabus LO.

Orr et al. (2022) argue that each assessment item should be matched with at least one objective. Although this does not necessarily mean that LOs that contain more than one action word should be separated, it makes the matching process easier and more accurate.

Effect of Learning Outcomes on Students

A study by Osueke et al. (2018) examined how undergraduate science students ($n = 185$) incorporated LOs into their study strategies and found multiple benefits. Participants reported that using LOs not only guided their study behaviours but also led to perceived improvements in academic outcomes, including higher

exam scores and increased confidence in mastering course material. These outcomes align with broader evidence that clear, structured LOs support enhanced student performance and deeper engagement with content.

Students described how LOs helped them narrow their focus and organize their studying (Osueke et al., 2018). One participant noted, “The book is dense and the cases are detailed. The LOs serve to direct my studying so as not to waste time. It helped emphasize what’s important” (Osueke et al., 2018, p. 4). Such prioritization reflects metacognitive strategies, whereby learners consciously select and monitor study activities to improve understanding and retention. Almost half of the students (47.4%) transformed LOs into self-assessment questions, actively engaging with the material through practice testing. This behavior illustrates how LOs can stimulate deeper cognitive processing and self-regulated learning, contributing to enhanced mastery of content. Moreover, 81.2% of students perceived a very good alignment between LOs and exam questions, with an additional 15.0% indicating fair alignment, which is evidence that well-constructed LOs can boost students’ confidence in the relevance of assessments (Osueke et al., 2018).

A study by Brooks et al. (2014) surveyed biological sciences, English, and medicine students from the University of Leicester, UK, where 918 students responded. The vast majority (81%) agreed that learning outcomes (LOs) serve as helpful study aids, and nearly half reported that LOs became more useful, and that they engaged with them more over the course of their degree. When asked about timing, almost half the sample found LOs most valuable during revision sessions, with far fewer citing pre- or in-class uses. Although roughly half of respondents felt that full comprehension of an LO only emerges after completing the relevant module, a substantial minority disagreed. Some students (around 18–27%, depending

on year) expressed concerns that LOs can narrow their learning scope or fragment their understanding of the broader subject. Paradoxically, two-thirds of students nonetheless desired even more detailed, prescriptive statements of outcomes, suggesting that clarity is broadly welcomed (Brooks, et al., 2014).

Sana et al. (2020) performed three experimental studies on psychology undergraduate students at McMaster University. In Experiment 1 ($n = 164$), students studied five neuroscience passages under three conditions: some students did not receive LO statements (control, $N = 56$), some were presented to 15 LOs at once (LO-massed, $N = 53$), and some were shown LOs before each passage (LO-interpolated, $N = 55$). On a 15-item final test, the control group averaged 47% correct, the LO-massed group 53%, and the LO-interpolated group 55%. Both LO conditions produced clear gains over control, with interpolated presentation yielding a modest additional benefit. These results indicate that simply exposing students to explicit LOs enhances retention and test performance compared to no objectives. In Experiment 2, a new sample of 158 students compared three study-phase strategies: reading passive LO statements ($N = 53$), reading factual statements that included the correct answers ($N = 52$), or answering multiple-choice pretest questions based on the objectives ($N = 53$). On the final assessment, those who engaged in passive LO reading scored 53% correct, those reading factual statements 57%, and those completing multiple-choice pretests 67%. The multiple-choice pretest condition markedly outperformed both passive conditions, demonstrating that active engagement with objectives via pretesting, rather than mere exposure to outcomes or facts, yields the greatest improvement in learning and retention. In a 2×2 design with 193 participants in Experiment 3, researchers tested multiple-choice versus short-answer pre-tests and the presence or absence of immediate feedback. Both multiple-

choice and short-answer formats led to similar final scores (around 62% correct). However, students who received corrective feedback on their pre-test responses scored 58%, whereas those who did not receive feedback scored 66%. This counterintuitive finding suggests that withholding feedback on pre-tests can actually enhance subsequent learning, perhaps by encouraging more effortful retrieval during study (Sana et al, 2020).

Despite a number of rigorous investigations at the university level demonstrating how clearly articulated LOs can improve student engagement, self-regulation, and academic performance, my comprehensive literature search uncovered little to no credible empirical studies addressing these effects specifically in the high-school context. This absence is particularly striking given that adolescence represents a critical period for study habits that underpin later academic success. Although exploring this “high school gap” is beyond the scope of this thesis, recognizing its existence underscores an important direction for future research.

These studies together show that clear LOs help students to focus their study and improve their test performance. LOs give students a clear idea of what they need to learn and help them to organize their revision more efficiently. Many students use LOs to create their own practice questions or to guide their self-testing, which gives them more confidence when they go into assessments. At the same time, the results about feedback timing and the amount of detail in outcomes remind teachers that how they present objectives matters. If LOs are too general, students may feel lost. Conversely, if they are too detailed, students may feel constrained. In this way, finding the right balance in writing and sharing LOs can help students build stronger study habits and feel more assured in their own learning.

In this section, I looked at how LOs effect students' performance in assessments. In the next section, I will explain how assessments influence both teaching practices and student learning, a phenomenon known as the backwash effect.

Backwash Effect

The concept of backwash (or sometimes referred to as washback) is the effect of assessment on teaching and learning. It helps explain how LOs interact with assessments in shaping educational outcomes. Negative backwash occurs when assessments emphasize low-order knowledge and skills, causing both teaching and learning to become test-driven rather than learning-driven. Crooks (1988), and Frederiksen and Collins (1989) believe that backwash is almost always negative (as cited in Biggs and Tang, 2007). Although teachers believe that LOs are the core of the teaching system, Ramsden (1992) states that it is the opposite for students: "from our students' point of view, assessment always defines the actual curriculum" (p. 187), highlighting how exam-focused systems can constrain substantive learning.

In contrast, positive backwash occurs when assessments are constructively aligned with clear LOs, encouraging both teaching and studying practices that foster higher-order thinking and authentic comprehension. Alderson and Wall (1993) hypothesize that "a test will influence what and how teachers teach and what and how learners learn" (p. 9), underscoring the formative potential of well-designed assessments to reinforce meaningful learning experiences.

Together, the findings on LO-driven student strategies and the dual nature of backwash emphasize the critical role of LOs in achieving constructive alignment. When learning outcomes guide both study behaviours and assessment design, they may lead to surface learning if washback is negative, but foster deeper engagement

and better outcomes when washback is positive. This dual perspective informs the present study's analysis of coherence among curriculum standards, textbooks, and assessment practices in the mathematics program. Although Biggs and Tang (2007) emphasize the importance of constructive alignment, they do not provide a detailed procedure for its implementation.

Textbooks in Curriculum Delivery

In mathematics education, textbooks serve as a crucial bridge between broad curricular goals and the realities of classroom instruction. Pepin and Haggarty (2001) state that textbooks are an important vehicle in connecting knowledge to school domains, positioning them as the most tangible representation of the intended curriculum in teachers' hands. Unlike some literacy-based subjects, which occasionally use the help of textbooks in classroom instruction, mathematics has consistently relied on textbooks as the main instructional tool (Remillard, 2005). This dependence is influenced by societal perceptions of the subject and many teachers' preference for structured content (Remillard, 2005). In a study done by Sosniak and Stodolsky (1993), they found that elementary teachers who adapted and enriched reading materials often followed math textbooks more strictly and rigidly. For this reason, efforts to reform mathematics instruction frequently centre on producing revised textbooks and curriculum materials (Ball & Cohen, 1996).

Commercially published curriculum materials shape teachers' beliefs about important content and their role in instruction. Ball and Cohen (1996) observe that these materials dominate teaching practice, creating a uniquely intimate connection to classroom work. Fan and Zhu (2007) further note that many mathematics teachers use textbooks as a source while structuring their teaching approach, demonstrating how textbooks inform the sequencing of topics and the selection of tasks in

developing lesson plans. Henning (1996, p.2) reports that “between 67 to 90 percent of all classroom instruction consists solely of textbook applications,” with mathematics classes at the top end of this scale with 90 percent. This high dependency is reinforced by teachers’ professional identities: those lacking confidence may resist changing their practice and/or gravitate towards more scripted curricula (Remillard, 2005).

In contexts where alternative curriculum supports are limited, textbooks often become the default guide for instruction. Polikoff (2015) states that textbooks mediate the standards-to-practice continuum, effectively driving instruction even when digital or reform-based materials exist. Research also highlights that textbook usage in classrooms ranges from minor use to the de facto curriculum, dependent upon individual teachers’ views on teaching and learning and the discipline taught.

The heavy reliance on the textbooks of mathematics teachers is what prompted me to choose this topic for my thesis. In the next chapter, I will show methodologies for alignment between three important components of a curriculum: LOs, textbooks, and assessments.

Alignment Studies

Following a comprehensive review of the literature on curriculum alignment, three primary methodologies have been identified for analysing the alignment of curriculum components: the Webb Methodology (Webb, 1997), the Achieve Methodology (Rothman et al., 2002), and the Survey of Enacted Curriculum (SEC) developed by Porter and Smithson (2001). In addition, a more recent framework introduced by Kazemi (2022) builds on the SEC model to examine patterns of misalignment. The following sections provide a brief overview of each of these methodologies.

Webb Methodology

One of the most widely cited and implemented models for evaluating curriculum alignment is Webb's methodology, developed by Norman L. Webb (1997). This approach was initially designed to assess the alignment between educational standards and standardized assessments, particularly in the context of U.S. educational reform. According to Webb (1997), alignment refers to "the degree to which expectations and assessments are in agreement and serve in conjunction with one another to guide an education system toward students learning what they are expected to know and do" (p.4). This methodology aims to evaluate not just content correspondence, but also the cognitive rigor demanded by both curriculum standards and assessment tasks. Webb's model relies on four main alignment criteria: categorical concurrence, depth-of-knowledge (DOK) consistency, range-of-knowledge correspondence, and balance of representation.

Categorical concurrence is present when the same general content categories appear in both the curriculum and the assessment. This occurs when similar topic headings and subtopics are included in each, though the level of detail may differ depending on how broadly or specifically the standards and assessments are defined.

Depth-of-knowledge consistency evaluates the degree to which the cognitive complexity of the content matches across the two components. Webb defined four DOK levels, which allow evaluators to judge the level of reasoning or thinking required: Level 1 (recall), Level 2 (skill/concept), Level 3 (strategic thinking), and Level 4 (extended thinking) (Webb, 1999).

Range-of-knowledge correspondence refers to how well the assessment reflects the full scope of knowledge outlined in the expectations or standards within each topic. Even when the general content categories match (i.e., categorical

concurrence is present), the assessment may not fully capture the breadth of knowledge intended due to constraints like time, cost, or test length, which shows low range-of-knowledge correspondence.

Balance of representation refers to whether the expectations and assessments give similar emphasis to different content areas and skills. It is not just about including topics, but also about how much importance is given to each. For proper alignment, the distribution of topics and the weight they receive in both documents should reflect the same priorities (Martone & Sireci, 2009; Webb, 1997). The process typically involves trained subject-matter experts who independently evaluate whether assessment items align with standards in terms of both content and DOK level.

Afterward, alignment indices are calculated for each criterion based on predefined cut-off thresholds. If the resulting values meet or exceed the thresholds, the alignment is considered acceptable (Martone & Sireci, 2009). Despite its strengths such as its structured criteria, transparent thresholds, and reliability across multiple subject domains, Webb's model has limitations. Most notably, it was developed for standards–assessment comparisons and is therefore not suitable for evaluating instructional materials such as textbooks or classroom teaching (Bhola et al., 2003; Martone & Sireci, 2009). This restricts its applicability in studies like the present one, which aims to investigate the alignment of a textbook to curriculum standards.

Achieve Alignment Methodology

Another prominent approach to alignment analysis is the Achieve methodology, developed by the U.S.-based organization Achieve, Inc. during the early 2000s in response to growing interest in standards-based educational reform

(Rothman et al., 2002). Similar to Webb's model, the Achieve methodology is primarily concerned with evaluating the degree of alignment between curriculum standards and assessments, particularly in terms of both content and cognitive demand. However, unlike Webb's matrix-based, quantitatively scored model, the Achieve approach is characterized by its qualitative and judgment-based orientation. It employs panels of experts who analyse the extent to which assessment tasks faithfully represent the expectations set by curriculum standards.

The Achieve model relies on a process known as item-to-standard matching, where each assessment item is individually reviewed and aligned to the most appropriate learning standard. This process includes identifying whether an item fully, partially, or insufficiently addresses the standard, and also whether it assesses the intended level of cognitive complexity. The model emphasizes the accuracy, depth, and breadth of alignment, incorporating both content representation and cognitive challenge. Importantly, the Achieve methodology uses descriptive summaries rather than numeric indices, highlighting strengths and weaknesses in alignment through written evaluations and expert consensus (Martone & Sireci, 2009; Rothman et al., 2002).

A distinctive feature of Achieve's approach is its attention to instructional implications. Reviewers not only examine whether an item aligns with a standard, but also whether the item reflects the type of instructional task that the standard implies. This focus on instructional validity makes the method particularly useful for evaluating how well assessments support instructional goals. However, the lack of a formal quantitative index makes it difficult to compare alignment results across studies or track changes over time.

In terms of limitations, the Achieve methodology was designed specifically for analysing alignment between standards and assessments. It does not provide a systematic framework for evaluating textbooks or instructional content, and it lacks the generalizability needed for comparing multiple curriculum components in a unified structure. As such, it is not appropriate for textbook–curriculum alignment studies, a point underscored in alignment reviews such as Martone and Sireci (2009), who argue that Achieve’s method is “less flexible” than models like Porter’s, which allow for cross-component analysis.

Despite these limitations, the Achieve methodology has been employed in several large-scale evaluations of state and national assessment systems, often as a supplement to other alignment tools. It offers valuable qualitative insights into how well assessments capture the intent and rigor of curriculum standards. While it does not offer the methodological breadth required for the present study, its conceptual focus on fidelity to instructional intent provides a useful contrast to more technical, matrix-based models.

Survey of Enacted Curriculum and Porter’s Alignment Index

The Survey of Enacted Curriculum (SEC), developed by Porter and Smithson (2001), represents a comprehensive and flexible model for analysing alignment between various elements of the curriculum. Unlike the Webb and Achieve methodologies, which were designed specifically for comparing standards and assessments, the SEC is built to facilitate comparisons between any two components of an educational system, including standards, assessments, instruction, and textbooks.

At the core of the SEC approach is a two-dimensional content matrix that captures both subject matter and cognitive demand. Each item from the source being

analysed, whether it is a standard, textbook exercise, or instructional activity, is classified according to these two dimensions. The cognitive dimension is based on a taxonomy closely aligned with Bloom's Taxonomy, encompassing categories such as recall, basic skills, conceptual understanding, strategic thinking, and extended reasoning. This results in a detailed profile of the content coverage and cognitive expectations of each component.

What distinguishes the SEC model from others is its use of a survey instrument administered to teachers, who report on the content they actually teach and the level of cognitive demand required of their students. Teachers complete the survey by indicating the relative emphasis placed on each cell of the two-dimensional matrix over a given instructional period. In large-scale applications, this has allowed researchers and policymakers to aggregate data across schools, districts, or regions to examine how closely enacted instruction matches official standards or assessments. Thus, the survey aspect of the SEC provides direct, empirical insight into the enacted curriculum as opposed to the intended curriculum reflected in standards documents.

The SEC methodology also includes a quantitative alignment index, known as Porter's Alignment Index (PAI). This index compares the distribution of emphasis across the matrix for two components and produces a value between 0 (no alignment) and 1 (perfect alignment). Polikoff (2012) emphasizes that there is no absolute standard for interpreting PAI scores; rather, alignment should be understood in relative terms and used primarily for comparative analysis. To address the need for more objective interpretive criteria, Fulmer (2011) developed empirically derived critical values through simulation, enabling researchers to determine whether observed alignment exceeds what would be expected by chance. This combination of

survey data and quantitative analysis makes the SEC uniquely positioned to assess not only how well instructional materials support curriculum goals, but also how faithfully they are enacted in classroom settings.

While the SEC model is methodologically demanding, requiring trained coders and considerable data input, it offers a high degree of transparency and diagnostic detail. In contrast to Webb and Achieve, whose applications are limited to specific component pairs, the SEC model's versatility and empirical foundation position it as the most suitable choice for comprehensive alignment analysis.

Martone and Sireci (2009) emphasize that Porter's model is the only alignment approach developed specifically to accommodate comparisons among any of the core curriculum elements, including instruction and textbooks.

Kazemi's Misalignment Framework

Polikoff (2015) argues that textbook content frequently diverges from curriculum standards, particularly through an overemphasis on procedural knowledge and a lack of attention to conceptual understanding and higher-order thinking. Building on this concern, Kazemi (2022) explores the nature of misalignment in greater depth in his doctoral dissertation, extending on Porter's Alignment Index (2002), where he introduces a nuanced typology to distinguish among four specific, non-overlapping types of misalignment: over-coverage (OC), under-coverage (UC), missed coverage (MC), and pure-contamination (PC). For instance, a standard that is addressed too frequently in assessments would be coded as over-coverage (OC), whereas an important topic that is minimally represented would be categorized as under-coverage (UC). If a topic appears in the assessment but is not found in the standards, it is considered pure-contamination (PC). Finally, topics listed in the standards but entirely absent in the assessment are classified as

missed coverage (MC). These categories offer a more detailed account of how misalignment can occur when the intended curriculum, instructional content, and assessments are not adequately aligned. By disaggregating misalignment into these clearly defined types, Kazemi's method offers a more refined tool for analysing coherence across educational components and will serve as a guiding framework for this research.

In summary, various methodologies have been proposed to evaluate the alignment of curriculum components, each with distinct analytical focuses. While the Webb and Achieve methodologies contribute useful perspectives on content and cognitive complexity, the alignment matrix developed by Porter (Porter & Smithson, 2001; Porter, 2002) offers a structured approach to simultaneously analyse topic coverage and cognitive demand. Kazemi's (2022) misalignment model further extends this framework by introducing categories that help interpret the quality and nature of alignment. As this study aims to investigate both the degree and character of alignment within a single curriculum, Porter's framework and Kazemi's misalignment framework together provide a suitable and comprehensive analytical foundation.

CHAPTER 3: METHODOLOGY

Introduction

This chapter presents the methodological framework used to investigate the alignment between the syllabus, textbook, and assessment materials in the Cambridge IGCSE International Mathematics 0607 Extended course. The focus is limited to the functions topic, which was selected for its foundational role in secondary mathematics and its frequent appearance in both instructional and assessment contexts. In addition to its prevalence, the topic includes a wide range of question types that vary in cognitive demand, making it suitable for a detailed alignment study. The analysis begins with an item to learning objective (LO) mapping process, followed by a matrix-based alignment analysis using Porter's alignment index and Kazemi's misalignment adaptation for mathematics education. This chapter explains the overall research design, the instruments selected for analysis, and the procedures used to collect and analyse data.

This research aims to answer the following research questions:

1. What is the extent and emphasis of coverage in the Haese Mathematics textbook review sets and the Cambridge IGCSE International Mathematics examinations of the syllabus' function topic learning objectives?
2. To what extent do the Haese Mathematics textbook review sets and the Cambridge IGCSE International Mathematics examinations align for function topic learning objectives, as measured by Porter's Alignment Index?

3. Which misalignment types, per Kazemi's misalignment framework, are observed between the Haese review sets and the Cambridge IGCSE International Mathematics examinations for the function topic learning objectives?

Research Design

This study adopts a comparative document analysis design supported by both quantitative and qualitative alignment methodologies. The overarching goal is to assess the coherence between the IGCSE International Mathematics (0607) syllabus, the Haese textbook, and past IGCSE assessment materials with respect to the topic of functions.

The analysis is carried out in three stages. In the first stage, a direct item to learning objective mapping is conducted. Each question from the textbook Review Sets and each functions-related question from IGCSE past examination papers administered between 2021 and 2025 is mapped to one or more disaggregated LOs from the syllabus. This mapping process enables a fine-grained evaluation of which objectives are addressed and emphasized, and to what extent, in both textbook and assessment documents. It also identifies any underrepresented or omitted objectives. It quantifies the individual alignment of assessment and textbook items with the syllabus LOs in a clear, precise, and descriptive manner, ensuring that each curriculum component's reflection of the prescribed syllabus objectives is identified with clarity and precision.

The second phase employs a quantitative method to investigate the alignment specifically between assessments and the textbook. To achieve this, Porter's Alignment Index (2002) is utilized, adapted suitably for the limited topical scope of this study. While Porter's original formulation can indeed be applied broadly across

multiple curriculum components, it requires consistent categorization by both topics and cognitive demand. Given the narrowed topical focus of this research on functions alone, the original syllabus LOs (E3.1–E3.7) are employed as thematic categories to serve as the "topics" for Porter's analysis, coupled with explicitly defined cognitive demand categories for each item. By systematically categorizing assessment and textbook items in terms of these syllabus-derived topics and their cognitive demand categories, Porter's Alignment Index (PAI) provides a quantitative measure of the degree of alignment between assessments and the textbook.

The third stage applies Kazemi's (2022) misalignment framework to further examine the nature and sources of discrepancy. By analysing deviations in topic and cognitive demand at the matrix cell level, this stage offers a qualitative perspective that complements the numerical scores produced by the previous analysis. Kazemi's framework is particularly useful in identifying specific areas where content is missed, under-covered, over-covered, or misrepresented.

This three-stage design offers both detailed and holistic insights into the alignment of curriculum components. The results of each stage are presented in the following chapter.

Documents

This study utilized three primary documents, each corresponding to a key component of the Cambridge IGCSE International Mathematics (0607) course: the syllabus, the textbook, and the assessment. For clarity and consistency, the term *syllabus* refers to the Cambridge IGCSE International Mathematics (0607) Syllabus (2025–2027), *textbook* refers to the Haese Mathematics Cambridge IGCSE International Mathematics (0607) Extended Third Edition, and *assessment* denotes the selected Cambridge IGCSE International Mathematics 0607 Extended past

examination papers between the years 2021-2025. These documents serve as the primary sources from which data will be gathered for the alignment analysis. The specific strategies and tools employed to extract and analyse data from these sources are detailed in the Method of Data Collection.

Syllabus

The Cambridge IGCSE International Mathematics 0607 syllabus (CAIE, 2023) outlines the official LOs for the course and defines the scope and sequence of mathematical content to be taught and assessed. The document is divided into Core and Extended curricula. This study focuses exclusively on the Extended syllabus, specifically the *functions* topic, which is represented by the LOs E3.1 through E3.7. These LOs encompass a range of skills including function notation, graphing, transformation, composition, and inverse functions. Notably, across the versions of the syllabus used in recent years, the functions topic has undergone minor revisions. There were no changes in this topic from the 2020–2022 syllabus to 2023–2024 syllabus (CAIE, 2017; CAIE, 2020). However, the 2025–2027 revision introduced several modifications: absolute value functions, the transformation $y = kf(x)$, and rules of logarithms were removed; new content was added requiring students to plot points using a graphic display calculator (GDC), and in composite functions of the form $f(g(x))$, $g(x)$ is no longer limited to linear expressions.

Textbook

The textbook, Haese Mathematics Cambridge IGCSE International Mathematics (0607) Extended Third Edition is officially endorsed by CAIE. I chose this textbook because it is the textbook that I am using in my lessons. With proof of purchase, students are able to activate an online version of the textbook for 24 months. In the online version, students are able to access Self-Tutor video

recordings, which solve the worked examples in a video format. They also have access to interactive links that have games, illustrations, tools for graphics and statistics, and printable pages. There are also clickable video instructions for four different graphic display calculators that students are allowed to use in the IGCSE exam. The students are also able to access Review Set B, which is located at the end of each chapter. Review Sets A are printed, whereas Review Sets B are only found in the online version. The Background Knowledge section of the textbook is again only accessible online. All the question numbers in the textbook are either written in green or blue, denoting a non-calculator or calculator question, respectively.

There are 37 chapters in the textbook, where each chapter is denoted by a number, and the subtopics within the chapter are denoted by capital letters. The functions topic is distributed across four chapters: Chapter 30 (Functions), Chapter 31 (Quadratic Functions), Chapter 32 (Exponentials and Logarithms), and Chapter 33 (Further Functions). Each chapter starts with an opening problem and follows with subtopic A. Within subtopics, there are instructive texts, discovery exercises, worked examples, and exercise sets. At the end of each chapter, there are two Review Sets: Review Set A is printed, and Review Set B is accessed online.

Assessments

The assessment component of this study consists of past examination papers from the Cambridge IGCSE International Mathematics 0607 series. Specifically, Extended level past examination papers from the five most recent years (2021 to 2025) were examined. The IGCSE examinations are administered across six Administrative Zones, and each examination centre is located in one of six Administrative Zones (CAIE, n.d.-a). For Cambridge IGCSE International

Mathematics 0607, there are 3 variants of each paper, and the distribution of variants across Administrative Zones is explained below.

Table 3

Distribution of Examination Variants Across Administrative Zones for Cambridge IGCSE International Mathematics 0607

Administrative Zone	Variant
1	3
2	1
3	1
4	2
5	2
6	3

Note. Summarized from <https://www.cambridgeinternational.org/exam-administration/cambridge-exams-officers-guide/phase-1-preparation/timetabling-exams/exam-timetables/> (CAIE, n.d.-f)

As an example, examination centres in Türkiye fall under Administrative Zone 3. Referring to Table 3, this zone is assigned Variant 1 of the examination for Cambridge IGCSE International Mathematics 0607. Each examination paper is identified by a code that reflects both the paper number and its variant. For instance, in the case of the Cambridge IGCSE International Mathematics 0607 syllabus, students in Türkiye who are taking the Extended level examinations would receive papers coded 21, 41, and 61. In this coding system, the first digit indicates the paper number (Paper 2, Paper 4, and Paper 6, respectively), and the second digit denotes Variant 1, which corresponds to Administrative Zone 3.

Each year typically includes the March, June, and November examination series. For the March series, only Variant 2 papers are published, while the June and November series include papers from all three variants. This results in a total of

seven examination sets per year. For the year 2025, the March examination has already been released, and although the June examination is yet to be officially published, the November examination has not been administered yet. For the new 2025–2027 syllabus, a set of sample examination papers (Specimen Paper) has been shared, which has been included in this study. Only Extended content has been considered for this thesis (Papers 2, 4, and 6). In total, the dataset includes 30 examination sessions across five years: 30 Paper 2s, 30 Paper 4s, and 30 Paper 6s. The breakdown of exam availability is provided in Table 4.

Table 4

Distribution of Cambridge IGCSE International Mathematics 0607 Extended Exam Sets Between Years 2021 and 2025

Year	March (V2)	June (V1, 2, 3)	November (V1, 2, 3)	Total Number of Exam Sets
2021	1	3	3	7
2022	1	3	3	7
2023	1	3	3	7
2024	1	3	3	7
2025	1	0 (Not yet published)	0 (Not yet administered)	1
Specimen Paper	-	-	-	1
Total				30

Note. V refers to Variant number.

Method of Data Collection

This section outlines the procedures followed to extract and prepare data from the syllabus, textbook, and assessment documents.

Learning Objective Disaggregation

The syllabus learning objectives (LOs) related to the functions topic were first disaggregated into smaller, measurable components to enable a more precise and systematic analysis. The full list of disaggregated LOs used in this study is presented in Appendix B. Several of the original LOs in the Cambridge IGCSE International Mathematics (0607) syllabus are compound in nature, incorporating multiple skills, concepts, or operations within a single statement. To ensure clarity and consistency in the coding process, such LOs were split into distinct sub-learning objectives, each representing a single, assessable skill. For example, LO E3.2 in the syllabus is titled *Sketching graphs on a calculator* and consists of six distinct parts. It expects students to use a graphic display calculator (GDC) to: (a) sketch the graph of a function, (b) produce a table of values, (c) plot points, (d) find zeros, local maxima or local minima, (e) find the intersection of the graphs of functions, and (f) find the vertex of a quadratic. Each of these subskills involves a separate process and requires a different form of technological or mathematical reasoning. Therefore, E3.2 was disaggregated into six distinct LOs (E3.2.a to E3.2.f), allowing greater clarity in the mapping process and enabling a more transparent comparison across the textbook and assessment materials, supporting the need for precise categorisation. This disaggregation approach was applied across all compound LOs within the functions topic and served as the analytical foundation for both item-to-objective mapping and the matrix construction procedures used in Porter's Alignment Index (2002) and Kazemi's Misalignment Method (2022).

Item Identification and Segmentation

Items were extracted from each document according to the criteria already outlined in the Instrumentation section. The analysis of the textbook was limited to the Review Sets found at the end of each relevant chapter. These sections are designed to consolidate learning and reflect the kinds of tasks that are typically used to evaluate mastery. As such, they offer a more appropriate basis for comparison with both syllabus LOs and formal assessments. In contrast, the questions embedded within the body of the chapters primarily serve a formative purpose. They are intended to support conceptual development, introduce new ideas progressively, or guide students through scaffolded practice. These tasks are often exploratory in nature and are not always intended to align directly with the specific LOs listed in the syllabus. These Review sets provide a more standardized and summative representation of textbook content, making them a suitable source for alignment analysis. In total, 298 textbooks items were identified.

For the assessment component, only questions from the Extended-level Papers 2, 4, and 6 between 2021 and 2025 were considered. Each item was reviewed and segmented into the smallest analysable unit. Multi-part questions were separated into sub-items if they addressed different skills or cognitive processes. It is worth mentioning here that the majority of function questions in past examination papers are gathered in Paper 4s, a small set of questions in Paper 2s, and there were no questions in Paper 6 between the years 2021-2025. Questions that assessed content no longer included in the current syllabus, such as absolute value functions, transformations of the form $y = kf(x)$, and rules of logarithms, were excluded from the assessment data. In total, 294 textbook items were identified.

All items were systematically recorded in an Excel spreadsheet at their most disaggregated level, allowing for accurate item to learning objective mapping. Each entry included relevant metadata such as source (textbook or assessment), paper number or review set, item number, and mark allocation where applicable, ensuring consistency and traceability throughout the analysis process. The sample of the spreadsheet for both textbook and assessment is provided in Appendix C. With all components systematically disaggregated, identified, and recorded, the dataset was prepared for in-depth analysis to evaluate the degree of alignment across the syllabus, textbook, and assessment materials, which is explained in the following section.

Methods of Data Analysis

This section outlines the analytical procedures used to examine the alignment of the IGCSE International Mathematics (0607) curriculum components, specifically within the topic of functions. While I served as the sole researcher responsible for the overall design and implementation of the study, steps were taken to enhance the trustworthiness of the data analysis process. To this end, a sample of textbook exercises (Review Sets 30A, 32B, and 33A) and assessment items (Paper 22 and 42 from March 2025, Paper 41 from June 2024, Paper 43 from November 2023, and Paper 21 and 42 from November 2022, as well as Paper 21 and 41 from June 2021) was independently analysed by two additional reviewers: one holding a PhD in education, and the other holding a Master's degree in education and currently pursuing further graduate study. I sampled these materials using a stratified approach that mirrors the full corpus: assessment items are distributed across recent years and across Papers 2, 4 and 6, and textbook items are balanced between the A and B versions of the relevant Review Sets, so the verification subset captures temporal and

format variation without overrepresenting any single year, paper or set. These experienced educators coded the items by mapping them to the corresponding LOs, topics, and levels of cognitive demand. Both reviewers coded the selected items by mapping them to the corresponding LOs, content categories, and cognitive demand levels. Any differences were discussed until a consensus was reached. This step functioned as a form of investigator triangulation (Denzin, 1978), reducing the potential for individual bias in the analysis. The analysis was carried out in three stages, and each stage is described in detail below.

Item to Learning Objective Mapping

In order to investigate the alignment of curriculum components, each item within the Review Sets of the textbook and the assessments from the past five years was systematically mapped to one of the disaggregated LOs derived from the official syllabus. This process involved a close reading of the mathematical content required to solve each item, with the aim of identifying the LO that most accurately captured the item's demand. In most cases, each item was exclusively assigned to one LO, based on its dominant mathematical focus.

In the case of assessment items, however, some questions were mapped to multiple LOs. When this occurred, the item was split into sub-items based on the structure of the mark scheme, which often attributed different parts of the total mark to distinct mathematical skills. These items were separated accordingly, and each part was mapped to a different LO with its corresponding mark value preserved. This allowed for a more accurate representation of how LOs were assessed. A small subset of items, particularly those involving inequalities, did not allow for precise distribution of marks across multiple LOs. For these items, marks were awarded solely for the correctness of the final answer, even though the item required more

than one conceptual step. As a result, while such items could still be mapped to more than one relevant LO, it was not possible to assign a specific mark to each. These exceptions were noted accordingly. Some of the textbook items were also mapped to more than one LO. As the textbook items do not have marks associated with them, these items could not be split according to their mark distribution.

By applying this item to learning objective mapping procedure to both the textbook and assessment items, it became possible to quantify the extent to which each LO is represented in these two curriculum sources. The mapping process produced both frequency counts and corresponding percentages for each LO in the textbook and in the assessments. These metrics were recorded separately for each source, enabling a descriptive comparison of coverage patterns and revealing which LOs were emphasized more or less across the materials under review.

Porter's Alignment Methodology

Porter's alignment methodology (2002) has been employed extensively in curriculum alignment research across different subjects and contexts, usually coupled with Surveys of Enacted Curriculum (SEC). Its repeated application by multiple researchers has demonstrated that the method is reproducible and produces consistent findings, lending credibility to its reliability. Porter's alignment methodology requires the classification of curriculum items along two key dimensions: the content category to which each item belongs and the cognitive demand it places on students. The content dimension captures the specific mathematical ideas or procedures addressed, while the cognitive dimension reflects the nature of thinking required to engage with the item, ranging from recall and routine procedures to reasoning and problem-solving. To implement this method, a predefined set of categories for both dimensions must be established to ensure consistency across sources.

Content Categories

In most applications of Porter's alignment methodology, the topic dimension encompasses broad curriculum areas such as algebra, statistics, or geometry, as the analysis typically spans the full scope of a syllabus. However, this study focuses exclusively on the topic of functions. As a result, dividing the content into broader curriculum areas would be both unnecessary and inappropriate. To maintain consistency with Porter's framework while preserving the integrity of the subject focus, the original syllabus LOs for functions (E3.1 to E3.7) were adopted as the topic categories in this study. The names of the LOs were adapted for clarity.

E3.1: Graphs of Functions

E3.2: Graphic Display Calculator (GDC) Skills

E3.3: Function Notation, Inverse and Composite

E3.4: Quadratic Function Derivation

E3.5: Asymptotes

E3.6: Transformations

E3.7: Exponentials and Logarithms

Other: For items that could not be included in any content category

Cognitive Demand Categories

The classification of cognitive demand plays a central role in Porter's alignment methodology, as it helps to determine the type of thinking and reasoning that students are expected to engage with when completing mathematical tasks. In selecting an appropriate framework for this dimension, several alternatives were considered, including Bloom's Taxonomy and the Survey of Enacted Curriculum (SEC) framework. However, after careful evaluation, both were found to be unsuitable for the purposes of this study.

Bloom's Taxonomy is a hierarchical model commonly used across educational contexts to describe levels of cognitive engagement, ranging from lower-order skills such as remembering and understanding to higher-order skills such as analysing, evaluating, and creating. While it is widely cited and has broad applicability, its use in this study was limited by the nature of the textbook and assessment items. The vast majority of these items would have been placed in the lower levels of Bloom's Taxonomy, with very few demanding higher-order cognitive processes. The SEC framework, which is widely used in alignment studies, was also considered. However, when applied to the function-related items in this study, most of the items would have been clustered in two categories: B (memorize) and C (perform procedures). As a result, both of these categorisations would have produced a narrow and uninformative distribution that failed to reflect meaningful differences in cognitive expectations.

In light of these constraints, the framework developed by Stein and Smith (1998) was selected as the most appropriate alternative. Their model was specifically designed for use in mathematics education and provides a more nuanced account of the cognitive processes involved in mathematical problem-solving. It identifies four distinct levels of cognitive demand: *Memorization*, *Procedures Without Connections*, *Procedures With Connections*, and *Doing Mathematics*.

Table 5*Cognitive Demand Levels*

Cognitive Demand Level	Description
Memorization	Represent the lowest level of cognitive demand. They involve the reproduction or recall of previously learned facts, rules, formulas, or definitions without any need for understanding or conceptual reasoning.
Procedures without connections	Involve the application of algorithmic procedures that are familiar to students through prior instruction. Although they require some degree of procedural fluency, they do not encourage reflection on underlying concepts. Tasks at this level are typically routine, predictable, and focus on producing correct answers without requiring explanation or reasoning beyond the execution of a known method.
Procedures with connections	Involve the use of procedures that are closely tied to conceptual understanding. These tasks encourage students to make connections among multiple representations and require attention to meaning and structure. While procedures may be involved, they cannot be applied mindlessly. Instead, students must engage with the underlying ideas to arrive at a solution, which demands a moderate level of cognitive effort.
Doing mathematics	Represent the highest level of cognitive demand. They require non-algorithmic thinking, meaning that the solution pathway is neither obvious nor rehearsed. These tasks involve exploration, analysis, and the application of prior knowledge to unfamiliar situations. Students must monitor and regulate their thinking, consider multiple solution strategies, and justify their reasoning. Such tasks typically involve a high degree of

Cognitive Demand Level	Description
	uncertainty and cognitive effort, reflecting the complexity and open-endedness of real mathematical problem-solving.

Note. Adapted from Stein and Smith (1998)

This four-level framework was adopted in this study because it allows for a nuanced classification of mathematical thinking and is particularly well suited for evaluating the depth and quality of engagement required by items in both instructional and assessment contexts.

Once each item is coded into a specific content–cognitive pair, a two-dimensional matrix is constructed in which each cell represents the proportion of items associated with that particular combination. These matrices serve as representations of the distribution of emphasis within each source.

Porter's Alignment Index

The degree of alignment between two sources is then quantified using Porter's Alignment Index (PAI). The PAI compares two matrices by calculating the absolute difference between corresponding cells and summarizing the total deviation. The formula for the index is given as:

$$PAI = 1 - \frac{1}{2} \sum_{i=1}^m \sum_{j=1}^n |A_{ij} - B_{ij}|$$

Here, A_{ij} and B_{ij} represent the proportion of items in cell (i, j) for the two matrices being compared, and m and n denote the number of content categories and cognitive levels. The resulting value ranges from 0 to 1, where a score of 1 indicates perfect alignment, meaning both sources place equal emphasis across all dimensions, and values closer to 0 indicate greater misalignment. This index thus offers a structured

and interpretable way to measure how closely two curriculum components align in both topic coverage and cognitive expectations.

In this study, PAI was used to quantify the degree of alignment between textbook content and assessment items across a 24-cell content–demand matrix. While Porter’s original formulation does not prescribe fixed thresholds for interpreting alignment values, Fulmer (2011) addressed this limitation by generating simulated distributions of alignment scores based on varying matrix sizes and numbers of standards points. His work provides empirically derived critical values that allow researchers to determine whether an observed alignment score significantly exceeds or falls below what would be expected by chance. Given that the matrices in this study contain 24 cells and the matrices include around 300 items each, Fulmer’s thresholds for 120 items were adopted as a conservative reference point for interpreting statistical significance.

Kazemi’s Misalignment Framework

Building upon Porter’s Alignment methodology (2002), Kazemi (2002) proposed an extension that offers a more detailed and diagnostic view of curriculum alignment by introducing a set of complementary misalignment indices. Kazemi’s misalignment framework is a recent contribution developed within the scope of a doctoral thesis. While it introduces valuable conceptual refinements, its reliability and validity currently rest on the methodological choices and analyses presented in Kazemi’s own work. Further applications by other researchers are required before the framework’s generalisability and robustness can be firmly established.

A central contribution of Kazemi’s (2022) extension to Porter’s Alignment Index is the introduction of directionality into the measurement of alignment. In Porter’s original formulation, alignment is treated to have a non-directional

relationship, meaning that the alignment of component A to component B is numerically identical to the alignment of B to A. In contrast, Kazemi argues that alignment should be understood as a directional relationship, where one component sets the expectations and the other is evaluated in reference to those expectations. He introduces the analytical distinction between a *target* component and an *instrument* component. The *target* is the fixed reference that defines the intended distribution of content and cognitive demand, while the *instrument* is the component being assessed for how closely it reflects the emphasis outlined in the target. The instrument component is always evaluated for its alignment to the target component (Kazemi, 2022).

In this study, the assessment was assigned as the *target* and the textbook as the *instrument*. This structure reflects the way instruction is typically designed to prepare students for formal evaluation. The assessment defines the performance expectations that students must meet, and the textbook is expected to provide opportunities for students to engage with similar content and skills. By treating the textbook as the instrument in this comparison, the analysis examines whether students have access to adequate instructional support for what they will encounter in the assessment. Any discrepancies point to potential weaknesses in the alignment between instructional materials and evaluative outcomes.

Kazemi developed a framework in which total misalignment is defined as the complement of the alignment index, that is, $1 - \text{PAI}$. This total is then partitioned into four mutually exclusive (non-overlapping) categories of misalignment: missed coverage (MC), under-coverage (UC), over-coverage (OC), and pure contamination (PC). These categories are determined by comparing the emphasis assigned to each cell in the content–cognitive demand matrix by the target and the instrument. In

addition to these four forms of misalignment, two forms of alignment are also identified: trivial perfect alignment (TPA), where both the target and instrument assign zero emphasis to a cell, and non-trivial perfect alignment (NTPA), where both assign equal nonzero proportions. Table 6 summarises the logic used to classify each cell.

Table 6

Alignment and Misalignment Categories

Label	Condition	Description
TPA (Trivial Perfect Alignment)	$T_{ij} = 0$ and $I_{ij} = 0$	Neither the target nor the instrument places emphasis on the cell. This alignment is structurally perfect but trivial.
NTPA (Non-Trivial Perfect Alignment)	$T_{ij} = I_{ij} > 0$	Both the target and instrument assign the same non-zero emphasis to the cell, indicating a strong and meaningful alignment.
MC (Missed Coverage)	$T_{ij} > 0$ and $I_{ij} = 0$	The target expects emphasis in the cell, but the instrument provides none. Important content or skills may be entirely unaddressed.
UC (Under-Coverage)	$T_{ij} > I_{ij} > 0$	The instrument reflects the target but with less emphasis, indicating partial but insufficient coverage.
OC (Over-Coverage)	$I_{ij} > T_{ij} > 0$	The instrument places more emphasis than the target.

Label	Condition	Description
PC (Pure Contamination)	$T_{ij} = 0$ and $I_{ij} > 0$	The instrument includes content or skills not found in the target at all.

Note. Adapted from Kazemi (2022). T_{ij} and I_{ij} represent the proportions in cell (i, j) for the target and instrument, respectively.

Chapter Summary

In summary, this chapter outlined the methodological framework employed to investigate the alignment between the syllabus, textbook, and assessments within the topic of functions. The process began with a detailed mapping of each item to the most relevant disaggregated LO, followed by the application of Porter's Alignment Index to quantify the degree of alignment between curriculum components. Finally, Kazemi's (2022) extended framework was used to analyse the nature of observed misalignments in a more nuanced and directional manner. Together, these methods provide a comprehensive approach to evaluating curricular coherence. The next chapter presents the results derived from these procedures.

CHAPTER 4: RESULTS

Introduction

This chapter presents the results of the alignment analysis focusing on the topic of functions in the IGCSE International Mathematics (0607) curriculum. The findings are organised in three stages. First, the outcomes of the item to learning objective (LO) mapping are reported separately for the textbook and the assessments. Second, Porter's Alignment Index (PAI) is applied to quantitatively measure the degree of alignment between each pair of curriculum components: syllabus–textbook, syllabus–assessment, and assessment–textbook. Finally, Kazemi's (2022) misalignment framework is used to classify and describe the nature of the observed misalignment. All findings are presented descriptively in this chapter, with interpretation and implications addressed in the following section.

Item to Learning Objective Mapping

This section presents the results of the item to learning objective mapping for both the Haese Mathematics textbook review sets and the past five years of IGCSE International Mathematics 0607 past examination papers, focusing on the topic of functions. Each item was examined and mapped to the corresponding disaggregated LO from the official syllabus. The findings are reported in terms of item frequency for both sources, with mark allocation provided only for the assessment items.

Assessment Items to Learning Objective Mapping

A total of 294 items were extracted from the past five years of Cambridge IGCSE International Mathematics 0607 Extended level examination papers,

corresponding to a total of 603 marks. In the IGCSE International Mathematics (0607) examinations, each question is allocated a number of marks that reflect the expected length, difficulty, and number of solution steps. A one-mark item typically requires a short factual response, while multi-mark items involve more complex reasoning, multi-step procedures, or extended written answers. Marks are awarded according to a published mark scheme, which specifies the criteria for partial credit as well as for full solutions. Therefore, while 294 distinct items were identified, their combined weighting in the assessments amounted to 603 marks, reflecting that while some items were single-step and worth only one mark, others required multi-step reasoning and were allocated several marks. The items were drawn from Paper 2s and Paper 4s, with 18 items originating from Paper 2s (6.12% of all assessment items) and 276 items from Paper 4s (92.6% of all assessment items). Paper 6s did not contain any items relevant to the topic of functions and were therefore excluded from the analysis. Table 7 shows the summary of the assessment items to learning objective mapping.

Table 7

Summary of Assessment Items to Learning Objective Mapping

Learning Objective Code	Number of Items	Total Marks
Algebra LOs excluding E2.6.3	15	37
E2.6.3 with E3.2.e (and E3.5)	15	42
E3.1.1.b	1	1
E3.1.1.c	1	3
E3.1.1.f	3	6
E3.1.2	2	5
E3.2.a	47	107

Learning Objective Code	Number of Items	Total Marks
E3.2.d	28	52
E3.2.e	37	77
E3.3.1	50	62
E3.3.2	28	52
E3.3.3	37	81
E3.4.a	1	4
E3.5	16	28
E3.6	2	4
E3.7.1	11	21
E3.7.2	12	19
Items without mapping	1	2
Total	307	603

Note. The descriptions for the learning objectives can be found in Appendix B.

During the item to learning objective mapping process, several items were found to align with more than one disaggregated LO. In such cases, items were split based on the distribution of marks across distinct LOs, resulting in 307 items. This was particularly feasible when mark allocations within an item corresponded clearly to different skills or concepts. However, a specific type of inequality-based question posed a limitation: these items awarded marks solely for the final answer, without partial credit reflecting one particular LO. As a result, it was not possible to split these items across multiple LOs even when they appeared to involve multiple mathematical processes. These items were labelled with E2.6.3 with E3.2.e (and E3.5) in Table 7. Hence, the first row of Table 7, which is the algebra LOs, excludes E2.6.3.

Overall, the assessment data reflect a strong emphasis on the graphical and functional use of technology, particularly the use of a graphic display calculator (GDC), as well as foundational function concepts such as notation, domain, and range.

Algebra Learning Objectives

Out of the 307 items, 15 involved algebraic reasoning. Eight of these were drawn from split items, meaning that only a portion of the original item required the student to engage with algebra. The algebra-related LOs covered expanding algebraic expressions, collecting like terms, solving linear equations with one unknown, solving fractional equations with algebraic denominators, solving quadratic equations, and changing the subject of a formula. Each of these was assessed in at most two items. Manipulating algebraic fractions appeared more frequently, with four items addressing this objective.

In addition, two items required students to shade a region based on given inequalities, while one item asked students to write inequalities based on a shaded region. These items involve graphical representations of inequalities and could arguably be categorized under either algebra or functions. While inequalities are not functions in themselves, their graphical treatment often overlaps with the function topic.

Graphs of Functions (E3.1)

The disaggregated LOs under Syllabus Objective E3.1 focus on recognising functions from their graphical representations (E3.1.1.a–f), which also involves recognition of symmetry. Among these, the LO on quadratic functions (E3.1.1.b) and the LO on cubic functions (E3.1.1.c) were each assessed once, both in the context of symmetry. The LO related to trigonometric functions (E3.1.1.f), involving the

identification of amplitude and period, appeared in three items. The LOs on linear (E3.1.1.a), reciprocal (E3.1.1.d), and exponential functions (E3.1.1.e) were not assessed. The LO on determining the coefficients of a function (E3.1.2), applicable to all types mentioned in E3.1.1.a-f, was assessed twice: once for trigonometric and once for quadratic functions. The LO on extracting values from a function's graph (E3.1.3) was not assessed. Overall, original syllabus LO E3.1, which includes all the above-mentioned disaggregated LOs, accounts for 2.23% of all items and 2.49% of the total available marks.

Graphic Display Calculator (GDC) Skills (E3.2)

The second most frequently assessed LO is E3.2.a, which involves using a GDC to sketch the graph of a function. This LO appeared in 47 items, accounting for 15.5% of all items. Although it is not the most frequently assessed LO, its mark allocation highlights its significance. E3.2.a accounted for 107 marks, representing 17.7% of the total available marks, which is the highest among all LOs. The use of the GDC to identify key features of functions, such as zeros, local maxima or minima (E3.2.d), and points of intersection (E3.2.e), was also prominently represented. These were assessed in 28 and 37 items, respectively, corresponding to 52 and 77 marks. In some inequality-type items, the use of GDC to find intersection points also appeared under dual coding, listed as E2.6.3 with E3.2.e (and E3.5) in Table 7. However, since the marks awarded in such items could not be mapped to distinct LOs, the specific contribution of E3.2.e to the total mark weight remains uncertain. Altogether, original syllabus LO E3.2 (E3.2.a-f in disaggregated LOs) makes up 36.5% of all items and 39.1% of the total available marks. Notably, the LOs involving producing a table of values (E3.2.b), plotting points on a graph (E3.2.c), and finding the vertex of a quadratic function (E3.2.f) were not assessed at all.

Function Notation, Domain and Range, Composite, and Inverse Functions (E3.3)

The most frequently assessed LO is E3.3.1, which involves understanding functions, identifying domain and range, and using function notation. This LO appeared in 50 items, representing 16.3% of all items, and accounted for 62 marks, corresponding to 10.3% of the total available marks.

The majority of these items focused on function notation, while domain and range were assessed far less frequently, appearing in only two and three items, respectively. Seven of the items were part of split items, where the initial part assessed function notation and the remaining parts focused on algebraic manipulation.

Figure 1

Question 5, part (d) from Paper 41 in June 2021 Examination and Its Mark Scheme

5	$f(x) = 2x - 1$	$g(x) = 3 - x$	$h(x) = x^2$
(d) Solve $f(x) \times g(x) + 2h(x) = 0$. $x = \dots\dots\dots$ [3]			
5(d)	$\frac{3}{7}$ oe	3 B2 for $6x - 3 + x - 2x^2 + 2x^2 [= 0]$ or better or B1 for $6x - 3 + x - 2x^2$ or M1 for $(2x - 1)(3 - x) + 2x^2 [= 0]$	

As an example, Question 5, part (d) from Paper 41 of the June 2021 examination is presented below in Figure 1. As can be seen above, 1 method mark (**M1** on Figure 1) is awarded for substituting the functions into the equation, relating to function

notation (E3.3.1), and the remaining 2 marks relate to solving linear equations in one unknown (E2.5.2).

Inverse functions (E3.3.2) and composite functions (E3.3.3) were also assessed with notable frequency, appearing in 28 items (9.12 % of all items) and 37 items (12% of all items), respectively. These LOs also accounted for a substantial portion of the total marks: E3.3.2 received 52 marks (8.62% of all marks), while E3.3.3 accounted for 81 marks (13.4% of all marks). Notably, composite functions (E3.3.3) received the second highest total mark allocation among all LOs, following the LO on graph sketching using a GDC (E3.2.a). Overall, original syllabus LO E3.3, which includes E3.3.1, E3.3.2, and E3.3.3, makes up 37.5% of all items in terms of frequency, and 32.3% of all available marks.

Quadratic Functions (E3.4)

The original syllabus objective E3.4, which focuses on finding a quadratic function when certain points are given, was disaggregated into three specific LOs: E3.4.a, E3.4.b, and E3.4.c. Among these, only E3.4.a was assessed, and only once. This item involved finding a quadratic function given its vertex and one additional point, and it was allocated 4 marks.

Asymptotes (E3.5)

The concept of asymptotes, addressed in LO E3.5, was assessed in 16 items (5.21% of all items) with a total of 28 marks (4.64% of all marks). This objective requires students to understand the concept of asymptotes and identify simple examples that are parallel to the axes. In addition, asymptotes were also present in certain inequality-type items, which were coded as E2.6.3 with E3.2.e and E3.5 in Table 7. However, due to the nature of these items, the marks could not be

specifically attributed to each LO, and the precise contribution of E3.5 remains uncertain.

Transformations (E3.6)

The LO E3.6, which focuses on the transformation of functions, was assessed in two items, totalling four marks. Although the original LO addressed both horizontal and vertical translations of the functions, both items assessed only horizontal translations.

Logarithmic Functions (E3.7)

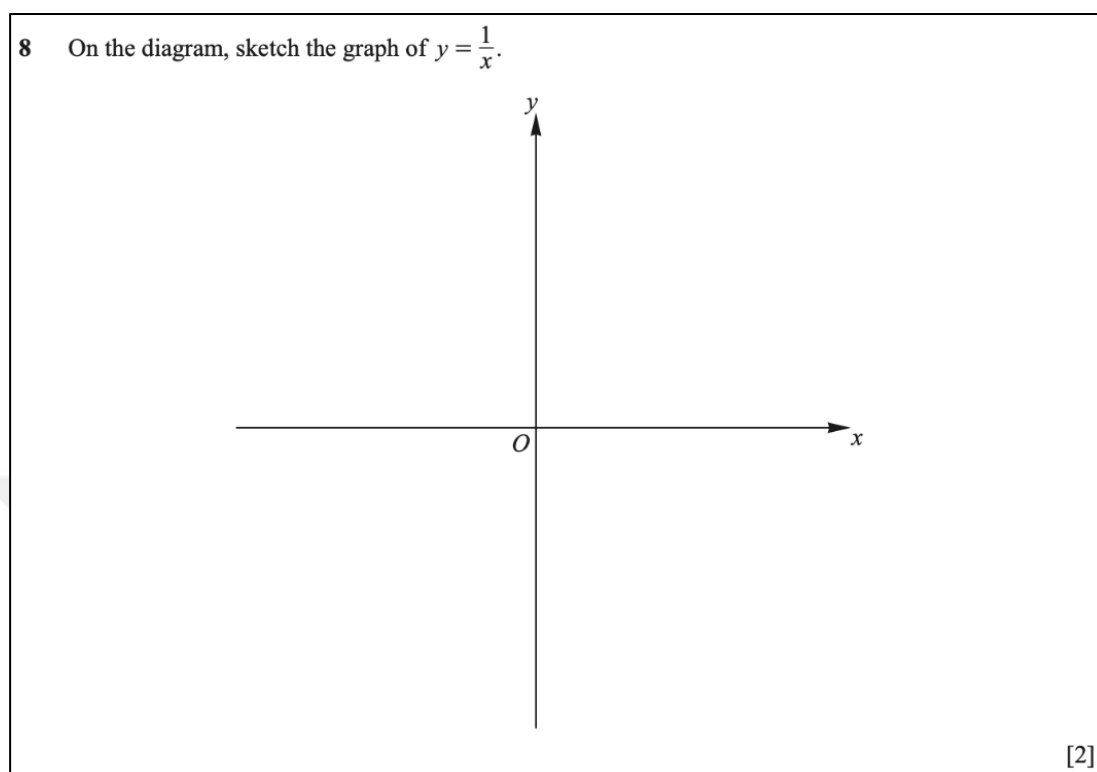
The logarithmic function LOs were also represented. LO E3.7.1, which involves understanding and using the logarithmic function as the inverse of the exponential function, was assessed in 11 items and received 21 marks. Similarly, LO E3.7.2, which focuses on understanding and using $y = a^x$ as $x = \log_a y$, appeared in 12 items with a total mark allocation of 19. Understanding and using the solution to $a^x = b$ as $x = \frac{\log b}{\log a}$ (E3.7.3) was not assessed in any item. Overall, the original syllabus LO 3.7 makes up 7.5% of all items, with 23 items, and 6.63% of all available marks, with 40 marks.

Items without Mapping

One item could not be mapped to any specific syllabus objective which was Question 6 from Paper 22 of the November 2021 examination.

Figure 2

Question 8 from Paper 22 in the November 2021 Examination



The item is shown in Figure 2. As this item appeared in Paper 2, the use of calculators was not permitted. The question required students to sketch a reciprocal function, a task that would typically be facilitated by the use of a GDC. While it may be argued that this item relates to E3.1.1.d, which is recognising reciprocal functions from the shape of their graph, the cognitive demand goes beyond simple recognition, as it requires students to construct, rather than identify, the graph. As the item was from the November 2021 examination, the corresponding version of the syllabus was also reviewed. However, no relevant LOs could be identified that align with the demands of this item.

Solving Inequalities Involving Functions with GDC

The LO labelled as E2.6.3 with E3.2.e (and E3.5) in Table 7 refers to solving inequalities involving functions with GDC. The disaggregated LOs are:

E2.6.3: Use GDC to find the intersection of the graphs of functions.

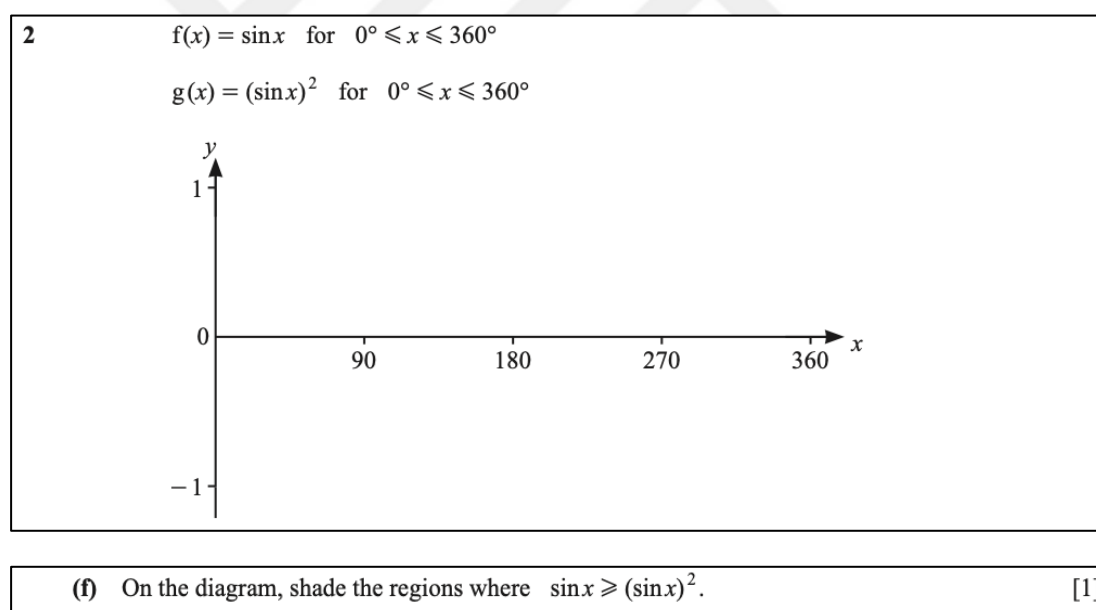
E3.2.e: Use GDC to sketch the graph of a function.

E3.5: Understand the concept of asymptotes and identify simple examples parallel to the axes on a graph.

This combined LO appeared in 15 items, accounting for a total of 42 marks. In six of these items, the functions in the item did not include any with asymptotes; therefore, the LO related to asymptotes (E3.5) is noted in parentheses to reflect its limited relevance. One item of particular note is Question 2, part (f), from Paper 42 of the November 2021 examination, which is different from all other items.

Figure 3

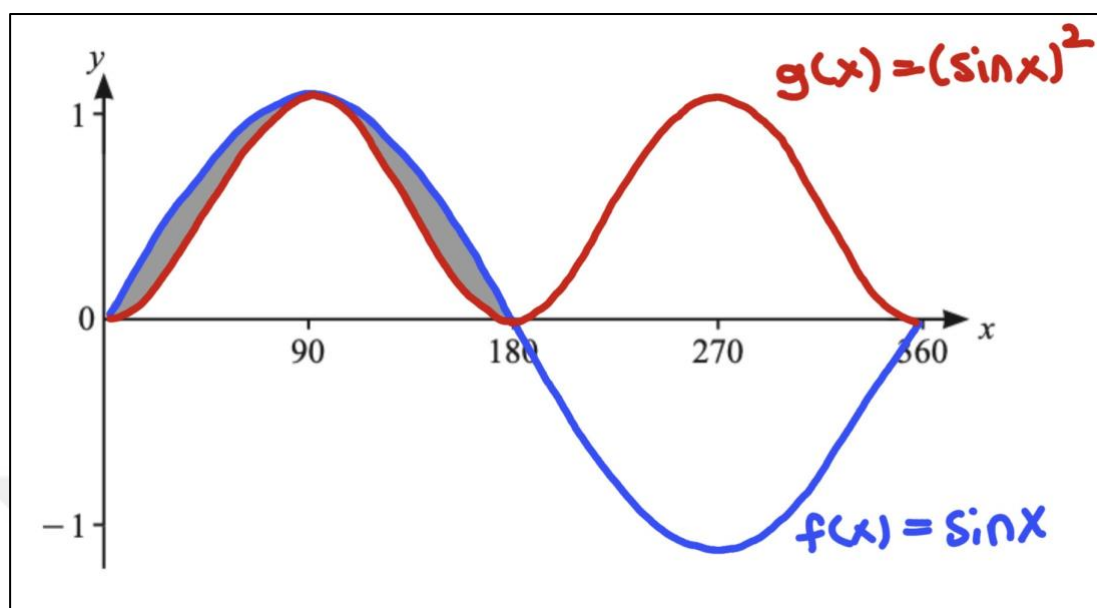
Question 2, part (f) on Paper 42 in the November 2021 examination



The mentioned item is Question 2, part (f) on Paper 42 in November 2021 examination. The previous parts of the question already ask the student to draw $f(x) = \sin x$ and $g(x) = (\sin x)^2$. On part (f), student is asked to shade the regions where $\sin x \geq (\sin x)^2$.

Figure 2

Solution to Question 2, part f on Paper 42 in the November 2021 Examination



The student should shade the region shown in Figure 4. The LO, solving inequalities using a graphic display calculator (E2.6.3) refers to finding the values of x that satisfy a given inequality, typically by identifying intervals on the x -axis. In the syllabus, shading is only mentioned in the context of linear inequalities, where students are expected to represent solution regions graphically. The item in question asks students to shade the region where $\sin x \geq (\sin x)^2$ which involves trigonometric functions rather than linear ones. Shading this region shows all coordinate points (x,y) that satisfy the inequality, rather than identifying only the values of x . Therefore, although not fully equivalent to solving the inequality in the sense of identifying x -values, the item remains closely related to the LO and can reasonably be mapped to E2.6.3.

Another example question from Paper 42 in the June 2023 examination involves all three disaggregated LOs.

Figure 3

Question 6 from Paper 42 in the June 2023 examination

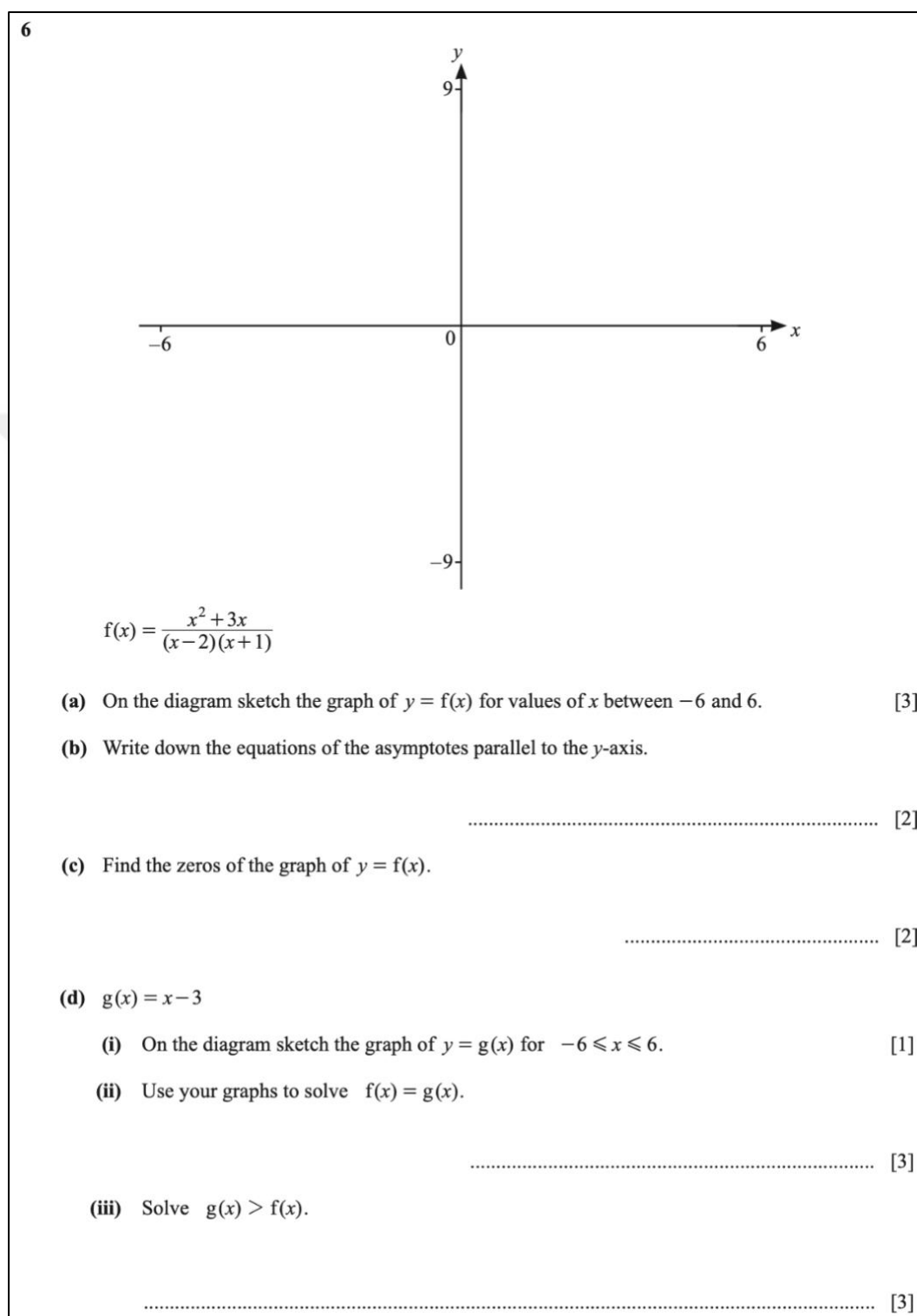
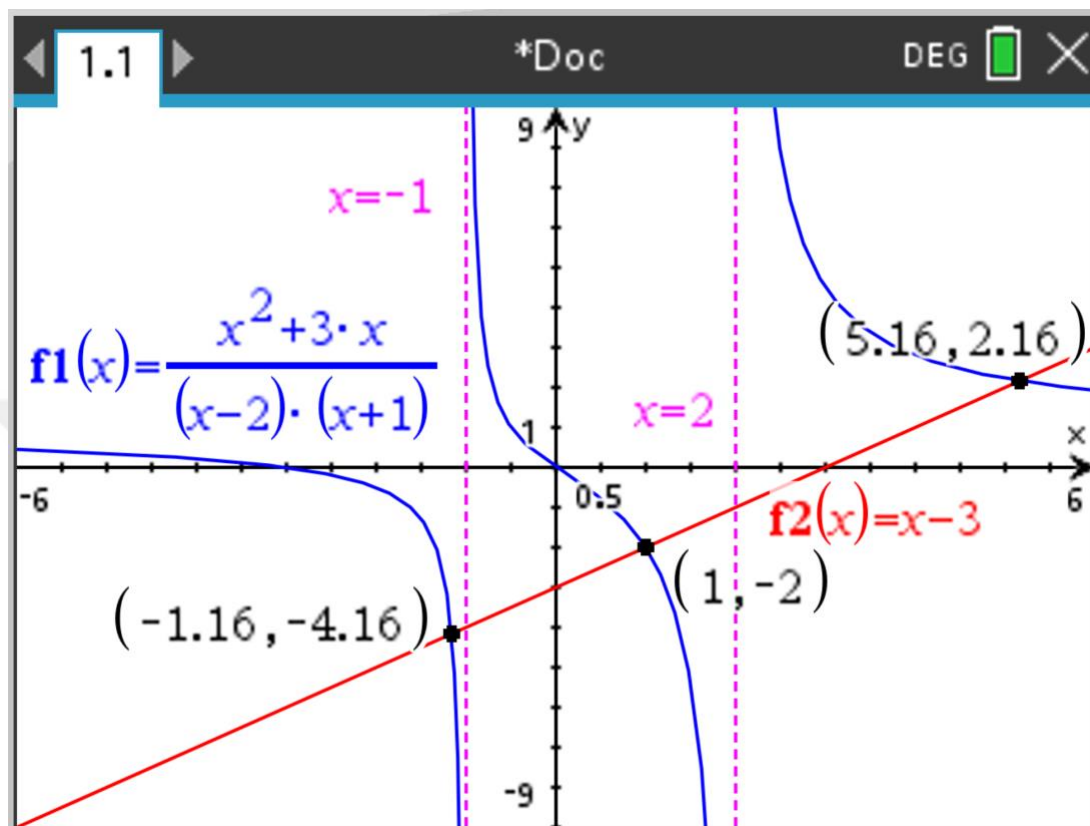


Figure 4

Screenshot from GDC to solve Question 6, part (d)(iii) on Paper 42 in June 2023

Examination

**Table 8**

Item to Learning Objective Mapping for Question 6 on Paper 42 in June 2023

Examination

Question Number	Part	Mark	Learning Objective
6	a	3	E3.2.a
	b	2	E3.5
	c	2	E3.2.d
	di	1	E3.2.a
	dii	3	E3.2.e
	diii	3	E2.6.3 with E3.2.e (and E3.5)

Question 6 shown on Figure 5 is a six-part question with a total of 14 points, the solution to part (d)(ii) is shown on Figure 6, and the item to LO mapping is shown in Table 8. The item to LO mapping for parts (a), (b), (c), (d)(i), and (d)(ii) are straightforward. The last part, (d)(iii), involves the understanding of asymptotes, the intersection of two graphs, and inequalities, hence it is mapped to the mentioned LOs. Using part (b), the student must have already written the vertical asymptotes (LO: E3.5), which are $x = -1$ and $x = 2$, shown in pink dashed lines in Figure 6. In order to find the solution to $g(x) > f(x)$, the student should find the intersection of the two functions (LO: E3.2.e), which the student needs to do three times, as there are three intersection points, shown as black points on Figure 6. Next, students should be able to solve the inequality (LO: E2.6.3), meaning that the students should know that the behaviour of the function changes at every critical point (vertical asymptotes and intersection points). At the end, the student should get to the solution: $-1.16 < x < -1$, $1 < x < 2$, $x > 2.16$, each worth one mark. These inequalities correspond to values of x where $g(x)$ (red function on Figure 6) is larger than $f(x)$ (blue function on Figure 6).

To summarize, the five most frequently assessed LOs, both in terms of frequency and marks, were E3.3.1 (functions and notation), E3.2.a (GDC graph sketching), E3.2.e (intersection of graphs), E3.3.3 (composite functions), and E3.2.d (zeros and extrema). Together, these five LOs accounted for 227 out of 307 items, making up 73.9% of all items, and 431 out of 603 marks, which corresponds to 71.5% of the total mark allocation.

LOs 3.5 (asymptotes), E2.6.3 with E3.2.e (and E3.5) (inequality-type questions) were assessed 16, and 15 times, respectively. LOs about logarithms (3.7.a

and 3.7.b) were assessed 12 and 11 times, respectively. Items involving algebra totalled to 15 items.

A small number of LOs were assessed less frequently, each contributing minimally to the overall mark distribution. These include E3.1.1.f (writing down the period and amplitude of trigonometric functions), assessed in 3 items with 6 marks; E3.1.2 (determining function coefficients), in 2 items with 5 marks; and E3.6 (graph transformations), in 2 items with 4 marks. The LOs E3.1.1.b, E3.1.1.c (quadratic and cubic recognition, respectively), and E3.4.a (finding a quadratic from the vertex and one point) were each assessed once. Additionally, one item worth 2 marks could not be mapped to any LO.

Out of the 25 disaggregated LOs, ten were not assessed in any of the past five years of examinations. These LOs are listed in Table 9.

Table 9

Learning Objectives Which Have Not Been Assessed in 2021—2025 Cambridge IGCSE International Mathematics 0607 Extended Level Examinations

LO Code	Learning Objective
E3.1.1.a	Recognise linear functions from the shape of their graph.
E3.1.1.d	Recognise reciprocal functions from the shape of their graph.
E3.1.1.e	Recognise exponential functions from the shape of their graph.
E3.1.3	Determine values in a function from its graph.
E3.2.b	Use GDC to produce a table of values.
E3.2.c	Use GDC to plot points.
E3.2.f	Use GDC to find the vertex of a quadratic.
E3.4.b	Find a quadratic function given x -intercepts and a point.
E3.4.c	Find a quadratic function given vertex or x -intercepts in the case where $a = 1$.
E3.7.3	Understand and use the solution to $a^x = b$ as $x = \frac{\log b}{\log a}$.

Textbook Items to Learning Objective Mapping

This section presents the results of the item to learning objective mapping for the Haese Mathematics textbook, functions topic. The analysis was limited to the Review Sets found at the end of four chapters directly related to the functions strand: Chapter 30 (Functions), Chapter 31 (Quadratic Functions), Chapter 32 (Exponential and Logarithmic Functions), and Chapter 33 (Further Functions). Each of the four chapters includes two Review Sets, labelled A and B. Review Set A is available in both the printed and digital editions of the textbook, while Review Set B is accessible exclusively through the online platform. Due to copyright restrictions, the full content of these items cannot be reproduced within this study. Only items from the Review Sets were considered for this analysis. These sections are intended to consolidate learning and simulate the types of tasks used to evaluate mastery, making them a more appropriate basis for alignment analysis. In contrast, exercises embedded within the main body of each chapter primarily serve a formative function. They often introduce new concepts, provide scaffolded practice, or encourage exploratory reasoning, and therefore do not consistently align with the specific LOs outlined in the syllabus.

A total of 298 items were identified across the selected review sets. Each item was mapped to the relevant disaggregated LO on Appendix B. The summary of the mapping results is provided in the table below.

Table 10

Summary of Textbook Items to Learning Objective Mapping

Learning Objective Code	Number of Items
Number and Algebra LOs excluding E2.6.3	22
E2.6.3 with E3.2.e (and E3.5)	6

Learning Objective Code	Number of Items
E3.1.1.b	2
E3.1.2	7
E3.1.3	2
E3.2.a	11
E3.2.a, E3.2.d, E3.5	2
E3.2.b	3
E3.2.d	9
E3.2.e	10
E3.3.1	87
E3.3.2	9
E3.3.3	16
E3.4.a	6
E3.4.b	1
E3.4.c	4
E3.5	3
E3.6	9
E3.7.1	5
E3.7.2	30
Items without mapping	54
Total	298

Number and Algebra Learning Objectives

A small proportion of textbook items were mapped to number and algebra related LOs. One item from the Exponential and Logarithmic Functions chapter involved writing an exponential expression in the context of a word problem and was mapped to E1.16 (exponential growth and decay). One item was aligned with E2.2.1

and E2.2.2 (expanding and collecting like terms), while 12 items were mapped to E2.4.1 (understanding and using positive, negative, zero, and fractional indices). Three items addressed E2.5.1 (constructing algebraic expressions), one item was aligned with E2.5.4 (solving simultaneous linear equations), and four items were mapped to E2.5.5 (solving quadratic equations). Overall, these algebra LOs accounted for 22 items, representing 7.38% of the total textbook item set.

Graphs of Functions (E3.1)

A total of ten items were mapped to LOs under the original syllabus LO E3.1, making up 3.35% of all items. Two items addressed E3.1.1.b (recognising quadratic functions from their graphs), both requiring students to identify the line of symmetry. Seven items were mapped to E3.1.2 (finding coefficients of functions). These included one item for a quadratic function, one for a cubic function, three for reciprocal functions, and two for exponential functions, all requiring algebraic derivation based on given graphs or values. For exponential functions, the equations of the functions were in the form $y = p \times a^x$, rather than $y = a^x$, but the process of finding is not much different, so these two items were mapped to E3.1.2. Only one item was mapped to E3.1.3 (determining values from a graph), specifically asking students to find the vertex of a quadratic function from its graph.

Graphic Display Calculator (GDC) Skills (E3.2)

Sketching functions with GDC (E3.2.a) was assessed in 11 items independently. Producing a table of values (E3.2.b) was covered in three items, while E3.2.d (finding zeros, local maxima or minima) was addressed in nine items. E3.2.e (finding intersections of functions) was assessed in ten items. Two items labeled as *E3.2.a*, *E3.2.d*, *E3.5* required students to sketch two unfamiliar functions and label their intercepts, turning points, and asymptotes. These tasks

involved multiple GDC-related skills and were therefore included under the broader category of GDC use. When these are considered alongside other items primarily focused on GDC-based LOs, the total number of items assessing GDC skills rises to 35, representing 11.7% of all textbook items.

Function Notation, Domain and Range, Composite, and Inverse Functions (E3.3)

With 87 items (29.2% of all items), E3.3.1, which covers understanding functions, domain and range, and function notation, is the most frequently assessed LO. Nearly all of these items focused on function notation, while domain and range were addressed in only three instances. Inverse functions (E3.3.2) appeared in nine items, and composite functions (E3.3.3) were assessed in 16 items. Together, these three disaggregated LOs under the original syllabus LO E3.3 accounted for a total of 112 items, representing 37.6% of all textbook content, highlighting the strong emphasis placed on core function concepts throughout the review sets.

Quadratic Functions (E3.4)

Despite having its own dedicated chapter, only 11 items from Quadratic Functions (Chapter 31) could be mapped to a disaggregated learning objective. Six of these items involved finding a quadratic function given the vertex and one point (E3.4.a), one item required constructing it from the x -intercepts and a point (E3.4.b), and four items involved finding the function from the vertex or x -intercepts in cases where $a = 1$ (E3.4.c).

Asymptotes (E3.5)

Asymptotes (E3.5) were addressed in only three items. Two more items called for the knowledge of asymptotes (coded as *E3.2.a*, *E3.2.e*, *E3.5* in Table 10), but these items were counted towards E3.2 as the primary focus of the tasks involved

GDC-based graphing skills. This makes E3.5 one of the least represented LOs in the textbook.

Transformations (E3.6)

Transformations of functions (E3.6) were assessed in nine items. The distribution of horizontal and vertical translations was balanced across these tasks. Three of these items required students to work with both types of transformations within the same item.

Logarithmic Functions (E3.7)

All 35 items related to logarithms came from their dedicated chapter, Exponential and Logarithms (Chapter 32). Five items were mapped to understanding the logarithmic function as the inverse of the exponential function (E3.7.1), while 30 items involved understanding and using $y = a^x$ as $x = \log_a y$. (E3.7.2). Together, these items accounted for 11.7% of all textbook items. The LO E3.7.3: understanding and using the solution to $a^x = b$ as $x = \frac{\log b}{\log a}$, was not assessed.

Solving Inequalities Involving Functions with GDC

There were six items that addressed solving inequalities involving functions with GDC, labelled as *E2.6.3 with E3.2.e (and E3.5)* in Table 10. As previously explained in the assessment items to learning objective mapping, these questions involve a combination of these LOs. Four of these six items involved asymptotes (E3.5).

Items without Mapping

Out of the 298 textbook items, 54 items (18.1%) could not be mapped to any LO. Of these, five items asked students to identify the axis of symmetry of a quadratic function without providing its graph, and three items involved finding the

reflection of a function. However, reflection is not included among the transformations listed in the LO E3.6, and thus these items could not be mapped either. The remaining 41 items required students to sketch graphs, find the vertex of a quadratic function, or determine the intersection points of graphs without the use of a GDC. While these skills are related to those described in the original syllabus objective E3.2, that objective explicitly specifies the use of a GDC.

To summarize, the most frequently represented LO in the textbook was E3.3.1 (functions and notation), with 87 items, comprising nearly one-third (29.2%) of all textbook items. This was followed by E3.7.2 (logarithmic functions), with 30 items, and E3.3.3 (composite functions), which appeared in 16 items. E3.2.a (graph sketching with GDC) and E3.2.e (intersection of graphs) were addressed, with 11 and 10 items, respectively. Together, these five LOs accounted for 154 items, representing 51.7% of the entire textbook dataset.

Other moderately represented LOs included E3.2.d (zeros and local maximum and local minimum), E3.3.2 (inverse functions), and E3.6 (graph transformations), each with 9 items. E3.1.2 (determining function coefficients) appeared in 7 items, while E3.4.a (finding a quadratic given a vertex and a point) and E3.7.1 (logarithmic functions as inverses) were covered in 6 and 5 items, respectively. The textbook also included 6 items involving compound mappings related to inequality-type tasks (E2.6.3 with E3.2.e and E3.5) and an additional 2 items that drew upon multiple LOs (E3.2.a, E3.2.d, and E3.5). Number and algebra content accounted for 22 items.

Several LOs were only minimally addressed, such as E3.4.c (4 items), E3.2.b (3 items), E3.5 (3 items), and E3.4.b (1 item). A small number of items were

associated with E3.1.1.b and E3.1.3 (2 items each). In contrast, ten LOs were not represented at all, including E3.1.1.a, E3.1.1.c–f, E3.2.c, E3.2.f, and E3.7.3.

Notably, 54 items (18.1% of all textbook items) could not be mapped to any of the disaggregated LOs. These typically involved skills such as sketching graphs, identifying the vertex of a quadratic function or finding intersections without using technology, or doing transformations in ways that were not found in the syllabus.

Comparison of Assessment and Textbook Item to Learning Objective Mappings

A comparison of the percentage distributions of item to learning objective mappings reveals key differences in curricular emphasis between the textbook and assessments, which can be found on Table 11.

Table 11

Percentage Distribution of Disaggregated Learning Objectives Mappings in Assessment and Textbook

Learning Objective	Assessment (%)	Textbook (%)
E3.1.1.a	0	0
E3.1.1.b	0.33	0.67
E3.1.1.c	0.33	0
E3.1.1.d	0	0
E3.1.1.e	0	0
E3.1.1.f	1.3	0
E3.1.2	0.33	2.35
E3.1.3	0	0.67
E3.2.a	15.31	3.69
E3.2.b	0	1.01
E3.2.c	0	0
E3.2.d	9.12	3.02

Learning Objective	Assessment (%)	Textbook (%)
E3.2.e	12.05	3.36
E3.2.f	0	0
E3.3.1	16.29	29.19
E3.3.2	9.12	3.02
E3.3.3	12.05	5.37
E3.4.a	0.33	2.01
E3.4.b	0	0.34
E3.4.c	0	1.34
E3.5	5.21	1.01
E3.6	0.65	3.02
E3.7.1	3.58	1.68
E3.7.2	3.91	10.07
E3.7.3	0	0
Number and Algebra	4.89	7.38
Item not mapped	0.33	18.12
E2.6.3 with E3.2.e (and E3.5)	4.89	2.01
E3.2.a, E3.2.d, E3.5	0	0.67

Note. Total of each column may not add up to 100% due to rounding.

Certain LOs showed strong alignment across both sources. For instance, E3.3.1 (functions and notation) was the most emphasized LO in both the assessments and the textbook, comprising 16.29% and 29.19% of items, respectively. Similarly, composite functions (E3.3.3) were consistently addressed, appearing in 12.05% of assessment items and 5.37% of textbook items.

However, some LOs exhibited considerable discrepancies in their relative emphasis. E3.2.a (graph sketching using GDC), for example, represented 15.31% of assessment items but only 3.69% of textbook items, suggesting that while heavily

assessed, it is less thoroughly reinforced in the textbook. A similar pattern emerged for E3.2.d (zeros, local maximum, and local minimum) and E3.2.e (intersection points), which were more prevalent in assessments (9.12% and 12.05%, respectively) than in the textbook (3.02% and 3.36%). These patterns suggest an assessment emphasis using GDC skills for sketching and finding certain points on functions, which is not equally reflected in textbook content.

In contrast, the textbook gave more weight to certain LOs that were less frequently assessed. E3.7.2 (logarithmic functions) made up 10.07% of textbook items but only 3.91% in assessments. Likewise, E3.1.2 (determining function coefficients) accounted for 2.35% in the textbook but only 0.33% in assessments. Graph transformations (E3.6) followed a similar trend (3.02% in textbook, 0.65% in assessments). Inequality-type items, mapped to the combination of E2.6.3, E3.2.e, and E3.5, appeared in both the assessments and the textbook but with notable differences in emphasis. In the assessments, these items accounted for 4.89% of all items, whereas in the textbook, they made up only 2.01%.

A number of LOs were minimally addressed in either source. LOs such as E3.4.a–c (finding a quadratic function under given different points), E3.1.1.a–f (recognising basic function types), and E3.1.3 (determining values of function from its graph) together accounted for less than 2% of items in both sources. In particular, E3.1.1.a, E3.1.1.d, E3.1.1.e, E3.2.c, E3.2.f, and E3.7.3 were entirely absent from both the assessments and the textbook.

Lastly, a substantial disparity emerged in the proportion of unmapped items. While only 1 item (0.33%) of assessment items could not be linked to a disaggregated LO, this figure was significantly higher in the textbook with 54 items at 18.12%. This indicates that a considerable portion of textbook content fell outside

the scope of the official LOs, often requiring students to perform skills that are specified in the syllabus to be done using a GDC, but instead presented without one.

To facilitate a broader comparison, the disaggregated LOs were regrouped under their original syllabus codes (E3.1 to E3.7), allowing for a more streamlined analysis of coverage across sources. Table 12 presents the percentage distribution of items mapped to each original syllabus LO in both the assessments and the textbook.

Table 12

Percentage Distribution of Original Syllabus Learning Objectives Mappings in Assessment and Textbook

Syllabus Learning Objective	Assessment (%)	Textbook (%)
E3.1	2.28	3.69
E3.2	36.48	11.07
E3.3	37.46	37.58
E3.4	0.33	3.69
E3.5	5.21	1.01
E3.6	0.65	3.02
E3.7	7.49	11.74
Items without mapping	0.33	18.12
Other topics and multiple LOs	9.77	10.07

Note. Total of each column may not add up to 100% due to rounding.

This representation reveals patterns that may not be immediately apparent in the item to disaggregated LO mapping. For instance, while the overall emphasis on functions (E3.3) remains consistent between the two sources, other areas such as graphing using GDC (E3.2), exponential and logarithmic functions (E3.7), and transformations (E3.6) display notable discrepancies. The category labelled *Other topics and multiple LOs* includes items that were mapped to algebra and number

LOs, as well as those mapped to multiple LOs. Items that could not be mapped to any syllabus objective are also reported separately in *Items without mapping*.

Table 12 shows the percentage distribution of how each original syllabus LO (E3.1–E3.7) was represented across the assessment and textbook items. This breakdown offers an initial descriptive view of which LOs were more or less emphasized in each source. While informative, this distribution alone does not provide a unified measure of alignment between the curriculum components. To address this, the next section applies Porter’s Alignment Index, which enables a quantitative comparison of emphasis patterns between the syllabus, textbook, and assessments, resulting in a single numerical indicator of alignment for each pairwise combination.

Porter’s Framework

This section presents the results of the alignment analysis using Porter’s Framework (2002). While the methodological foundations of this approach were explained earlier, it is important to recall that the index quantifies the degree of alignment between curriculum components by comparing the distribution of content across a two-dimensional matrix organized by content category and level of cognitive demand. The resulting numerical value reflects the extent to which two components emphasize the same skills and concepts in similar proportions.

To ensure consistency and interpretability in the construction of alignment matrices, specific categorization choices were applied. Inequality-based items from the assessments were categorized under *E3.2: GDC Skills*, as all of these items require students to determine the intersection points of graphs (E3.2.d). Furthermore, assessment items were not disaggregated into smaller subitems. Each item was assigned to a single content category based on its primary mathematical focus within

the functions topic. For example, if an item involved both the use of function notation (E3.3.1) and algebraic manipulation, it was classified under *E3.3: Function Notation, Inverse and Composite Functions*, rather than being placed in the *Other* category solely because it included algebraic manipulation.

There were some items that could not be mapped to any of the disaggregated LOs derived from the syllabus. These items were therefore placed into *Other* content category to allow their inclusion in the analysis without distorting the representation of LOs. Items that only involved any other LO from the syllabus were also classified in this category. For example, some items in the textbook only addressed use of indices (E2.4.1), and therefore, they were classified as *Other*. Using this classification approach, a total of 294 assessment items and 298 textbook items were included in the alignment analysis.

No items in either the assessment papers or the textbook were classified at the memorization level of cognitive demand from Stein and Smith (1998). For clarity, the remaining demand levels have been abbreviated as follows:

- PWOC: Procedures Without Connections
- PWC: Procedures With Connections
- DM: Doing Mathematics

The distribution of assessment and textbook items across these cognitive demand levels and content categories is shown below in Tables 13 and 14.

Table 13

Alignment Matrix for Assessment Items (Raw)

Content Categories	Cognitive Demand Level		
	PWOC	PWC	DM
E3.1	4	2	1

Content Categories	Cognitive Demand Level		
	PWOC	PWC	DM
E3.2	69	43	12
E3.3	61	45	7
E3.4	0	1	0
E3.5	10	5	1
E3.6	1	1	0
E3.7	13	8	2
Other	5	1	2

Table 14

Alignment Matrix for Textbook Items (Raw)

Content Categories	Cognitive Demand Level		
	PWOC	PWC	DM
E3.1	5	6	0
E3.2	19	16	7
E3.3	77	34	3
E3.4	10	1	0
E3.5	0	3	0
E3.6	1	6	1
E3.7	21	13	0
Other	20	53	1

Although the total number of items is similar across the two sources (294 for the assessments and 298 for the textbook), the matrices were normalized to allow for a more accurate comparison. Normalization in this context refers to converting the raw item counts in each cell into proportions relative to the total number of items in that source. This approach enables a fair comparison by accounting for any minor

differences in item totals and highlighting the relative emphasis placed on each cell.

All proportions were rounded to four decimal places to maintain consistency and precision in reporting.

Table 15

Alignment Matrix for Assessment Items (Normalized)

Content Categories	Cognitive Demand Level		
	PWOC	PWC	DM
E3.1	0.0136	0.0068	0.0034
E3.2	0.2347	0.1463	0.0408
E3.3	0.2075	0.1531	0.0238
E3.4	0	0.0034	0
E3.5	0.0340	0.0170	0.0034
E3.6	0.0034	0.0034	0
E3.7	0.0442	0.0272	0.0068
Other	0.0170	0.0034	0.0068

Note. The sum of all cells might not add up to 1 due to rounding.

Table 16

Alignment Matrix for Textbook Items (Normalized)

Content Categories	Cognitive Demand Level		
	PWOC	PWC	DM
E3.1	0.0168	0.0201	0
E3.2	0.0638	0.0537	0.0235
E3.3	0.2584	0.1141	0.0101
E3.4	0.0336	0.0034	0
E3.5	0	0.0101	0
E3.6	0.0034	0.0201	0.0034

Content Categories	Cognitive Demand Level		
	PWOC	PWC	DM
E3.7	0.0705	0.0436	0
Other	0.0671	0.1779	0.0034

Note. The sum of all cells might not add up to 1 due to rounding.

Porter's Alignment Index (PAI) was calculated using Python and found to be 0.6093. The Python code used to calculate the PAI is provided in Appendix D. The matrices were generated from a total of 294 assessment items and 298 textbook items, each distributed across 24 content–cognitive demand cells. According to Fulmer's (2011) simulation study, the 2.5th percentile threshold for random alignment in a 24-cell matrix with 120 points is 0.6583. Since the observed score falls below this threshold, the alignment between the assessment and the textbook is significantly lower than what would be expected by chance at the $p < 0.05$ level. Given that both matrices contain over twice as many points as the simulated benchmark, this threshold is conservative and thus strengthens the conclusion of statistically significant misalignment.

Kazemi's Misalignment Framework

By comparing Table 15 and Table 16, the misalignment matrix can be constructed in accordance with the methodology proposed by Kazemi (2022). This matrix forms the basis for identifying and classifying the nature of misalignments between the two curricular components. The descriptions of misalignment categories can be found on Table 5.

Table 17*Alignment and Misalignment Matrix for Assessment and Textbook*

Content Categories	Cognitive Demand Level		
	PWOC	PWC	DM
E3.1	OC	OC	MC
E3.2	UC	UC	UC
E3.3	OC	UC	UC
E3.4	PC	NTPA	TPA
E3.5	MC	UC	MC
E3.6	NTPA	OC	PC
E3.7	OC	OC	MC
Other	OC	OC	UC

As shown in Table 17, all six alignment and misalignment types described by Kazemi (2022) are represented in the matrix: Trivial Perfect Alignment (TPA), Non-Trivial Perfect Alignment (NTPA), Missed Coverage (MC), Under-Coverage (UC), Over-Coverage (OC), and Pure Contamination (PC). However, it would be misleading to draw conclusions based solely on their frequency or visual distribution in the matrix. Some classifications may appear more frequently due to small proportional differences that nonetheless meet the formal criteria for misalignment. Therefore, a more nuanced analysis is required, one that considers not only the number of occurrences but also the magnitude of misalignment in each cell.

Trivial Perfect Alignment (TPA)

Only one cell in the matrix was classified as Trivial Perfect Alignment (TPA), specifically the E3.4–DM cell. This indicates that neither the textbook nor the assessment contains items requiring students to derive quadratic functions at

the *Doing Mathematics* cognitive demand level. This absence is reasonable, given that such derivation tasks typically involve structured procedures rather than complex reasoning or problem-solving.

Quadratic functions can be expressed in vertex form $y = a(x - h)^2 + k$ where (h, k) is the vertex, or in x -intercept form as $y = a(x - p)(x - q)$ where p and q are x -intercepts. If $a = 1$ in either of these equations, these expressions simplify greatly and direct substitution of vertex for vertex form, and x -intercepts for x -intercept form gives the quadratic function. In such cases, students are not required to engage in extended reasoning; they only need to recall the correct form and substitute values appropriately. When $a \neq 1$ students must substitute an additional point into the equation and solve for a , introducing a second step. However, even this extended task remains procedural and follows a well-defined sequence of operations. As a result, items involving the derivation of quadratic functions typically align more closely with the *Procedures Without Connections (PWOC)* or *Procedures With Connections (PWC)* categories, rather than reaching the cognitive complexity associated with *Doing Mathematics*.

Non-Trivial Perfect Alignment (NTPA)

Non-Trivial Perfect Alignment (NTPA) was observed in two cells of the matrix: E3.6–PWOC and E3.4–PWC. This classification arises when both the target (assessment) and the instrument (textbook) allocate an equal and non-zero proportion of items to a specific content–cognitive demand pairing. In both cases, each source included exactly one item aligned to the respective cell, resulting in matching proportions once normalized and rounded to four decimal places. While these cells demonstrate proportional consistency between the two components, the absolute

frequency remains low, suggesting that these content-demand areas received only minimal emphasis overall.

Missed-Coverage (MC)

Missed Coverage (MC) was identified in four cells of the matrix: E3.1–DM, E3.5–PWOC, E3.5–DM, and E3.7–DM. This category refers to cases where the target component (assessment) includes items addressing a particular content–demand pair, while the instrument (textbook) contains none. Although this suggests a lack of instructional support for assessed content, the extent of this misalignment varies across the cells.

For E3.1–DM and E3.5–DM, each cell corresponds to only one item in the assessment, while E3.7–DM includes two. Given their low frequency, these instances may not represent substantial omissions in the textbook and should be interpreted with caution. In contrast, E3.5–PWOC shows a more notable case of misalignment, with ten items in the assessment and none in the textbook. This indicates a genuine case of missed coverage in the area of logarithmic functions at the *Procedures Without Connections* level.

Under-Coverage (UC)

Under-Coverage (UC) was identified in seven distinct content–cognitive demand pairings. To better understand the extent and nature of this misalignment, Table 18 presents the corresponding number of items for each pair as found in the assessment and textbook.

Table 18*Assessment and Textbook Item Frequencies for Under-Coverage (UC) Classification*

Under-Coverage Pairs	Assessment	Textbook
E3.2–PWOC	69	19
E3.2–PWC	43	16
E3.2–DM	12	7
E3.3–PWC	45	34
E3.3–DM	7	3
E3.5–PWC	5	3
Other–DM	2	1

The most substantial discrepancy appears in E3.2–PWOC, with 69 items found in the assessments compared to only 19 in the textbook. Similarly, E3.2–PWC has 43 items in assessments, whereas the textbook had 16 items. This suggests a significant underrepresentation of graphic display calculator skills, which are heavily emphasized in assessment but not proportionally reinforced in the textbook.

Although E3.3–PWC is classified as under-coverage, both the assessment and the textbook include a substantial number of items in this category, with 45 and 34 items, respectively. Despite the numerical discrepancy, the frequent representation in both sources suggests that this content–cognitive demand pairing received considerable attention overall. Similarly, E3.2–DM, E3.3–DM, and E3.6–PWC were assessed with relatively low frequency in both components. The small differences in item counts in these cases do not reflect substantial misalignment and are therefore of limited interpretive value.

The category Other–DM is excluded from further analysis, as it combines items that could not be mapped to any specific LO with those aligned to topics outside the scope of the functions strand. As such, it does not lend itself to meaningful interpretation within the framework of this study.

Over-Coverage (OC)

Over-Coverage (OC) was identified in eight distinct content–cognitive demand pairings. To better understand the extent and nature of this misalignment, Table 19 presents the corresponding number of items for each pair as found in the assessment and textbook.

Table 19

Assessment and Textbook Item Frequencies for Over-Coverage (OC) Classification

Over-Coverage Pairs	Assessment	Textbook
E3.1–PWOC	4	5
E3.1–PWC	2	6
E3.3–PWOC	61	77
E3.6–PWC	1	6
E3.7–PWOC	13	21
E3.7–PWC	8	13
Other–PWOC	5	20
Other–PWC	1	53

Both sources put great emphasis on E3.3–PWOC, with 77 textbook items compared to 61 in the assessment. Although both sources focus heavily on this pairing, the textbook's greater emphasis classifies it as over-coverage. Other cases, such as E3.1–PWOC, E3.1–PWC, and E3.6–PWC, involve relatively small item counts in both sources. While the textbook contains more items in each case, the absolute differences are minor. In both E3.7–PWOC and E3.7–PWC, the textbook

includes more items than the assessment, 21 vs. 13 and 13 vs. 8, respectively.

Although these differences result in an over-coverage classification, they are not substantial. The slightly higher emphasis in the textbook is understandable, as it contains a dedicated chapter on exponential and logarithmic functions, naturally leading to broader coverage.

For both Other–PWOC and Other–PWC pairings, the differences between the textbook and the assessment are substantial. However, these over-coverage classifications should be interpreted with caution. The *Other* category includes a mix of items, such as those that could not be mapped to any specific LO and those related to topics outside the functions strand. Notably, the majority of these textbook items fall under the "items without mapping" group, where students are asked to perform tasks (sketching graphs, finding intersections) that are typically designated as calculator-based tasks in the syllabus, which results in over-coverage in Other–PWC pairing.

Pure Contamination (PC)

Pure Contamination (PC) means the assessment (target) includes no items, while the textbook (instrument) includes several. PC was identified in two cells: E3.4–PWOC and E3.6–DM.

In E3.4–PWOC, the textbook contains 10 items, while the assessment includes none. This indicates that the textbook places emphasis on basic procedural tasks related to deriving quadratic functions, even though such tasks are not assessed at this cognitive level in the assessment. This suggests a potential overuse of low-level procedural exercises that are not aligned with assessment expectations.

In E3.6–DM, the textbook includes one item, and the assessment includes none. Given the low frequency, this case of pure contamination is minor and not of

major concern. It reflects a rare instance where the textbook introduces a higher-level reasoning task that does not appear in the assessment.

Inequality Items in Assessment and Textbook

Inequality items appear recurrently in assessments, although inequalities are not explicitly specified under the functions LOs in the syllabus. Terminology and convention mismatches between the syllabus and the assessments created boundary cases for coding: under prevailing exam conventions these items can be mapped to disaggregated LOs, yet under the syllabus definitions they arguably should not be.

To preserve comparability, these items were retained in the dataset and their mappings were recorded with an explicit note on this convention issue. In the textbook, five inequality items were identified. They exhibited lower cognitive demand than the assessment cases and posed no classification difficulty; each mapped straightforwardly to one or more disaggregated LOs.

These types of items required students to solve inequalities involving the given functions. However, such tasks did not correspond to a single LO, as solving inequalities is located in the Algebra strand of the syllabus (E2.6) and not under the functions section. These items are often quite complex, and for this reason, they were matched to the Doing Mathematics level of cognitive demand in the second stage of analysis. When reading the functions LOs in the syllabus, students are unlikely to anticipate that they will be asked to solve inequalities involving those same functions.

One might also argue that this ambiguity extends to teachers as well. Since solving inequalities is not a LO listed under the functions strand, and it is not clearly stated as being integrated into these types of questions, it can be easily missed. If the teacher is not thoroughly familiar with past papers and has not reviewed them

carefully enough to recognise these inequality-type tasks (which are not as frequently assessed) they may not prepare students for them at all. This is especially likely if the teacher is inexperienced, new to the IGCSE curriculum, or lacks professional development and departmental support. These questions are also not the kind that students can figure out intuitively on their own. They often involve nuances, particularly when asymptotes are present, making them especially difficult unless explicitly taught in class.

There were two items that were interesting that involved inequalities.

Although inequalities are not considered functions in a formal sense, their representation on the coordinate plane often involves skills and concepts commonly taught within the functions unit, such as interpreting graphs, identifying boundary lines, and understanding regions defined by conditions. The first item was mapped to the LO E2.6.4 as shown in Figure 7 and the item is from Question 15 from Paper 2 in the June 2021 examination, shown in Figure 8.

Figure 7

Learning Objective E2.6.4 from syllabus

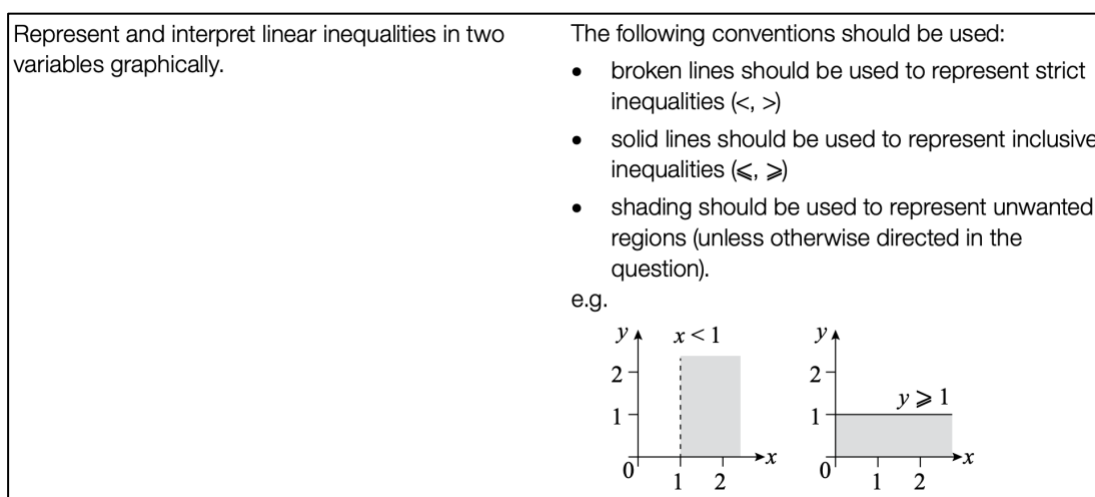
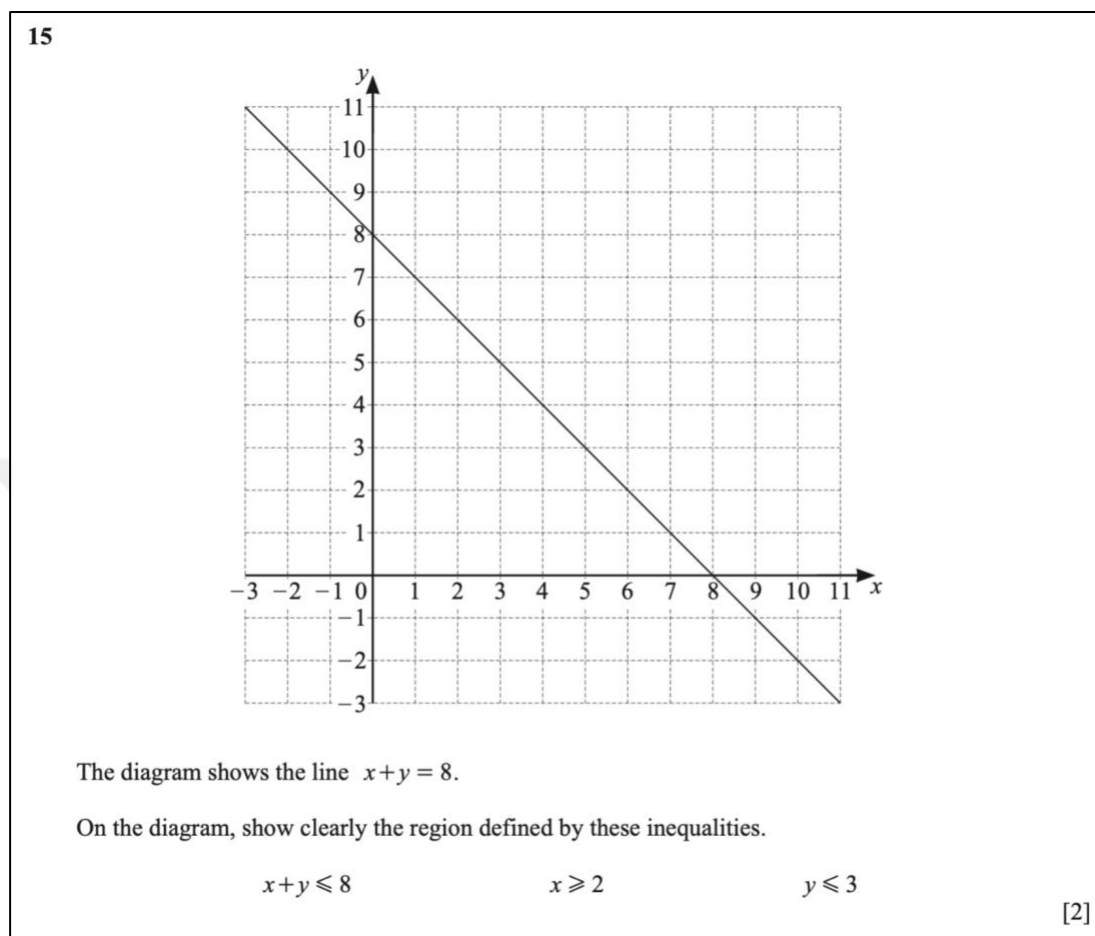


Figure 8

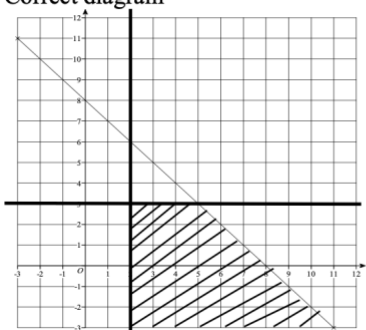
Question 15 from Paper 2 in June 2021 examination



This LO explicitly states that shading should be used to represent *unwanted* regions. Although this item was not from the most recent syllabus, its respective syllabus for examinations 2020—2022 (CAIE, 2017) also states to shade *unwanted* regions. In contrast, the mark scheme of the item shades the *wanted* region as shown below in Figure 9. In standard mathematical practice, the convention is to shade the *wanted* region.

Figure 9

Mark scheme of Question 15 from Paper 2 in June 2021 examination

15	Correct diagram 	2 B1 for $x = 2$ and $y = 3$ drawn
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This inconsistency between the LO and the mark scheme introduces a significant source of confusion for both students and teachers. The LO (E2.6.4) clearly states that students should shade the *unwanted* regions of a graph to visually represent the solution set. However, the mark scheme for the June 2021 item indicates that the *wanted* region should be shaded instead, directly contradicting the guidance provided in the syllabus.

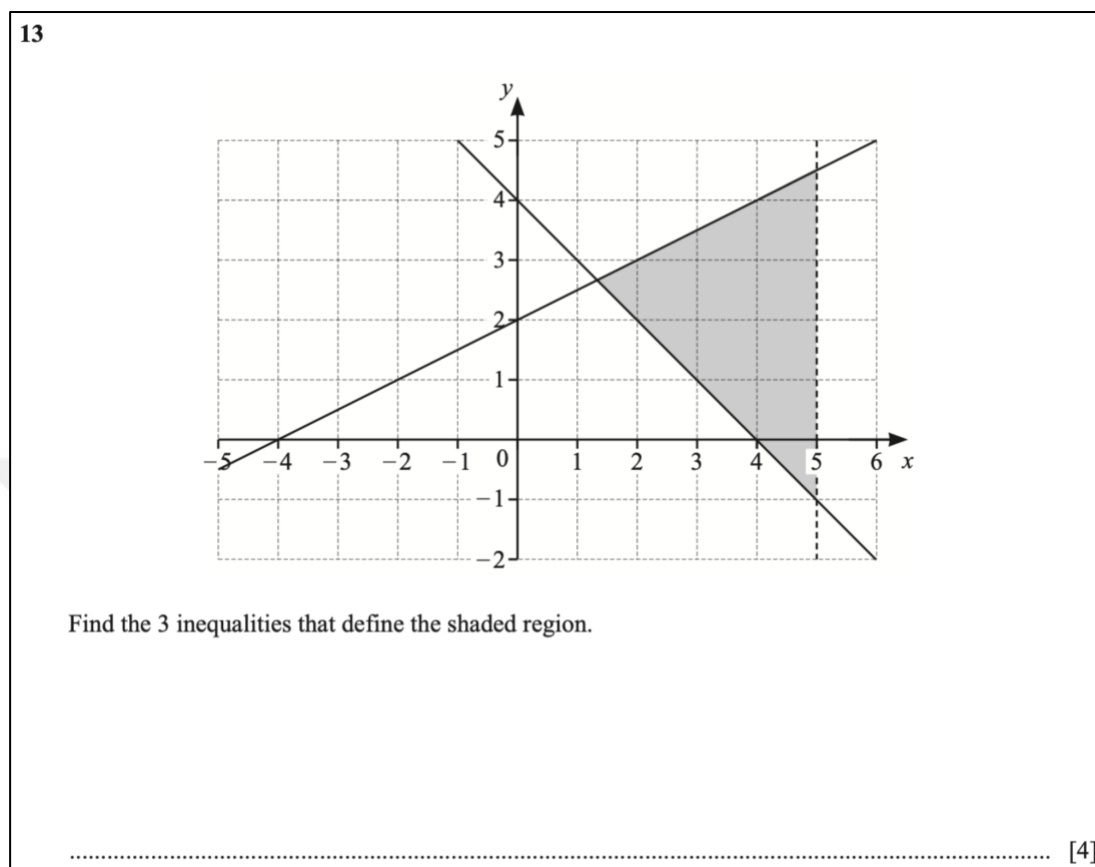
For students, such a discrepancy can lead to misunderstandings about what constitutes a correct solution, especially if they have been consistently taught to follow the syllabus instructions. They may produce a correct answer according to the curriculum but be penalized for not matching the marking scheme, which is particularly problematic in high-stakes assessments.

For teachers, this misalignment complicates the task of preparing students for examinations. If the syllabus promotes one convention while the assessment rewards another, teachers may feel uncertain about which approach to emphasize. This undermines both instructional consistency and fairness in evaluation.

The second noteworthy item appeared in Paper 22 from the March 2025 examination, which is the most recent published paper at the time of this analysis.

Figure 10

Question 13 from Paper 22 in March 2025 examination and its mark scheme



13	$x < 5$ $x + y \geq 4$ oe $y \leq \frac{1}{2}x + 2$ oe	4	B2 for $x [=] 5$, $x + y [=] 4$ oe, $y [=] \frac{1}{2}x + 2$ oe or B1 for $y [=] \frac{1}{2}x + 2$ oe or $x + y [=] 4$ oe B1 for one correct inequality
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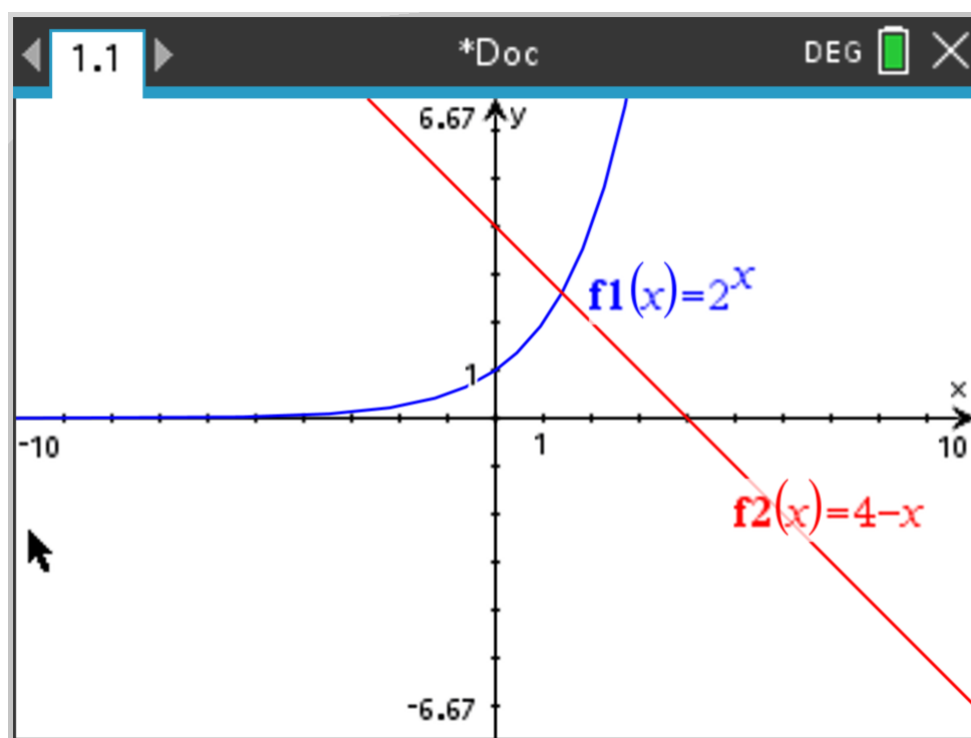
The item in Figure 10 was mapped to LO E2.6.5: *List inequalities that define a given region*. Unlike E2.6.4, this objective is not accompanied by any explanatory notes or illustrative examples in the syllabus. The absence of such guidance leaves room for interpretation regarding what conventions students should follow when identifying or representing regions defined by inequalities. In the context of the preceding LO (E2.6.4), where shading the *unwanted* region is explicitly required, students may reasonably assume that the same convention applies in E2.6.5 as well.

This assumption becomes particularly relevant if the item in question includes a shaded region on a diagram. Without clear instructional clarification, students might interpret the shaded area as representing the *unwanted* region. The mark scheme for the question reveals that the shaded region actually represents the *wanted* region. This lack of consistency and explicit guidance could lead to errors not stemming from a misunderstanding of the mathematical content itself, but rather from the ambiguity of conventions used in the syllabus and assessments.

In the textbook, only five items addressed inequality-type questions involving functions. Although this thesis does not systematically analyse the instructional content of the textbook, such as worked examples, the treatment of these tasks appears problematic in both the syllabus and the textbook. The only worked example related to solving inequalities of functions solves this inequality: $2^x < 4 - x$.

Figure 11

Solution to $2^x < 4 - x$



As seen in Figure 11, the two functions intersect at a single point, and neither includes a vertical asymptote. This makes the example relatively straightforward. In contrast, assessment items often involve functions that intersect at multiple points and contain vertical asymptotes, which significantly increase both the complexity and cognitive demand of the task. Among the five inequality items in the textbook, only one includes a vertical asymptote. Even in that case, both functions share the same asymptote, limiting the conceptual challenge. As a result, none of the textbook items match the representational or procedural demands observed in the assessment tasks. It is important to note, however, that this discrepancy may not lie entirely with the textbook. These types of tasks are not explicitly described or exemplified in the syllabus, which may lead to inconsistent interpretation by textbook authors. This ambiguity across curriculum documents complicates the instructional preparation of students and may contribute to gaps between taught and assessed content.

Chapter Summary

In summary, this chapter presented the results of the alignment analysis across three stages. First, individual items from the assessments and textbook were mapped to the disaggregated LOs to identify the extent to which each source reflected the official curriculum content. This stage revealed differences in emphasis and coverage across specific LOs. Next, Porter's Alignment Index (PAI) was calculated to provide a numerical measure of alignment between the textbook and the assessment, resulting in a moderate score of 0.6093. Finally, Kazemi's misalignment methodology was applied to identify the nature and direction of specific mismatches between the two components. This revealed both minor and more substantial discrepancies in content and cognitive demand distribution. The next chapter will explore the educational implications of these findings, discussing how the observed

patterns relate to broader concerns in curriculum alignment and classroom practice.

Additionally, the analysis documented the recurrent inclusion of inequality items within the functions unit that are not explicitly specified in the functions LOs, a pattern that complicates the interpretation of alignment.



CHAPTER 5: DISCUSSION

Introduction

The purpose of this chapter is to discuss the implications derived from the results presented in this research, identify areas for future exploration, and acknowledge the inherent limitations of the study. This discussion synthesizes insights obtained from alignment analyses between curriculum components, emphasizing the impact these findings may have on educational practice and curricular development.

Overview of the Study

This study investigated the alignment between the syllabus, textbook, and assessments within the Cambridge IGCSE International Mathematics 0607 Extended curriculum, specifically focusing on functions. Employing item to learning objective (LO) mapping, Porter's framework (2002) and Kazemi's misalignment framework (2022), the study examined how the Haese textbook and IGCSE assessments cover the syllabus functions LOs and how coverage is distributed across cognitive demand, quantified alignment between the textbook and the assessments using Porter's Alignment Index, and identified key misalignment types. The findings highlighted areas of strong alignment, as well as critical gaps requiring attention from educators, administrators, and textbook authors.

Discussion of Major Findings

Item to Learning Objective Mapping Findings

The mapping of the assessment items shows a stable and quite narrow pattern. Almost all items are from Paper 4s (94.1 percent); the rest are from Paper 2s.

Two main question types were present in the assessments. The first type asks students to work with function notation by substituting values, finding inverses, or forming composite functions. These map to E3.3.1, E3.3.2, and E3.3.3, with E3.7 when the functions are exponential or logarithmic. The second depends on the graphic display calculator. Students sketch graphs, find zeros, local maxima or minima, and intersections, which map to E3.2.a, E3.2.d, and E3.2.e, and to E3.5 when asymptotes are relevant.

On the positive side, students who practise a few representative examples feel safer and more confident because the examination looks familiar. On the negative side, the same predictability encourages routine practice around these two formats and leaves less room for other skills that the syllabus values (Polikoff, 2012). In other words, students learn to expect the same moves and may not be asked to show broader understanding.

Several LOs are under-sampled or appear only indirectly, which narrows what the assessments actually make visible. Recognition of function types from graphs (E3.1.1a–f) appears only four times across five years and never in the straightforward form intended by the syllabus. The few instances lean on symmetry or on amplitude and period in trigonometric graphs, which are listed in the syllabus notes as examples rather than the central aim. Identifying coefficients for the families in E3.1.1 (E3.1.2) occurs once, again through trigonometric amplitude and period. Deriving a quadratic from given points or conditions (E3.4) appears once. Transformations of functions (E3.6) are also scarce, and three transformation items were excluded because the latest syllabus no longer includes those cases. Even if they were counted, transformation items would total five out of 294.

Taken together, this imbalance shifts the message the examinations send. By sampling function notation, inverse and composite functions, and calculator-based graph routines heavily, while rarely sampling LOs such as recognising a function type from its graph, determining the coefficients or parameters of standard function families, deriving a quadratic function from given points or conditions, and describing and predicting how transformations change a function's key features, the assessments redefine what counts as achievement. In practice, LOs that are seldom assessed lose instructional weight, which makes it harder for teachers to justify sustained emphasis on them in planning and lesson time. This is consequential because these neglected aims develop central forms of understanding, including visual identification of function families, inference about parameters across models, and reasoning about transformations that link algebraic expressions to graphical behaviour.

Turning to the textbook, 54 items did not map to any disaggregated LO. Most of these asked students to carry out tasks that the syllabus designates as GDC-skills, but without the graphic display calculator. Typical examples include sketching graphs, identifying local maxima and minima, and finding intersections. In the textbook they are set as manual exercises. This creates a clear gap between what the syllabus intends students to do with a calculator and what the materials actually ask them to do (Polikoff, 2015).

This gap carries practical costs. Students who do not know the syllabus expectations often try to complete these tasks by hand as instructed by the textbook, spend disproportionate time on algebra, and miss chances to build graphic display calculator fluency such as choosing a viewing window, tracing intersections, and interpreting numerical outputs. It also sends mixed messages to teachers about what

to prioritise, since the textbook emphasises manual routines while the syllabus frames these tasks as GDC skills. In practice, method choice becomes a source of confusion rather than a learned skill, and differences in prior calculator experience can widen achievement gaps (Pepin & Haggarty, 2001).

A further source of unmapped items comes from algebraic procedures and transformations that do not align with the function-specific expectations. The most visible example is reflection. Many items ask students to reflect graphs, yet reflection is not among the transformations specified for functions in the syllabus. From a textbook-author viewpoint, this can feel natural because reflection is taught earlier in the chapter on transformation geometry, and a function can be treated as a set of points. From a student viewpoint that follows the syllabus, there is no explicit requirement to perform such tasks within the functions topic.

With the exception of GDC-based graphing skills, whose absence in the textbook is striking given their role in the syllabus and emphasis in assessments, most LOs receive at least some coverage. However, recognising the type of a function from its graph is almost entirely overlooked. Several LOs do not appear at all, including plotting points using a graphic display calculator, finding the vertex of a quadratic function using the calculator, and solving exponential equations using logarithms.

Taken together, these patterns indicate a consistent drift. The textbook foregrounds manual graph work and certain transformations, while the syllabus emphasises GDC-mediated techniques and specific function competencies. This divergence shapes what students come to see as important. It also makes it harder for teachers to sustain emphasis on LOs that receive little support in the textbook, even though those LOs are central for the topic of functions.

One important comment regarding the textbook is that Review Set B tasks are only accessible through the online platform. While the textbook includes 24-month access to these digital materials, this raises equity concerns. In many contexts, students may inherit textbooks from older siblings or former students, but they would not have access to the associated online subscription. This limitation restricts access to the full set of review materials for those who rely on second-hand books. Notably, earlier editions of the textbook included Review Set B tasks in the physical copy, making them equally available to all users regardless of subscription status. The shift to an online-only format introduces a barrier that may disproportionately affect students with limited resources.

Another notable limitation is that the Background Knowledge section is also available only in the online version of the textbook. While the exclusion of this section from the printed edition may be understandable from the publisher's perspective, particularly to reduce printing costs, it raises concerns about accessibility and content prioritization. Although this issue lies beyond the primary scope of this thesis, it is important to note that the Background Knowledge section includes several topics that are essential for student understanding. For example, it covers rotational symmetry and line symmetry, a concept that is explicitly included in the syllabus and could have been integrated within its relevant topic area. Instead, the section discusses rotational symmetry of solids and planes of symmetry, which is not part of the syllabus content.

Inequalities-type items are a recurring problem across both the assessments and the textbook. In the assessments, inequality tasks appear often even though the functions topic syllabus LOs do not state them clearly and explicitly. Students are asked to decide where one function is greater than another or to read sign changes

and intervals from graphs or a calculator. This blurs the target and reduces clarity about what the assessment is meant to measure. It also makes careful mapping difficult and disadvantages students who organise their study around the written LOs rather than past paper habits.

In the textbook, the pattern reverses. There are only a few inequality exercises, mostly routine, with little connection to the functions work or to calculator use. Conventions are inconsistent, and the level of cognitive demand is lower than what appears in assessments. Students who rely on the textbook are not prepared for the kind of inequality work the assessment assumes, and teachers must fill the gap with extra materials. In short, inequalities operate like a hidden requirement: they matter for performance, but they are not defined or developed where students and teachers would reasonably expect.

Overall, the item to learning-objective mapping establishes the coverage profile for the functions topic, indicating where the Haese textbook and past IGCSE examinations provide strong, limited, or no coverage of the prescribed LOs. Building on this, the next section discusses the findings from Porter's Alignment Index and Kazemi's misalignment methodology to interpret the size and direction of the discrepancies identified.

Porter's and Kazemi's Framework Findings

Following the item to learning objective mapping, the items were also classified into levels of cognitive demand based on the framework developed by Stein and Smith (1998). After each item was classified and matrices were formed, Porter's Alignment Index (PAI) was calculated to be 0.6093. Relative to a chance benchmark, this value shows limited overlap between the textbook and the assessments in how they cover functions and in the levels of cognitive demand they

require. In Fulmer’s study (2011), critical values for “alignment due to chance” were derived for specific design points. For a design with 120 items distributed across 24 content-by-demand cells, the chance threshold is 0.6583. Because my study includes close to 300 items per source over a comparable number of cells, the corresponding chance threshold would be higher. In other words, when there are more items, the chance threshold gets higher, so a PAI of 0.6093 falls even farther below that threshold. This suggests the observed alignment is not due to random chance.

However, this study is a strict test for alignment, which makes a high PAI harder to get. Most alignment studies using Porter’s framework include many topics from the whole course (Polikoff, 2012). When you average across many topics, a mismatch in one place can be offset by a good match somewhere else. I analysed only the functions topic. In a single topic, small differences between the textbook and the exams count more because there is nothing else to balance them out. That tends to pull the two distributions further apart and lowers the PAI.

To better understand the nature of the observed misalignment, Kazemi’s (2022) framework was applied to disaggregate alignment at the level of individual content–demand cells and classify the types of divergence between the textbook and the assessment. The analysis revealed the presence of all six alignment and misalignment categories. While some instances were negligible, such as a cell with one item in the assessment and none in the textbook, other patterns indicated more substantial discrepancies. As anticipated, there was consistent under-coverage across all cognitive demand levels in GDC-related skills (E3.2), which were almost entirely absent from the textbook. Within the *Doing Mathematics* cognitive demand level, four content categories exhibited under-coverage (UC) or missed coverage (MC),

showing that the textbook failed to provide sufficient support for tasks requiring higher-order reasoning that appeared in the assessments.

There was also a notable instance of pure contamination (PC) in the E3.4—Procedures Without Connections (PWOC) cell. This misalignment is understandable in context. Although the assessment addressed the LO of deriving quadratic functions from given points (E3.4) only once in the past five years, and not at the PWOC cognitive demand level, the topic remains an essential component of the broader concept of quadratic functions. The textbook, which includes a dedicated chapter on quadratic functions, contains multiple procedural exercises aligned with this objective and cognitive demand level. As a result, the apparent overrepresentation in the textbook relative to the assessment should not necessarily be viewed as a flaw, but rather as an instance where so-called misalignment reflects legitimate instructional emphasis beyond what has been captured in recent examinations.

Implications for Practice

Implications for Educational Policy

The results suggest that alignment could be best supported at the level of educational policy rather than left to individual teachers. Authorities and examination boards could run regular curriculum reviews that examine syllabus LOs, endorsed textbooks, and released assessments together, checking both topic coverage and cognitive demand. Short public summaries of these reviews would help make expectations clear. It would also help to publish simple assessment blueprints that state intended coverage by subtopic and by demand level, and to add a brief note on conventions and notation for areas that were ambiguous in this study, for example inequalities and GDC use. Textbook endorsement and renewal could require basic

alignment evidence, such as an item to learning objective mapping and a cognitive-demand profile (Polikoff, 2015). Ongoing monitoring of coverage and demand across exam series would help keep the intended and the assessed curriculum consistent.

Implications for Teachers, Administrators and Schools

School-level action should focus on implementing system supports rather than reconstructing expectations. Departments can offer consistent support through short, collaborative item-analysis meetings that use official assessment blueprints, learning-objective mappings, and annotated exemplars where available. Targeted induction for teachers who are new to the course should cover the syllabus LOs, frequently assessed items, and known areas of ambiguity, for example inequalities. Targeted professional development can then build shared interpretations of cognitive demand and task features, so that classroom tasks better reflect assessment expectations.

Textbook selection can be strengthened with a brief alignment check that mirrors endorsement criteria, attending to topic coverage, cognitive demand, and the accessibility of essential content when materials are partly online. Alignment documentation released by authorities or publishers should be incorporated into schemes of work and internal assessments, and schools should protect teacher time for this work so that it is routine and sustainable.

Implications for Textbook Authors and Publishers

Textbook authors and publishers should rigorously align textbook content with the syllabus LOs and closely review patterns and emphases in past assessments (Pepin & Haggarty, 2001; Polikoff, 2015). Analysis from this research highlighted numerous textbook items not explicitly stated in the syllabus or assessments, creating

potential confusion and misalignment in instructional practices. Essential topics were either inadequately addressed or relegated to supplementary online content, disadvantaging students without consistent online access. Authors must ensure transparent content structuring and clear demarcation of essential versus supplementary topics, facilitating equitable student learning and effective curriculum implementation.

Implications for Further Research

Future research could expand upon the methodological approach employed in this study by conducting Porter's Alignment Index (2002) and Kazemi's (2022) misalignment methodology analysis across the entirety of the curriculum rather than limiting the focus to a single topic. Applying this analysis to multiple textbooks and across a broader spectrum of examinations could yield more comprehensive insights into curricular alignment and textbook effectiveness. Extending this framework to additional subjects would also provide valuable comparative data, enhancing the generalizability and utility of the findings.

In addition, future studies could complement this analysis with alternative research methods. For instance, incorporating teacher perspectives through interviews, surveys, or focus groups would provide insights into how teachers perceive and respond to alignment or misalignment in practice. This would bridge the gap between the documented curriculum and its classroom implementation. Other methodological approaches, such as classroom observations or mixed-methods designs, could further illuminate how alignment manifests in actual teaching and learning processes. Such methodological diversification would strengthen the evidence base and offer a more holistic understanding of curriculum alignment.

Limitations

This research was conducted by a single researcher, raising potential concerns regarding objectivity and bias. To mitigate these concerns, investigator triangulation was implemented by engaging two colleagues in the review and verification processes. However, due to time constraints, the scope of the study was restricted to one subject, which I selected intentionally due to its frequency of assessment and its significance within mathematics education. The findings might have provided deeper insights had it been feasible to encompass the full curriculum and perform comparative analyses of multiple textbooks. Future studies should consider addressing these limitations by involving larger research teams and allocating sufficient time for broader curricular analyses.

In addition, the choice of analytical frameworks presents its own limitations. Porter's Alignment Index has been applied extensively in prior research, and its consistent use across studies lends support to its reliability and validity. By contrast, Kazemi's (2022) misalignment framework remains at an early stage of development, having been tested only within the scope of his doctoral thesis. As such, its robustness has yet to be confirmed through independent replications. Until the framework is examined in diverse contexts, any conclusions drawn from it should be interpreted with appropriate caution.

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Appendix A

Original Syllabus Learning Objectives for Functions

E3.1 Graphs of functions	Notes and examples
1 Recognise the following function types from the shape of their graphs: (a) linear $f(x) = ax + b$ (b) quadratic $f(x) = ax^2 + bx + c$ (c) cubic $f(x) = ax^3 + bx^2 + cx + d$ (d) reciprocal $f(x) = \frac{a}{x}$ (e) exponential $f(x) = a^x$ with $0 < a < 1$ or $a > 1$ (f) trigonometric $f(x) = a \sin(bx)$; $a \cos(bx)$; $\tan x$. 2 Determine one or two of a, b, c or d for the graphs above. 3 Determine values in a function from its graph.	Includes recognising any symmetry. Includes writing down the period and amplitude. Some of a, b, c or d may be 0.
E3.2 Sketching graphs on a calculator	Notes and examples
Use a graphic display calculator to: (a) sketch the graph of a function (b) produce a table of values (c) plot points (d) find zeros, local maxima or local minima (e) find the intersection of the graphs of functions (f) find the vertex of a quadratic.	Includes unfamiliar functions not mentioned explicitly in this syllabus.
E3.3 Functions	Notes and examples
1 Understand functions, domain and range and use function notation. 2 Understand and find inverse functions $f^{-1}(x)$. 3 Form composite functions as defined by $gf(x) = g(f(x))$.	Examples may include: $f(x) = 3x - 5$ $g(x) = \frac{3(x+4)}{5}$ $h(x) = 2x^2 + 3$. e.g. $f(x) = \frac{3}{x+2}$ and $g(x) = (3x+5)^2$. Find $fg(x)$. Give your answer as a fraction in its simplest form. Candidates are not expected to find the domain and range of composite functions. This topic may include mapping diagrams.

E3.4 Finding a quadratic function using given information**Notes and examples**

Find a quadratic function given:

- (a) vertex and another point
- (b) x -intercepts and a point
- (c) vertex or x -intercepts in the case where $a = 1$.

$y = a(x - h)^2 + k$ has a vertex of (h, k) .

E3.5 Asymptotes**Notes and examples**

Understand the concept of asymptotes and identify simple examples parallel to the axes on a graph.

e.g. $f(x) = \tan x$ has asymptotes at $90^\circ, 270^\circ \dots$

Excludes algebraic derivation of asymptotes.

E3.6 Transforming graphs of functions**Notes and examples**

Describe and identify transformations to a graph of $y = f(x)$ when $y = f(x) + k$ or $y = f(x + k)$.

e.g. The graph $y = f(x)$ is mapped onto the graph of $y = g(x)$ by a translation with a vector. Find $g(x)$ in terms of x .

When k is an integer.

E3.7 The logarithmic function**Notes and examples**

Understand and use:

- the logarithmic function as the inverse of the exponential function
- $y = a^x$ as equivalent to $x = \log_a y$
- the solution to $a^x = b$ as $x = \frac{\log b}{\log a}$.

All logs will be base 10 unless otherwise stated.

e.g. solve log equations in the context of a compound interest problem or exponential growth and decay problems.

e.g. solve a log equation from a graph or otherwise.

Note. From Syllabus Cambridge IGCSE International Mathematics 0607 (CAIE, 2023)

Appendix B

Functions Topic Disaggregated Learning Objectives

LO Code	Learning Objective
E3.1.1.a	Recognise linear functions from the shape of their graph.
E3.1.1.b	Recognise quadratic functions from the shape of their graph.
E3.1.1.c	Recognise cubic functions from the shape of their graph.
E3.1.1.d	Recognise reciprocal functions from the shape of their graph.
E3.1.1.e	Recognise exponential functions from the shape of their graph.
E3.1.1.f	Recognise trigonometric functions from the shape of their graph.
E3.1.2	Determine coefficients of the functions mentioned in 3.1.a-f.
E3.1.3	Determine values in a function from its graph.
E3.2.a	Use GDC to sketch the graph of a function.
E3.2.b	Use GDC to produce a table of values.
E3.2.c	Use GDC to plot points.
E3.2.d	Use GDC to find zeros, local maxima or local minima.
E3.2.e	Use GDC to find the intersection of the graphs of functions.
E3.2.f	Use GDC to find the vertex of a quadratic.
E3.3.1	Understand functions, domain and range and use function notation.
E3.3.2	Understand and find inverse functions.
E3.3.3	Form composite functions.
E3.4.a	Find a quadratic function given vertex and another point.
E3.4.b	Find a quadratic function given x -intercepts and a point.
E3.4.c	Find a quadratic function given vertex or x -intercepts in the case where $a = 1$.
E3.5	Understand the concept of asymptotes and identify simple examples parallel to the axes on a graph.
E3.6	Describe and identify transformations to a graph of $y = f(x)$ when $y = f(x) + k$ or $y = f(x + k)$.
E3.7.1	Understand and use the logarithmic function as the inverse of the exponential function.

LO Code	Learning Objective
E3.7.2	Understand and use $y = a^x$ as $x = \log_a y$.
E3.7.3	Understand and use the solution to $a^x = b$ as $x = \frac{\log b}{\log a}$.

Note. E3.1.1.a-f includes recognising any symmetry, and E3.1.1.f includes writing down the period and amplitude. Adapted from Syllabus Cambridge IGCSE International Mathematics 0607 (CAIE, 2023).



Appendix C

Sample of Assessment Items to Learning Objectives Mapping

Exam Code	Question Number	Part	Marks	LO Code
0607/42/F/M/25	8	a	2	E3.2.a
		b	4	E3.2.e with E2.6.3
	13	a	1	E3.3.1
		b	2	E3.3.3
		c	2	E3.3.2
		d	1	E3.3.2
0607/04/SP/25	2	a	2	E3.2.a
		b	2	E3.2.a
		c	1	E3.2.e
	16		2	E3.7.b
	17		3	E3.2.a
0607/43/O/N/24	4	a	2	E3.2.a
		b	3	E3.2.d
		c	3	E3.2.a
		d	1	E3.5
		e	4	E3.2.e with E2.6.3
	6	a	1	E3.3.1
		b	1	E3.3.1
		c	2	E3.3.3
		d	2	E3.3.2
		e	1	E3.3.1
			2	E2.3.2
		0607/42/O/N/24	2	a
b	1			E3.5
c	2			E3.2.e
di	2			E3.2.e
dii	2			E3.2.e with E2.6.3
9	a		1	E3.3.1
	b		1	E3.3.1
	c		2	E3.2.a
	d		2	E3.3.1

		e	2	E3.7.a
		f	1	E3.3.1
			2	E2.3.1
		a	3	E3.2.a
		b	2	E3.5
		c	2	E3.2.d
		d	3	E3.2.e
0607/41/O/N/24	9	e	3	E3.2.e with E2.6.3
		a	2	E3.2.a
		b	3	E3.2.d
		c	2	E3.2.d
		d	2	E3.2.d
	5	e	1	E3.2.e
		a	1	E3.3.1
		b	2	E3.3.1
		c	2	E3.3.3
		d	2	E3.3.2
		e	2	E3.3.3
			1	E3.3.3
			2	E3.2.a
0607/43/M/J/24	10	f	2	E3.2.e
		ai	1	E3.3.1
		aii	1	E3.2.d
		aiii	1	E3.2.d
		aiv	2	E3.2.e
		bi	3	E3.2.a
		bii	2	E3.5
		biii	1	E3.2.e
		biva	2	E3.2.a
	3	bivb	2	E3.2.e
		ai	1	E3.3.1
		aii	3	E3.3.3
		aiii	3	E3.3.3
		aiv	2	E3.3.2
0607/42/M/J/24	9	av	2	E3.3.1

		bi	2	E3.7.b
		bii	2	E3.7.a
0607/41/M/J/24	11	a	1	E3.3.1
		b	2	E3.3.1
		c	2	E3.3.2
			1	E3.3.1
		d	5	E2.5.3
0607/42/F/M/24	1	a	2	E3.2.a
		b	2	E3.1.1.f
		ci	2	E3.2.a
		cii	4	E3.2.e
		ciii	2	E3.2.e with E2.6.3
	10	ai	1	E3.3.1
		a ii	3	E3.3.3
		a iii	2	E3.3.2
		bi	3	E3.2.a
		bii	1	E3.5
		biii	3	E3.2.e

Sample of Textbook Items to Learning Objectives Mapping

Review Set	Question Number	Part	LO Code
Review Set 30A	1		E3.3.1
	2	a	E3.3.1
		b	E3.3.1
		c	E3.3.1
		d	E3.3.1
	3	a	E3.3.1
		b	E3.3.1
		c	E3.3.1
	4	a	E3.2.b
		bi	E3.2.d
		bii	E3.2.d
	5	a	E3.3.1

	b	E3.3.1
	c	E3.3.1
6	a	E3.3.1
	b	E3.3.1
	c	E3.3.1
	d	E3.3.1
7	a	E3.3.1
	b	E3.3.1
	c	E3.3.1
8	a	E3.3.3
	b	E3.3.3
	c	E3.3.3
	d	E3.3.3
9	a	E3.3.3
	b	E3.3.3
	c	E3.3.3
10		E3.6
11	a	no match
	b	E3.6
	c	E3.6
12	a	E3.1.2
	b	E3.1.2
	c	E3.1.2
13	a	E3.3.2
	b	E3.3.2
	c	E3.3.2
14	a	E3.3.2
	b	E3.3.2
	c	E3.3.2

Appendix D

Python Code for Calculating Porter's Alignment Index (PAI)

```
import numpy as np

def sum_normalize(matrix: np.ndarray) -> np.ndarray:

    """

    Normalize the input matrix by dividing each element
    by the sum of all elements.

    Parameters:

        matrix (np.ndarray): The input matrix to be
normalized.

    Returns:

        np.ndarray: The normalized matrix.

    """

    total_sum = np.sum(matrix)

    if total_sum == 0:

        raise ValueError("The sum of the matrix elements
is zero, cannot normalize.")

    return matrix / total_sum

def calculate_pai(first_matrix: np.ndarray,
second_matrix: np.ndarray) -> float:
```

```
"""
```

```
Calculate the PAI between two matrices.
```

```
Parameters:
```

```
first_matrix (np.ndarray): The first matrix.
```

```
second_matrix (np.ndarray): The second matrix.
```

```
Returns:
```

```
float: The PAI value.
```

```
"""
```

```
if first_matrix.shape != second_matrix.shape:
```

```
    raise ValueError("Both matrices must have the  
same shape.")
```

```
normalized_first = sum_normalize(first_matrix)
```

```
normalized_second = sum_normalize(second_matrix)
```

```
abs_diff = np.abs(normalized_first -  
normalized_second)
```

```
entry_sum = np.sum(abs_diff)
```

```
pai = 1 - 0.5 * entry_sum
```

```
return pai
```

```
first_matrix = np.array(
```

```
[  
  
    [5, 6, 0],  
  
    [19, 16, 7],  
  
    [77, 34, 3],  
  
    [10, 1, 0],  
  
    [0, 3, 0],  
  
    [1, 6, 1],  
  
    [21, 13, 0],  
  
    [20, 53, 1],  
  
],  
)
```

```
second_matrix = np.array(  
  
    [
```

```
[  
  
    [4, 2, 1],  
  
    [69, 43, 12],  
  
    [61, 45, 7],  
  
    [0, 1, 0],  
  
    [10, 5, 1],  
  
    [1, 1, 0],  
  
    ]  
)
```

```
[13, 8, 2],  
  
[5, 1, 2],  
  
],  
  
)  
  
pai = calculate_pai(first_matrix, second_matrix)  
  
print(f"PAI: {pai}")
```

