國立臺灣師範大學理學院科學教育研究所

碩士論文

Graduate Institute of Science Education

College of Science

National Taiwan Normal University

Master’s Thesis

當科學與音樂相遇：

設計跨領域課程以促進學生的科學學習興趣

When Science Meets Music:

Designing an Interdisciplinary Course

to Stimulate Students’ Interest in Science Learning

謝長達

Shie, Chang-Da

指導教授：劉湘瑤 博士

Advisor：Liu, Shiang-Yao, PhD.

中華民國 114 年 6 月

June 2025

謝辭

在本論文完成之際，我衷心感謝所有在這段旅程中給予我指引、支持與陪伴的人們。

首先，最深的感謝獻給我的指導教授劉老師。劉老師在整個研究歷程中，始終給予我極大的信任與彈性，讓我有空間去摸索真正想做的研究。他總是在我最需要幫助的時候，耐心傾聽、精準提點，引導我一步步走向更清晰的問題意識與研究路徑。在我為趕上口試期限而焦慮時，他溫柔地理解我進度的卡關，並鼓勵我繼續嘗試、不放棄。他的支持與信任，是我堅持到最後的重要力量。

感謝口試委員方老師與傅老師，謝謝您們在口試中的細緻建議與鼓勵，讓我有機會從不同的角度審視本研究，也對未來的發展方向有了更多想像與反思。

我特別感謝在研究中密切合作的卓邵老師。從第一次教學實施到後續的多次調整中，他總是義無反顧地投入與陪伴，細膩觀察學生反應、與我討論課程設計的每個細節。在現場的每一堂課、每一張學習單回收後，他的回饋都幫助我看見更多我未曾注意的面向。他不只是合作教師，更像是與我並肩作戰的夥伴，讓這份研究得以走得安穩，也走得長遠。

感謝參與研究的學生與老師，謝謝你們願意投入時間與心力，讓我能夠在真實的教育場域中學習，也讓這份研究有了真正的意義。

感謝科教所一路上支持我的前輩與夥伴們：謝謝助教們在修課與行政上的協助；感謝英凱學長在課程設計上給予建議並出席我的口試給予支持；謝謝瀞鉉當天協助紀錄與佈置，讓我能安心面對答辯。還有許多前輩與好友，總是願意聽我分享進度、幫我釐清思緒，是你們讓這條路不再孤單。

謝謝我的雙親與妹妹，總是在我需要的時候無條件給予陪伴與包容，從不催促我的進度，讓我能用自己的步調前行，同時也知道這個家始終是我最堅強的後盾。謝謝合唱團的朋友們，是你們的共鳴與笑聲，讓我研究之餘得到喘息與快樂。謝謝阿澤，我在論文最困難的時候遇見你，謝謝你一直都在。

最後，我也想感謝自己。在這三年裡，我一邊修完碩士與資優特教的學分，一邊投入多場演出與各式活動的籌辦，最終也完成了這篇對我而言極具挑戰的論文。論文

寫作並非我所擅長的領域，幸好有劉老師一路的引導與陪伴，才讓我有機會完成一份自己也覺得踏實的作品。我記得老師曾說過，指導學生若能在三年內畢業，對老師而言也是一種成就。我一直把這句話放在心上，如今我做到了，也真心希望老師能以我為榮。

三年的研究旅程既漫長又珍貴，謝謝所有陪我走過的人。未來，我會運用這段時間的所學與經歷，成為更好的教師，期盼你們能一同見證我的成長。

摘要

本研究旨在設計一門結合科學與音樂的跨領域課程，以提升學生對科學學習興趣（Interest in Science Learning, ISL）。雖然學習興趣長期被認為是教育中不可或缺的要素，但學生對科學學習興趣的低落已促使學者積極尋求有效的教學介入策略。先前研究指出，將物理與其他學科結合有助於提升科學學習興趣，然而，多數設計仍以物理知識為主體，將其他學科作為輔助素材，對於低 ISL 學生的吸引力有限。此外，音樂作為邊界物件（boundary object）的潛力往往被忽略，且相關設計未聚焦在高中階段。為了回應這些缺口，本研究發展了「泛泛知音」課程，結合物理與合唱音樂，聚焦於「音色」主題，期望同時促進學生的音樂學習與科學學習興趣。課程於高中合唱團實施，由合作教師授課，設計理念融入跨領域教學、真實科學學習情境與現象本位學習（Phenomenon-Based Learning, PhBL）。本研究採用設計本位研究（Design-Based Research, DBR）方法，透過多次循環蒐集多元質性資料以優化課程，並以課前後問卷量化檢測學生 ISL 的變化。質性資料採用主題分析法進行整理與歸納，量化資料則以描述性統計與 Wilcoxon 符號等級檢定（Wilcoxon Signed-Rank Test）進行分析。研究結果指出，跨領域課程設計需審慎考量相關主題、教學策略、科學知識難度、互動活動及時間配置；結果亦顯示，該課程能有效提升學生的科學學習興趣，並具可行性，未來可供其他高中合唱團採用。除促進學生的科學學習興趣外，本研究亦為跨領域教學設計與推動提供了實務啟示，對後續研究與教學實務具參考價值。

關鍵詞：合唱社、跨學科、設計研究

Abstract

This study aimed to design an interdisciplinary course integrating science and music to stimulate students' Interest in Science Learning (ISL). Although interest in learning has long been recognized as critical to education, students' low ISL has prompted efforts to explore effective interventions. Prior research has suggested that integrating physics with other disciplines could help enhance ISL. However, most designs emphasized physics content while treating other subjects as supplementary, which may not engage low ISL students. Moreover, the potential of music to serve as a boundary object has been overlooked, and the focus at the high school level remains limited. To address these gaps, this study developed the course *Overtones Know the Tone*, integrating physics and choral music with a focus on "tone," aiming to support both musical development and ISL stimulation. The course was implemented in high school chorus clubs and taught by a collaborating teacher. It incorporated interdisciplinary instruction, authentic science learning contexts, and phenomenon-based learning (PhBL) principles. A design-based research (DBR) approach was employed, with qualitative data collected from multiple sources across iterations to refine the course and quantitative data gathered through pre-/post-questionnaires to evaluate changes in ISL. Qualitative data were analyzed through thematic analysis, while descriptive statistics and the Wilcoxon Signed-Rank Test were used for quantitative analysis. The findings indicated that interdisciplinary course design requires careful consideration of related topics, teaching strategies, scientific content difficulty, interactive activities, and time allocation. Results also showed that the course effectively stimulated students' ISL and demonstrated feasibility for adoption by other high school chorus groups. Beyond enhancing students' ISL, this study provides practical insights into the design and promotion of interdisciplinary curricula, contributing to future research and educational practice.

Keywords: chorus, cross-curricular, design research

Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

The purpose of this study is to design and implement an interdisciplinary course that integrates acoustics into choral instruction in order to foster high school students' interest in science learning (ISL). By embedding scientific concepts into a familiar and personally meaningful musical context, the course seeks to promote engagement, enhance conceptual understanding, and address the persistent issue of low science interest among secondary school learners.

Stimulating students' ISL has become a critical concern in science education. Studies have shown a consistent decline in students' motivation to learn science during the transition to secondary education (Krapp & Prenzel, 2011; Osborne et al., 2003). In Taiwan, while students perform well in international assessments like PISA, they report low levels of enjoyment and motivation in science learning (OECD, 2016). This disconnect suggests that academic achievement alone does not guarantee meaningful engagement.

Learning interest has been reconceptualized in recent decades as a dynamic and multifaceted construct involving emotional, cognitive, and value-related components (Krapp et al., 1992; Schiefele, 1991). The four-phase model by Hidi and Ann Renninger (2006) further describes how situational interest, sparked by contextual features, can develop into long-term personal interest through supportive instruction. Effective instructional design, therefore, plays a key role in fostering ISL.

Three major approaches have emerged in response: interdisciplinary instruction, authentic science learning contexts, and phenomenon-based learning (PhBL). Interdisciplinary instruction connects science to students' everyday experiences and strengthens knowledge transfer (Michelsen & Sriraman, 2009). Authentic science learning contexts position science within real-world applications, increasing emotional engagement and perceived relevance (Braund & Reiss, 2006; Rule, 2006). PhBL encourages students to investigate complex, meaningful phenomena, promoting both curiosity and deep conceptual integration (Lonka, 2018; Penuel et al., 2024).

However, despite the growing interest in interdisciplinary and phenomenon-based learning, most existing designs continue to place physics or other science content at the center while treating non-science domains, such as music, merely as supplementary tools to illustrate scientific principles. This science-centered framing may not effectively engage students who already exhibit low ISL, as it overlooks opportunities to leverage their existing strengths or passions in other areas. In particular, the unique potential of music to function as a boundary object (Hultén, 2013)—serving as a meaningful link between abstract physics concepts and students' everyday musical experiences—has received little attention in prior research. Furthermore, few studies have explored how such an approach can be practically implemented in high school contexts, where students often participate in performance-oriented extracurricular activities like choruses. This leaves an important gap in understanding how science can be positioned as a supporting element to enrich music learning while simultaneously stimulating students' ISL in authentic, interest-driven environments.

To address these gaps, this study developed the course *Overtones Know the Tone*, which integrates physics and choral music with a central focus on the concept of *tone*. The course was designed to simultaneously support students' musical development and stimulate their ISL by embedding relevant physics concepts within familiar and meaningful musical contexts. Implemented in high school chorus clubs and co-taught with a collaborating teacher, the course draws on interdisciplinary instruction, authentic science learning, and PhBL principles to make scientific ideas more relatable and applicable to students' everyday rehearsal experiences.

In contrast to previous science-centered designs, this study explores how science can actively support learning in another domain—choral music—by positioning acoustics as a boundary object between disciplines. Key topics such as sound waves, resonance, overtones, and timbre are presented not as abstract scientific facts but as practical tools for improving vocal performance and understanding choral sound quality. This approach creates an entry point for students who may not be initially interested in science, leveraging their existing motivation in performance-based settings like chorus rehearsals. By doing so, the course seeks to lower the threshold for engaging with scientific ideas and to stimulate students' ISL.

To investigate this instructional design, the study adopts Design-Based Research (DBR) as its methodological framework. DBR emphasizes iterative refinement in real-world contexts, integrating theoretical development with practical problem-solving (Design-Based Research Collective, 2003; Wang & Hannafin, 2005). In science education, DBR has been used to design virtual labs (Chang et al., 2023), integrate engineering principles (Cunningham et al., 2020), and support motivation and socio-emotional learning (Zimmerman et al., 2022).

Despite these advancements, few DBR studies have explored integrating science into non-science domains like music, especially for high school students. Addressing this gap, the present study applies DBR to develop and refine a course that authentically merges acoustics with choral instruction.

Accordingly, this research addresses the following questions:

- **RQ1:** What design principles can be derived from the iterative development of an interdisciplinary course that integrates science and music to stimulate students' ISL?
- **RQ2:** To what extent does participation in the course influence students' ISL?
- **RQ3:** What challenges and opportunities arise when implementing such a course in authentic educational settings?

Through addressing these questions, this study aims to contribute to interdisciplinary science education by offering a practical, theory-informed instructional model that responds to students' low ISL and choral needs, while broadening the scope of DBR in science education research.

Chapter 2 Literature Review

This chapter provides the theoretical foundation for designing an interdisciplinary course that integrates science and music to promote high school students' ISL. Section 2.1 reviews definitions, importance, influencing factors, and assessments of learning interest, concluding with a focus on ISL. Section 2.2 examines instructional approaches that support ISL, including interdisciplinary instruction, authentic science contexts, and PhBL, and identifies key gaps in current research. Section 2.3 introduces DBR as the study's methodology, outlining its principles, processes, challenges, and applications in science education. Together, these sections inform the design and implementation of the present study.

2.1 Learning Interest

Learning interest has long been regarded as a key motivational construct that influences students' engagement, learning behavior, and academic outcomes. To provide a theoretical foundation for this study, this section reviews major perspectives on the definition, importance, contributing factors, and assessment of learning interest. It concludes with a focused discussion on ISL, highlighting current challenges and instructional implications.

2.1.1 Definition of Learning Interest

The concept of learning interest has evolved through decades of educational and psychological research. Dewey (1913) was one of the earliest thinkers to emphasize the role of interest in meaningful education, arguing that interest arises when a learner connects personal experience with external subject matter. His educational philosophy emphasized the necessity of cultivating interest to sustain engagement and thoughtful inquiry.

From a psychological perspective, Schiefele (1991) defined learning interest as a content-specific motivational trait composed of two components: feeling-related valences and value-related valences. Feeling-related valences refer to the emotional satisfaction derived from engaging with a topic, while value-related valences concern the learner's recognition of the topic's personal or educational importance. Building on this foundation, Krapp et al. (1992) proposed that interest should be regarded as a specific kind of relationship between a person and a content area, characterized by high value and high personal significance. He conceptualized learning interest as a psychological construct that integrates affective and cognitive dimensions, forming a relatively enduring disposition toward certain topics. Krapp’s definition bridges motivational psychology with educational practice and marks an important step in distinguishing interest from general motivation.

Further distinctions were proposed by Mitchell (1993), who emphasized the need to separate personal interest from situational interest. Personal interest is topic-specific and enduring, shaped by prior knowledge and personal values. Mitchell also highlighted that personal interest can be further divided into two subtypes. *Latent Interest* refers to a student’s existing interest that remains inactive unless triggered by context, while *Actualized Interest* manifests as observable engagement and motivation in learning activities. Situational interest, on the other hand, is context-dependent and can be evoked by features of the learning environment, such as novelty, challenge, or social interaction. Schraw and Lehman (2001) contributed further by emphasizing that interest is a complex motivational construct involving affective, cognitive, and value-oriented dimensions. They argued that both personal and situational interests involve emotional reactions, value judgments, and cognitive engagement. Instructional design, therefore, can strategically leverage these components to support learning.

The developmental process of interest was systematically described by Hidi and Ann Renninger (2006) in their four-phase model, which outlines how situational interest can lead to the formation of personal interest. The model includes (1) triggered situational interest, (2) maintained situational interest, (3) emerging individual interest, and (4) well-developed individual interest. This framework highlights the dynamic interplay between external stimuli and internal disposition, suggesting that well-structured learning experiences can promote the growth of enduring personal interest.

Building on these theoretical insights, this study applied these models to guide the development and interpretation of two learning interest scales tailored to the interdisciplinary context. Specifically, two learning interest scales were employed: the Music Learning Interest Scale and the Science Learning Interest Scale. Both scales adopt Mitchell’s (1993) framework to distinguish between latent and actualized personal interest. For situational interest, two classification schemes are applied based on the instruments used. In the music learning interest scale used in Iteration 1, we follow Schraw and Lehman's (2001) categorization of task-based, text-based, and knowledge-based interest guided item development. In the Science Learning Interest Scale used in Iteration 1 and Iteration 2, we adopt the three-component model by Linnenbrink-Garcia et al. (2010), which refines Hidi and Renninger's four-phase model into: triggered situational interest, maintained situational interest-feeling, and maintained situational interest-value. These theoretical models—grounded in distinctions among affective, cognitive, and value-based components—provide a robust foundation for designing interest measures in this interdisciplinary context. A detailed explanation of the instruments and their application is provided in the methodology section.

Understanding the definition and theoretical development of learning interest provides a necessary foundation for investigating its role in educational settings. The following section will examine the significance of learning interest by reviewing empirical findings on how it influences students' learning behavior, cognitive engagement, and long-term academic development.

2.1.2 The Importance of Learning Interest

The importance of learning interest has been widely recognized in the fields of education and psychology. Dewey (1913) was among the earliest scholars to emphasize that learning becomes meaningful when it connects with a learner's personal experience, leading to deeper engagement and sustained inquiry. Building on this foundation, Krapp et al. (1992) conceptualized interest as a specific kind of relationship between an individual and a content area, characterized by both emotional involvement and personal significance. He argued that learning interest is not merely a fixed personality trait but a dynamic disposition that educational experiences can influence. Along similar lines, Hidi (1990) highlighted the role of interest as a driver of attention and engagement during learning, suggesting that interest plays a crucial role in initiating and sustaining active participation.

Interest has also been found to correlate closely with learning strategies and performance. Schiefele (1991) proposed that learners with a strong interest are more likely to engage in deep processing, organize and integrate information more effectively, and show greater self-regulation. Krapp (1999) further emphasized that when students perceive content as personally meaningful, it enhances motivation and supports sustained cognitive engagement. Hidi and Harackiewicz (2000) extended these ideas by arguing that interest-driven instruction can directly improve conceptual understanding and learning outcomes. They maintained that effective instructional design should intentionally integrate elements that foster situational or personal interest, treating interest not just as a motivational factor, but as a central mechanism in instructional planning.

Beyond classroom engagement, interest also contributes to long-term educational outcomes. Harackiewicz et al. (2002) found that learning interest plays a significant role in shaping academic achievement and fostering enduring motivation in science education. Renninger et al. (2002) further observed that sustained individual interest can lead to greater self-directed learning and knowledge building over time. These insights highlight interest as a foundational element in the development of lifelong learners, particularly when educational contexts support the gradual transition from situational to personal interest. Lee et al. (2014) reinforced this view in the Taiwanese curriculum context, arguing that learning interest fosters stronger identity formation and increases students' persistence in pursuing disciplinary or career paths.

In sum, learning interest functions as a core motivational resource that facilitates attention, deep processing, and sustained engagement. It bridges emotional, cognitive, and value-based dimensions of learning and contributes to both current state of learning and long-term academic trajectories. To further explore how learning interest can be developed, the next section reviews key factors that shape interest formation, including pedagogical strategies, contextual relevance, and learner characteristics.

2.1.3 Factors Influencing Learning Interests

Learning interest is not a static or innate trait but a dynamic construct that evolves through continuous interaction between individuals and their learning environments. Prior research has identified three major categories of factors that influence the development and maintenance of learning interest: instructional context, task characteristics, and learner characteristics (Ainley et al., 2002; Hidi, 1990; Krapp, 1999; Mitchell, 1993; Schraw et al., 2001).

Instructional context plays a critical role in triggering situational interest. Mitchell (1993) emphasized that novelty, challenge, and social interaction within the learning environment can effectively capture students' short-term attention and engagement. Schraw et al. (2001) proposed three instructional strategies to enhance situational interest: providing choices, stimulating curiosity, and offering appropriately challenging tasks. These strategies help create engaging learning environments that foster emotional involvement. Hidi and Ann Renninger (2006) further argued that when situational interest is sustained and enriched with value-related components, it has the potential to develop into individual interest.

Task characteristics also significantly affect how interest is maintained and deepened. Ainley et al. (2002) proposed that interest impacts learning through psychological processes such as focused attention, emotional engagement, and the construction of meaning. These processes are closely tied to the structure and features of the task, including the clarity of learning goals, connections to prior knowledge, and the presence of immediate feedback. In an empirical study, Rotgans and Schmidt (2011) found that in active-learning classrooms, situational interest fluctuates dynamically during lessons and is closely linked to students' learning outcomes. Their findings highlight the importance of task design in supporting sustained engagement.

Learner characteristics constitute the third major influence on learning interest. Krapp (1999) conceptualized individual interest as a person–object relationship marked by high personal value and significance. This relationship is shaped by learners' self-concept, personal values, and prior knowledge. Renninger and Hidi (2011) further noted that the interaction between individual traits and the learning environment determines whether situational interest can develop into more enduring forms. As Hidi (1990) argued, interest serves as a mental resource that facilitates attention, comprehension, and memory, ultimately supporting deeper learning.

The integration of these three domains can be further understood through the lens of motivational psychology. According to Ryan and Deci's (2000) self-determination theory, students are more likely to develop intrinsic motivation—and thus interest—when the learning environment satisfies their needs for autonomy, competence, and relatedness. This perspective underscores that learning interest is not passively received but can be actively cultivated through thoughtful instructional design and supportive classroom practices.

In summary, learning interest is shaped by a complex interplay of individual characteristics, task design, and instructional context. Effective teaching must intentionally engage the emotional, cognitive, and value dimensions of interest to create meaningful and motivating learning experiences. To further explore how these principles operate within the domain of science education, the next section focuses on ISL, examining the widespread decline in students' interest in science, the factors contributing to this trend, and instructional strategies designed to address it.

2.1.4 Interest in Science Learning (ISL)

A consistent decline in students' ISL has been observed across various educational systems, particularly during the transition to secondary education. This trend has been attributed to multiple factors, such as developmental changes in adolescence, identity exploration, and the increasing abstraction of school science (Krapp & Prenzel, 2011; Osborne et al., 2003). In the Taiwanese context, this issue is particularly pronounced. Although students consistently perform well in international science assessments, such as PISA, their enjoyment of learning science and motivation to engage with scientific content remain notably low (OECD, 2016).

One major explanation is the disconnect between science education and students' everyday lives. Lee and Brophy (1996) highlighted that students often find science irrelevant, difficult, or overly theoretical, which diminishes their motivation to learn. Häussler (1987) and Kurniawan et al. (2019) similarly found that when students cannot relate science topics to real-world situations or personal relevance, their engagement tends to decline. Conversely, students are more inclined to develop an interest in science when instruction emphasizes meaningful applications, natural phenomena, or elements of everyday experience (Häussler & Hoffmann, 2000).

To address these challenges, numerous strategies have been proposed to enhance science learning interest. Hulleman and Harackiewicz (2009) demonstrated that helping students make connections between scientific content and their personal goals significantly increases their interest and academic outcomes. Empirical studies also support the use of instructional designs that incorporate relevance, novelty, and authenticity to trigger situational interest in science classrooms (Ainley et al., 2002; Renninger & Hidi, 2011). For example, Woithe et al. (2022) showed that student engagement and interest increased significantly in authentic science environments such as the S'Cool LAB at CERN, where learners participated in hands-on, inquiry-based activities with real-world significance.

In light of these findings, fostering ISL requires more than content delivery; it demands pedagogical strategies that make science personally meaningful and intellectually engaging. These include the use of interdisciplinary content, the creation of authentic scientific contexts, and the design of tasks that evoke curiosity and emotional involvement.

To better understand how instructional design can respond to this crisis in ISL, the following section reviews instructional approaches shown to stimulate students' interest in science effectively.

2.2 Course Designs That Stimulate ISL

Designing instruction to support students' ISL requires both theoretical grounding and practical alignment with learners' experiences. diSessa and Cobb (2004) proposed that educational design can be informed by theory at multiple levels: grand theories, which articulate overarching epistemological or psychological views of learning; orienting frameworks, which define the broad aims and content focus of instruction; frameworks for action, which guide how instruction is practically implemented in specific contexts; and domain-specific instructional theories, which inform the detailed design of learning tasks and activities within particular subjects.

In this study, interdisciplinary instruction serves as an orienting framework, shaping the overall purpose of integrating science with other domains and determining how content is selected and organized. Authentic science learning contexts function as a framework for action, specifying the learning environments, instructors, target audiences, and situational factors that make science learning personally relevant and meaningful. Finally, PhBL represents a domain-specific instructional theory, providing concrete principles for designing student-centered learning activities that connect complex phenomena with interdisciplinary knowledge.

This section introduces each of these three levels in sequence, highlighting their theoretical underpinnings, their roles in promoting ISL, and their implications for instructional design. A final subsection reviews prior studies employing these approaches, identifies persistent gaps in the literature, and lays the foundation for the design-based research strategy adopted in this study.

2.2.1 Interdisciplinary Instruction

Interdisciplinary instruction is an approach to curriculum design that emphasizes the integration of knowledge, skills, and perspectives from multiple disciplines. Its central premise is to transcend traditional subject boundaries and structure learning in a way that reflects the complexity and interconnectedness of real-world issues (Beane, 1997). Beane conceptualizes curriculum integration as a vehicle for democratic education, advocating that learning should revolve around meaningful themes drawn from students’ lives and experiences. Drake and Burns (2004) further categorize integrated curricula into three levels—multidisciplinary, interdisciplinary, and transdisciplinary—highlighting important distinctions among them. In a multidisciplinary approach, subjects remain separate while being organized around a common theme; each discipline contributes its perspective but retains its boundaries. In contrast, an interdisciplinary approach deliberately blends concepts and methods from different fields, encouraging students to construct unified understanding and draw connections across domains. This deeper integration is intended to promote holistic thinking and problem-solving skills that reflect authentic, complex situations.

In the context of science education, interdisciplinary instruction is recognized as a promising strategy for enhancing students' ISL. According to Hidi and Ann Renninger (2006), in the four-phase model of interest development, the instructional context plays a critical role in triggering and maintaining student interest. Ivanitskaya et al. (2002) found that interdisciplinary learning fosters deeper conceptual understanding, promotes knowledge transfer, and increases student engagement. These learning outcomes contribute directly to the cognitive and emotional components that support both situational and individual interest.

Building on this foundation, Michelsen and Sriraman (2009) conducted an empirical study showing that interdisciplinary instruction can significantly increase students' interest in mathematics and the natural sciences. Their findings suggest that when students perceive connections between subject matter and their existing experiences or interests, their motivation to engage with scientific content is enhanced, and their attitudes toward learning science improve.

Despite its potential benefits, implementing interdisciplinary instruction presents several challenges. McComas and Wang (1998) discussed the complexities of integrating science disciplines for instruction, noting that while interdisciplinary approaches may help students recognize the interconnectedness of scientific knowledge, they also demand careful curriculum organization and substantial teacher preparation. Effective interdisciplinary curriculum design requires coherence in instructional objectives, logical connections among core concepts, and strong links between academic content and students' lived experiences. Topic-centered structures, grounded in themes that are accessible and relevant to learners, are particularly useful in supporting meaningful engagement and interest development.

Taken together, interdisciplinary instruction serves as an orienting framework that informs the overall direction and philosophy of curriculum design. In science education, connecting disciplinary knowledge with student-centered, familiar contexts holds promise for enhancing students' interest in science and for fostering more integrated, authentic learning experiences. To translate this vision into practice, authentic science learning contexts function as a framework for action, specifying where, for whom, and under what circumstances science instruction can be made relevant and engaging. The next section discusses authentic contexts as practical environments that bring interdisciplinary goals to life and directly support students' ISL.

2.2.2 Authentic Science Learning Contexts

Authentic science learning contexts refer to instructional settings in which students engage with tasks that reflect the real-world application of scientific knowledge and practices (Braund & Reiss, 2006). Rather than treating science as a collection of abstract facts, these learning experiences aim to position science as a tool for interpreting phenomena and solving problems. Such designs typically involve socially relevant themes, interdisciplinary questions, and hands-on activities, allowing students to construct meaning through situated experience (Rule, 2006).

Scholars have proposed multiple frameworks for understanding the structure of authentic learning. Rule (2006) outlined seven key components, including contextual relevance, open-ended tasks, diverse forms of assessment, and embedded reflection. Woolnough (2000) introduced the idea of "quasi-authentic" science, arguing that although schools may not be able to replicate the full complexity of professional science, they can still create meaningful tasks that simulate aspects of real scientific inquiry. Similarly, Braund and Reiss (2006) advocated for expanding science learning beyond textbooks and classrooms by integrating out-of-school experiences, social contexts, and real-world applications.

From the perspective of learning interest, authentic contexts serve as important catalysts that connect scientific content with students' personal goals and values. In a longitudinal study of an informal science program, Habig and Gupta (2021) found that high school students who participated in authentic scientific research activities demonstrated elevated levels of ISL and disciplinary identity. Their findings suggest that exposure to meaningful scientific practices and societal relevance not only promotes immediate engagement but also supports the development of long-term motivation and commitment to science.

Implementing authentic learning contexts in formal education, however, presents structural challenges. McComas and Wang (1998) argued that even well-prepared teachers may struggle to design meaningful and context-rich science instruction due to rigid curriculum structures, time constraints, and limited resources. Standardized testing regimes and tightly scheduled syllabi often prevent the deep inquiry and flexibility required for authentic engagement. Woolnough (2000) further warned that if students are not supported in making sense of what they do through credible and coherent experiences, their learning may remain superficial and detached from genuine interest.

For efforts aiming to enhance ISL, authenticity should not be equated with mere simulation, but rather understood as the extent to which students perceive science learning as valuable, relevant, and worthy of serious engagement. While authentic science learning contexts establish where and for whom instruction should occur to maximize relevance, they do not by themselves prescribe the detailed structure of learning activities. At the level of domain-specific instructional theories, PhBL offers concrete design principles for crafting tasks and experiences that link complex phenomena with integrated scientific and disciplinary knowledge. The following section presents PhBL as a practical strategy for implementing interdisciplinary and authentic instruction that effectively supports ISL.

2.2.3 Phenomenon-Based Learning (PhBL)

PhBL is an instructional approach that centers learning around real-world phenomena, encouraging students to initiate inquiry through observation, questioning, and the integration of multidisciplinary knowledge (Lonka, 2018; Sahlberg, 2021). Originating in Finnish educational reform, PhBL aims to transcend disciplinary boundaries and foster holistic understanding through active exploration of meaningful, complex situations. The selected phenomena are typically embedded in social or everyday contexts, enabling students to anchor abstract scientific ideas in their lived experiences.

Recent research has highlighted PhBL’s potential to promote ISL. By allowing students to begin with personally observed or community-based events, PhBL creates space for curiosity and personal relevance to emerge. Dean (2024), for example, introduced the idea of “phenomenon walks,” in which students explore their school or neighborhood environment to identify and document natural or scientific phenomena. This kind of firsthand experience can trigger situational interest and stimulate students' desire to investigate further. Moreover, Penuel et al. (2024) argue that when instruction is designed around student-relevant contexts and questions, it not only enhances engagement but also supports the development of longer-term interest and disciplinary identity.

The successful implementation of PhBL depends not only on curriculum structure but also on teacher expertise. Halim et al. (2014) found that students' perceptions of their science teachers' pedagogical content knowledge—particularly the ability to contextualize content, explain concepts clearly, and respond to student questions—significantly impacted their motivation and understanding. These teacher qualities align closely with the instructional demands of PhBL, where the teacher acts not merely as a transmitter of knowledge but as a learning designer who scaffolds interdisciplinary inquiry and meaning-making.

Several key principles guide PhBL instruction. First, the learning process should begin with phenomena that are relevant to students' lives and socially significant, prompting them to initiate inquiry based on personal experience (Dean, 2024; Lonka, 2018). Second, teachers are expected to design tasks that facilitate conceptual integration across domains, often using open-ended investigations, multiple sources of information, and varied forms of assessment (Teresa & Fields, 2023). Third, Penuel et al. (2024) emphasize the importance of aligning instructional materials with students' interests and community priorities, ensuring that the content is not only educationally sound but also culturally responsive and personally meaningful.

In sum, PhBL promotes a shift from fragmented content delivery to holistic, experience-driven learning. As a framework for action, it offers concrete strategies for designing instruction that activates students' curiosity, supports conceptual depth, and fosters enduring ISL.

2.2.4 Review of Course Designs That Stimulate ISL

In response to the growing concern over students' declining ISL, a number of educational researchers have explored alternative instructional designs to foster engagement and motivation. Among the most prominent strategies are interdisciplinary instruction, applying authentic science learning contexts, and PhBL (Braund & Reiss, 2006; Lonka, 2018; Michelsen & Sriraman, 2009; Sahlberg, 2021). Each of these approaches emphasizes different mechanisms for connecting students more meaningfully with science content, and all have shown promise in stimulating ISL.

Interdisciplinary instruction aims to dissolve disciplinary boundaries and connect scientific concepts with students' everyday experiences. Michelsen and Sriraman (2009) demonstrated that integrating mathematics and natural sciences enhances students' appreciation for the applicability of scientific knowledge, which in turn fosters deeper interest. Korsun (2017) reported that using interdisciplinary activities in physics increased students' situational interest by creating varied and relatable learning contexts. Crowther (2012) combined music and biology by asking students to create and perform science-themed songs, which improved content retention and emotional engagement. However, most of these examples position science as the primary content, with other domains merely serving as supporting tools, limiting the depth of integration.

Authentic learning contexts, by contrast, prioritize the connection between scientific learning and students' lived realities. Braund and Reiss (2006) found that learning experiences situated in real-world environments, such as museums, outdoor explorations, or community spaces, can activate situational interest and make scientific concepts more tangible. Habig and Gupta (2021) demonstrated that informal science programs involving authentic scientific practices fostered sustained interest and engagement, particularly when students perceived themselves as participating in real scientific inquiry. Similarly, Penuel et al. (2024) highlighted that aligning instructional materials with students' cultural and community-based concerns significantly enhances their connection to science.

PhBL, a more recent design framework, encourages students to engage with complex phenomena that are socially and personally meaningful. Kennedy and Fields (2023) showed that when students investigate open-ended, phenomenon-based problems, they are more likely to sustain their curiosity and integrate knowledge across disciplines. In a similar vein, Tojeiro-Pérez and Gillanders (2024) demonstrated that combining music and ecology enabled students to explore scientific themes through culturally resonant and emotionally rich experiences. These findings align with Bequette and Bequette (2012), who advocate for the inclusion of arts and design in STEM education to support creativity, expression, and multimodal learning—all of which can enhance engagement with scientific ideas.

Despite the growing evidence supporting these approaches, several research gaps remain. First, most existing interdisciplinary or phenomenon-based instructional designs take science as the primary subject and situate learning within science classrooms. These designs focus on delivering scientific content with little attention to how science might be meaningfully integrated into other subject areas. For students with low ISL, such a framing may limit opportunities for engagement. Embedding science within domains that students already find meaningful, such as the arts, may provide more accessible entry points for fostering interest and identity development (Tan et al., 2013).

Second, while music has occasionally been incorporated into science instruction (e.g., Crowther, 2012; Tojeiro-Pérez & Gillanders, 2024), it is often positioned merely as a supplementary tool to support the communication or memorization of science content, rather than being leveraged as a boundary object that meaningfully connects the two disciplines. This underestimates the full potential of music as an interdisciplinary resource. Few studies have explored instructional designs that reflect the epistemic practices of both music and science in a balanced way. This limits the potential for interdisciplinary learning to draw on the strengths of both disciplines, particularly in contexts like acoustics, where conceptual overlaps naturally occur.

Third, even among the few studies that combine music and science in meaningful ways, the target population is rarely high school students. Much of the current literature focuses on university students or informal education settings. However, the high school years are a critical stage for shaping students' academic trajectories and personal interests. The PISA 2015 results showed that 15-year-olds—a typical age for early high school—already report lower levels of science interest compared to younger peers, particularly as they transition into more specialized, abstract science curricula (OECD, 2016). Prior studies have similarly documented a decline in ISL during this period (Osborne et al., 2003). Thus, instructional interventions designed for this age group are especially needed.

Taken together, these studies highlight promising strategies for fostering ISL through interdisciplinary, authentic, and phenomenon-based instruction. However, the limited integration of science into non-science subjects, the underdeveloped role of music as a co-equal disciplinary domain, and the lack of focus on high school learners reveal critical gaps in the current literature.

These gaps motivate the adoption of a DBR framework in the present study, which will be elaborated in the next section.

2.3 Design-Based Research (DBR) as a Methodology

To develop and refine instructional interventions situated in real-world educational contexts, this study adopts DBR as its primary methodological framework. DBR is particularly well-suited for addressing complex educational problems through iterative cycles of design, implementation, and analysis. This section introduces the origin and definition of DBR, elaborates on its core characteristics, explains how it is implemented in practice, discusses its methodological challenges and potentials, and reviews its applications in science education. Together, these discussions justify the adoption of DBR for this interdisciplinary instructional design.

2.3.1 The Origin and Definition of DBR

DBR emerged as a methodological response to the persistent gap between educational theory and practice. Its origins can be traced back to the early 1990s when researchers such as Brown (1992) and Collins (1992) introduced the concept of “design experiments.” These early efforts emphasized conducting systematic, theory-informed interventions within authentic learning environments to study complex educational processes (Cobb et al., 2003). Rather than isolating variables in controlled settings, these design experiments aimed to both test and generate theories in real-world contexts.

By the early 2000s, DBR was increasingly recognized as a distinct research paradigm. The Design-Based Research Collective (2003) formally articulated its purpose and defining features, positioning DBR as a method that integrates theory development with practical problem solving. It involves iterative cycles of designing, implementing, analyzing, and refining interventions within authentic settings. Through these processes, researchers aim to uncover how and why specific instructional designs work and to develop transferable theoretical insights.

Barab and Squire (2004) described DBR as a method that is “situated and pragmatic,” grounded in the dynamic realities of classroom environments. They emphasized the dual focus on improving practice and advancing theory, viewing design itself as a form of inquiry. Similarly, Collins et al. (2004) highlighted the methodological tensions that DBR must navigate, such as the balance between experimental rigor and contextual relevance.

In the field of educational technology, Wang and Hannafin (2005) defined DBR as “a systematic but flexible methodology aimed to improve educational practice through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings.” This definition underscores the dual aims of DBR: to solve practical instructional problems and to contribute to the development of grounded educational theory.

Other scholars have echoed this dual emphasis. Edelson (2002) and Obrenović (2011) stressed the epistemic value of engaging in design as a way of generating applicable knowledge. diSessa and Cobb (2004) further proposed that DBR holds potential for ontological innovation by producing “proto-theories” derived from iterative, situated inquiry. These theoretical contributions are not merely byproducts of practice, but integral outcomes of the research process itself. Furthermore, Hsu et al. (2012) provided a comprehensive account of DBR, particularly in science education. Their work emphasized the methodological structure of DBR and its value in curriculum innovation and instructional improvement, highlighting its applicability to educational research that seeks both theoretical and practical impact.

DBR is a relatively recent methodological development in the field of education, emerging in response to the growing need for approaches that bridge theory and practice. As seen in the preceding review, it reflects a shift toward research conducted in authentic contexts, where design and theory evolve together through iterative refinement.

Having clarified the origins and conceptual foundations of DBR, the next section elaborates on its five core characteristics as articulated by the Design-Based Research Collective (2003), providing a more detailed analysis of what distinguishes DBR from other methodological approaches.

2.3.2 Core Characteristics of DBR

According to the Design-Based Research Collective (2003), DBR is defined not merely by its context of application, but by a coherent set of interrelated features that distinguish it from traditional educational research methods. These five core characteristics highlight the methodological identity of DBR and clarify how it operates in complex instructional environments.

1. Addressing Practical and Significant Educational Problems. DBR begins with problems rooted in actual educational practice, rather than abstract theoretical concerns. The aim is to respond to pressing instructional challenges through iterative, theory-informed design interventions. This problem-solving orientation ensures that the research remains grounded in authentic needs. Barab and Squire (2004) emphasized that DBR is a methodology “rooted in practice,” where collaboration with practitioners plays a central role in transforming theoretical insights into viable designs.

2. Emphasizing the Interaction Between Theory and Design. One of DBR’s defining features is the iterative and reciprocal relationship between theoretical development and design enactment. Rather than treating design as an application of theory, DBR treats design as a means of generating and refining theoretical understanding. diSessa and Cobb (2004) introduced the concept of “proto-theories” to describe the types of theory that emerge from DBR—context-sensitive, practically grounded, and generative for future research.

3. Conducting Research in Real-World Contexts. In contrast to laboratory experiments that seek to control variables, DBR is conducted in real-world educational settings. It embraces the complexity of classroom environments and seeks to understand how interventions unfold under authentic conditions. As Cobb et al. (2003) noted, learning is shaped by multilayered interactions that cannot be replicated in artificial settings; therefore, DBR values ecological validity and situational responsiveness over strict experimental control.

4. Utilizing Iterative and Evolutionary Design Cycles. DBR operates through a progressive series of design–implement–analyze–redesign cycles. Each iteration serves both as a test of the current design and a basis for further refinement. This cyclic process allows researchers to adapt to emerging findings and evolving classroom dynamics. Collins et al. (2004) argued that such iterative refinement is essential for clarifying the relationships between instructional design elements and learning outcomes.

5. Pursuing Dual Goals of Practical and Theoretical Contributions. DBR is distinctive in its simultaneous pursuit of practical effectiveness and theoretical insight. Researchers must demonstrate not only that an intervention works, but also why and under what conditions it works. Wang and Hannafin (2005) described this as the development of "usable theory"—theoretical constructs that inform future design and guide practitioner decisions in real educational settings.

Taken together, these five characteristics demonstrate that DBR is not merely a flexible research strategy but a principled methodology that integrates design, implementation, and reflection. Its distinctive emphasis on context-sensitive inquiry, iterative development, and the mutual shaping of theory and practice makes it particularly suitable for exploring complex educational phenomena and informing innovation in instructional design.

In the next section, the discussion will turn to how these five principles are operationalized in practice, outlining the typical process of DBR implementation and how its methodological structure unfolds in real educational settings.

2.3.3 Implementation Process and Research Design in DBR

While DBR emphasizes the interplay between theory and practice, its implementation in educational contexts requires a systematic and iterative approach. Wang and Hannafin (2005) proposed a five-phase model that outlines the essential steps in conducting DBR, particularly within technology-enhanced learning environments. Their framework serves as a conceptual guide for research planning and execution, spanning from problem identification to theoretical refinement.

This model can be usefully compared with a parallel structure proposed by Hsu et al. (2012), who developed an eight-step process based on science education research in Taiwan. Their model, which is organized into three overarching stages— (1) problem clarification and initial design, (2) iterative implementation and refinement, and (3) theory building and practical recommendations—offers a culturally grounded perspective on how DBR is conducted in local educational settings. The following list integrates Wang and Hannafin's framework with relevant points from Hsu et al.'s model to enhance both theoretical grounding and contextual relevance.

1. Identifying and Analyzing the Problem. DBR typically begins with a genuine and pressing problem observed in an educational setting. Researchers are expected to analyze the context in depth, define the core challenges, and consult relevant literature to identify theoretical frameworks that inform the design. This phase corresponds to the first two steps in Hsu et al.'s model: defining the educational problem and formulating the research goals and questions. These steps ensure that the research is both theoretically informed and practically meaningful.

2. Designing the Instructional Intervention. Informed by theory and contextual analysis, the next phase involves designing a learning environment or instructional intervention. Researchers often collaborate with practitioners to create lesson plans, instructional tools, or teaching strategies that are sensitive to the constraints and affordances of the setting. This design phase aligns closely with Step 3 of Hsu et al.'s model: designing an initial instructional plan.

3. Implementing and Observing in Real Settings. The designed intervention is then enacted in an authentic classroom environment. During this phase, researchers observe how the intervention interacts with learners and teachers in practice, collecting data through methods such as classroom observation, interviews, or student artifacts. This corresponds to

Step 4 in Hsu et al.'s model: implementing instruction and collecting data.

4. Analyzing Data and Refining the Design. Once data are collected, researchers analyze them to evaluate the effectiveness of the design and identify areas for improvement. This process often reveals misalignments between theoretical intentions and actual practice. Findings from this phase inform the redesign of instructional components. Hsu et al. (2012) describe a similar process in Steps 5 and 6: analyzing data and evaluating the design, followed by revising the instructional plan accordingly.

5. Iterating and Developing Theory. The final phase involves conducting multiple design cycles to refine both the intervention and the underlying theoretical framework. Wang and Hannafin (2005) emphasized the importance of developing "usable theory" through this process—knowledge that can inform future design and support practitioners in similar contexts. In Hsu et al.'s model, this phase is reflected in Steps 7 and 8: deriving design principles and constructing instructional theory, along with practical recommendations for educational improvement.

In summary, Wang and Hannafin's five-phase model offers a high-level structure for conducting DBR. At the same time, Hsu et al.'s eight-step process provides a more granular view tailored to science education research in Taiwan. Integrating these perspectives strengthens the practical foundation of DBR and ensures that it remains responsive to both theoretical rigor and local educational realities.

The next section explores the methodological and practical challenges encountered during the DBR process, including issues related to data analysis, research validity, and the negotiation of researcher–practitioner roles.

2.3.4 Challenges and Potentials of DBR

Although DBR has been widely recognized as a promising methodology for bridging educational theory and practice, its implementation presents several methodological and practical challenges. These challenges relate to the dual role of the researcher, the complexity of research contexts, the demands of data analysis, and the nature of theoretical contributions. At the same time, these challenges underscore DBR's potential to generate rich, context-sensitive knowledge and to support meaningful educational innovation.

One of the defining characteristics of DBR is the active involvement of the researcher in both the design and implementation of educational interventions. However, this dual role can lead to tensions between supporting practice and maintaining analytical distance. On one hand, researchers may dominate the instructional process, limiting the autonomy of practitioners; on the other, they must balance the need to foster learning to produce generalizable insights (Barab & Squire, 2004). For researchers new to DBR, this dual engagement poses both practical and ethical challenges.

Unlike controlled laboratory studies, DBR is conducted in authentic educational settings where variables cannot be easily isolated or manipulated. As Collins et al. (2004) noted, DBR often involves long-term, multi-variable, and interaction-rich environments that are difficult to standardize. This complexity can hinder the replicability and generalizability of findings, and each iteration builds on the previous one in ways that are highly context-dependent.

DBR encourages the use of multiple forms of data, such as classroom observations, interviews, learning artifacts, and student performance records, to capture the richness of instructional environments. While this data diversity enhances ecological validity, it also places significant demands on the researcher's ability to integrate qualitative and quantitative methods. According to the Design-Based Research Collective (2003), producing theoretically meaningful insights from such data requires sophisticated analytical strategies and sustained engagement with the field.

Although DBR aims to generate "usable theory" or "proto-theory," there is limited consensus on what constitutes a sufficient theoretical contribution. Many DBR studies result in design narratives or practical insights that may lack broad explanatory power. Moreover, because these theories are often tightly coupled with specific contexts, their transferability and generality remain open to question (diSessa & Cobb, 2004). Clarifying the criteria for theoretical advancement within DBR remains a key issue in the field.

Unlike traditional research paradigms that emphasize internal validity or generalizability, DBR requires alternative standards of quality. Barab and Squire (2004) proposed four dimensions for evaluating DBR: the practical impact of the design, the clarity of the design theory, the transparency of the research process, and the degree to which findings are supported by evidence. However, the systematic application of these criteria in actual studies remains underdeveloped and varies significantly across research projects.

Despite these challenges, DBR offers distinct advantages that align with the complex and dynamic nature of educational environments. Through iterative implementation and close engagement with teaching and learning processes, researchers can develop situated theories that both inform practice and advance academic knowledge. Rather than treating these challenges as limitations, they can be reframed as opportunities for DBR to establish itself as a robust, practice-driven paradigm for educational research and innovation.

2.3.5 Applications of DBR in Science Education

DBR has emerged since the early 2000s as a prominent methodological approach in the fields of learning sciences and educational technology. It has gradually evolved into a research paradigm capable of addressing both practical instructional improvement and theoretical advancement (Akker et al., 2006; Barab & Squire, 2004; Design-Based Research Collective, 2003). According to McKenney and Reeves (2013), the growing popularity of DBR in science education reflects a shared desire among researchers and practitioners to promote evidence-based curriculum innovation that is both effective and sustainable.

Unlike traditional experimental or survey-based research, DBR emphasizes close interaction with real-world educational settings. It relies on iterative cycles of design, implementation, analysis, and revision to extract theoretically meaningful design principles and pedagogical strategies. This methodological orientation makes DBR particularly suitable for exploring complex variables in learning processes, abstract concept construction, and the integration of technology into instruction (Design-Based Research Collective, 2003; Wang & Hannafin, 2005). Consequently, DBR has been widely applied in science education to support curriculum development, instructional innovation, and the assessment of learning outcomes (Hsu et al., 2012; McKenney & Reeves, 2013).

In practice, DBR has been employed in a wide range of science education topics, including inquiry-based learning, virtual experimentation, engineering design, and interdisciplinary integration. For instance, Chang et al. (2023) applied a cyclic DBR model to design and evaluate a virtual lab curriculum for high school students, demonstrating a complete process of iterative refinement. Cunningham et al. (2020) developed engineering-informed curriculum design principles for elementary science learning, highlighting the impact of DBR on students' concurrent development of engineering and scientific literacy. Jacobson et al. (2017) explored learning about climate change as a complex system, showcasing DBR's potential to support causal reasoning and multi-level conceptual understanding.

In the local context, Hsu et al. (2012) reviewed the use of DBR in science education in Taiwan. They proposed a three-phase, eight-step framework that demonstrates how DBR can serve not only as a research method but also as a strategic system for supporting instructional development. More recent trends in DBR highlight its capacity to address not just cognitive but also affective and motivational outcomes. Woithe et al. (2022) examined the effectiveness of a science outreach lab at CERN and found that DBR-supported interventions significantly enhanced students' motivation and interest in science. Similarly, Zimmerman et al. (2022) applied DBR to the design of a youth science camp involving personal DNA data, successfully fostering both scientific understanding and socio-emotional engagement.

Building on these successful applications, this study adopts DBR as a strategic response to the identified gaps in interdisciplinary science education. Specifically, the iterative and context-sensitive nature of DBR allows for the continuous refinement of course design to better balance disciplinary knowledge and student engagement. By working closely with authentic classroom contexts and collaborating with practitioners, this approach ensures that the interdisciplinary integration of physics and music is not merely theoretical but directly informed by students' actual learning experiences and challenges. Furthermore, DBR supports the generation of empirically grounded design principles that address the overlooked role of music as a boundary object, bridging abstract scientific concepts with students' everyday musical practices. The flexibility of DBR also enables the researcher to explore how such interdisciplinary instruction can effectively engage high school students—a target group often neglected in previous research. Overall, employing DBR in this study provides both a practical framework for tackling complex design problems and a methodological means to produce transferable insights that contribute to sustainable curriculum innovation in science education.

Chapter 3 Methods

This chapter presents the methodological framework of the study, which adopts a DBR approach to develop and refine an interdisciplinary course aimed at enhancing students' ISL. The course was implemented in real-world educational settings, aligning with the core principles of DBR that emphasize the integration of theory and practice through iterative design.

Building on the literature reviewed in Chapter 2, the structure of this chapter follows the five-phase DBR model proposed by Wang and Hannafin (2005). This model serves as the organizational backbone for describing how the course was designed, implemented, evaluated, and refined across multiple iterations. Through this structure, the chapter illustrates how practical insights and theoretical contributions were generated in tandem throughout the research process.

3.1 Identifying and Analyzing the Problem

This study adopts a DBR approach to systematically design, implement, and refine an interdisciplinary course that aims to enhance high school chorus students' ISL. DBR emphasizes continuous design and improvement in authentic educational settings, making it particularly suitable for bridging theory and practice in real classrooms.

A persistent challenge in science education is the declining interest of students, especially when science is presented in abstract, decontextualized ways. At the same time, music education—particularly in choir settings—rarely incorporates scientific reasoning despite the inherently physical and acoustical nature of vocal production. Students are often trained to adjust their singing based on intuitive, experience-based feedback without understanding the scientific mechanisms behind concepts such as resonance, harmonics, or timbre. This disconnect represents a missed opportunity to leverage students' musical experience to foster interest in scientific thinking.

To address this gap, the current study proposes an interdisciplinary course that blends physics and music in the context of high school chorus classes. The course is designed not only to make science more engaging and personally relevant but also to support vocal technique through scientific understanding. The instructional intervention was implemented with naturally occurring student groups and no control group, making a pre-experimental design the most appropriate methodological choice for examining changes in student outcomes. A mixed-methods approach—combining quantitative pre-/post-questionnaires with qualitative data such as field notes, worksheets, and interviews—was used to analyze both the learning effects and the implementation process.

Accordingly, the study is guided by the following research questions:

- **RQ1:** What design principles can be derived from the iterative development of an interdisciplinary course that integrates science and music to stimulate students' ISL?
- **RQ2:** To what extent does participation in the course influence students' ISL?
- **RQ3:** What challenges and opportunities arise when implementing such a course in authentic educational settings?

3.2 Designing the Instructional Intervention

To design a course that could stimulate students' ISL through authentic and relevant experiences, this study integrated multiple educational approaches. The theoretical foundations included interdisciplinary instruction, authentic science learning contexts, and PhBL. These three design theories served distinct theoretical functions: interdisciplinary instruction acted as an orienting framework that defined the overall purpose and scope of the course; authentic science learning contexts functioned as a framework for action, specifying where, who and for whom the instruction should be situated to ensure relevance; and PhBL operated as a domain-specific instructional theory that guided the concrete design of learning tasks and activities. Together, these frameworks informed the course development by blending theoretical principles with practical considerations, ultimately enhancing students' engagement and understanding. The following sections elaborate on each level in detail.

3.2.1 Interdisciplinary Instruction

The course was designed based on interdisciplinary instruction that connects the fields of physics and choral music. Specifically, it integrated scientific concepts — such as harmonics, resonance, and waveform superposition — with the practical skills required in chorus singing, focusing on tone quality adjustment. Physics, which emphasizes theoretical understanding, and music, which values practical performance, were combined to complement each other. Through this integration, students were expected to enhance their musical capabilities by deepening their scientific comprehension.

3.2.2 Authentic Science Learning Contexts

Authenticity was emphasized by ensuring that the problems explored in the course mirrored real challenges commonly encountered in chorus practice. The scientific knowledge presented was directly linked to practical singing issues, such as controlling volume, stabilizing pitch, and adjusting timbre. By closely aligning with students' lived experiences in the chorus, the course intended to make science learning meaningful, relevant, and more likely to stimulate ISL.

3.2.3 Phenomenon-Based Learning (PhBL)

The course adopted a PhBL approach, focusing on observable phenomena such as the mechanism of trumpets, overtone singing, and the resonance chamber of guitars. Each session began by engaging students with a phenomenon, through activities such as watching demonstration videos or reflecting on their usual singing experiences, before guiding them toward an exploration of the scientific principles behind these phenomena. This design encouraged curiosity, experiential learning, and deeper conceptual understanding.

3.3 Implementing and Observing in Real Settings

This study was conducted in authentic educational settings, specifically within high school chorus groups. Rather than creating artificial experimental conditions, the course was implemented during regular chorus sessions at different schools, allowing the research to be grounded in the real-world contexts where students naturally learn and interact.

The participating choruses were all located in Taipei City, but varied in their size, student backgrounds, and instructional styles, reflecting the diversity commonly encountered in actual educational environments. Even within one chorus, the ages, the grades, and the academic divisions were blended, representing the diversity of students. Moreover, the teacher was a choral conductor with no teacher education background. Conducting the study in real contexts introduced challenges, such as students' differences in engagement, the teacher's weakness in teaching methods, and logistical constraints like limited instructional time. However, these challenges also ensured that the course design remained practical and adaptable to typical teaching conditions.

By situating the research in authentic settings, the study aligned with the fundamental principle of DBR, which emphasizes designing, implementing, and refining educational interventions in environments where they are intended to be used. This approach enhances the ecological validity of the findings and provides insights that are directly transferable to practice.

3.4 Analyzing Data and Refining the Design

Consistent with DBR principles, this study employed a mixed-methods strategy and triangulated data sources to examine the course's effectiveness and to inform iterative refinements.

3.4.1 Data Sources

In line with the DBR methodology, this study employed multiple sources of data to validate and refine the instructional design, aiming to ensure the reliability and richness of the findings.

First, the teaching plan served not only as an intervention intended to stimulate students' ISL but also as a means of inquiry to examine how an interdisciplinary design could be iteratively refined and adapted within a real-world educational setting—specifically, a high school chorus. By repeatedly designing, implementing, and revising the lessons, this process generated valuable data and practical insights that contributed to the development of context-specific design principles for integrating science and music in choral instruction, addressing RQ1.

In addition to the course design, four primary data sources were used throughout the two cycles of implementation:

- **Pre-/Post-Questionnaires:** Mainly administered to collect students' demographic information and to assess changes in students' ISL before and after the intervention, aiming to answer RQ2. Some other scales or questions were adopted in Iteration 1 and Iteration 2 differently, aiming to answer RQ3.

- **Student Worksheets:** Students' written responses to open-ended questions during the lessons provided insight into their participation, understanding, and feedback, which could answer RQ3. As one of the teaching materials, we could investigate each question to find out students' common misconceptions and thus answer RQ1.
- **Field Notes:** Taken by the researcher during each session to capture immediate observations of teaching practices. Field notes could be used to examine the teaching plan and observe the teacher and students, which answered RQ1 and RQ3.
- **Teacher Interviews:** Conducted after the course to gather in-depth feedback from the collaborating teachers. The interviews explored both the design considerations during the course development and the feasibility of implementing the course in real-world educational contexts, and therefore addressed both RQ1 and RQ3. During data analysis, the interview responses were categorized based on their relevance to either RQ1 or RQ3 to ensure a clear and systematic interpretation.

Table 3.1 summarizes the type and its corresponding research questions of each data source. By integrating these diverse sources, the study systematically tracked the interplay between design, enactment, and outcomes, allowing for evidence-based refinements across iterations. The combination of both quantitative and qualitative data supported a robust analysis of the course's effectiveness in achieving the intended educational goals.

Table 3.1

The Type and Its Corresponding Research Question (RQ) of Each Data Source

Data Source	Type	Corresponding RQ(s)
Teaching Plan	Qualitative	RQ1
Pre-/Post-Questionnaires	Quantitative (Iteration 1)	RQ2, RQ3
	Mixed (Iteration 2)	
Student Worksheets	Qualitative	RQ1, RQ3
Field Notes	Qualitative	RQ1, RQ3
Teacher Interviews	Qualitative	RQ1, RQ3

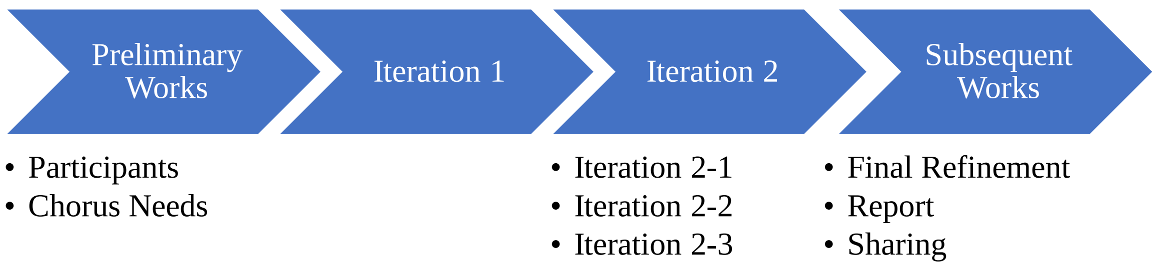
3.4.2 Iterative Design and Refinement

A defining feature of DBR is the iterative cycle of design, enactment, analysis, and refinement(Wang & Hannafin, 2005). In this study, two major research iterations were conducted to develop and optimize an interdisciplinary course integrating science and music for high school chorus students.

The overall research process of this study is illustrated in **Figure 3.1**. Before entering the main DBR iterations, several preliminary works were conducted, including recruiting participants and analyzing the needs of the chorus. After these preparations, the study proceeded into two major iterations.

Figure 3.1

Research Process



Iteration 1 involved the first implementation of the course, followed by data collection and analysis based on multiple sources. After completing Iteration 1, findings from these data informed revisions to the instructional design.

Iteration 2 expanded the iterative nature of the study by incorporating multiple rounds of refinement within the same iteration. The course was implemented, evaluated, and revised across three iterations. After each sub-iteration, systematic analysis of the collected data guided the adjustments to the course structure, activity design, and instructional strategies.

Within each iteration, a cyclic process was followed, as shown in **Figure 3.2**. In each iteration, there are six stages, including:

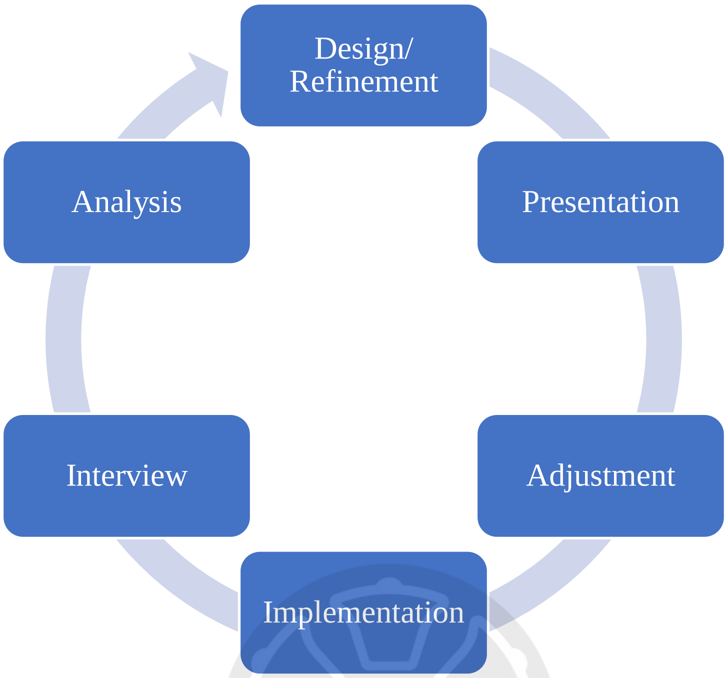
- **Design/Refinement:** The researcher designed or refined a new edition of the teaching plan based on previous data.
- **Presentation:** The researcher presented the teaching plan to the collaborating teacher.
- **Adjustment:** The researcher adjusted the teaching plan based on the collaborating teacher's feedback on the presentation.
- **Implementation:** The collaborating teacher taught the course in a high school chorus while the researcher took field notes simultaneously.
- **Interview:** The researcher interviewed the collaborating teacher a few days after the implementation to discuss the implementation.
- **Analysis:** The researcher analyzed the data collected during the iteration and prepared for the next iteration.

After completing the iterations, the research proceeded to subsequent works, which involved final refinements of the course, reporting the findings, and sharing the developed materials and insights with broader educational communities.

This process embodies the iterative nature of DBR, where design, implementation, analysis, and refinement are conducted cyclically to enhance both theoretical understanding and practical application.

Figure 3.2

Iteration Process



3.5 Iterating and Developing Theory

Last but not least, one of the core aims of DBR is to contribute to the development of theoretical insights that are transferable beyond the specific context of a given study. In this research, while the primary focus was on designing and refining a course that integrates science and music to stimulate students' ISL, an important secondary goal was to derive practical and theoretical implications that could inform future interdisciplinary instructional development and evaluate the course’s potential for further dissemination.

The findings contribute to a set of design guidelines that are usable not only within the original study context but also in similar educational settings. While the course was tailored to high school chorus classes, the underlying design logic—connecting scientific concepts with students’ lived musical experiences—holds potential for adaptation in other interdisciplinary teaching scenarios. These principles may inform future efforts in curriculum development, teacher training, and educational innovation aimed at fostering ISL through integrative, phenomenon-based approaches.

To this end, the study maintained a strong link between local design decisions and broader theoretical reasoning. Each refinement and adjustment was not merely context-specific but also reflected a growing understanding of how various design elements—such as the use of real-world contexts, explicit instructional strategies, and hands-on activities—can contribute to the enhancement of ISL and ensure the course's viability for wider application. The resulting design principles are intended to support future researchers and practitioners interested in interdisciplinary course design within music and science education, while also providing a practical foundation for scaling up similar instructional innovations to benefit diverse learning contexts.

Summary

This chapter outlined the methodological framework employed in this study. DBR served as the primary methodology, supplemented by a pre-experimental design and a mixed-methods approach to ensure both the rigor and the relevance of the findings. Five core characteristics of DBR were systematically integrated into the study: conducting research in real-world contexts, integrating theory and practice, collecting multiple sources of data, employing iterative design and refinement, and developing transferable theories.

The interdisciplinary course combining science and music was carefully designed as a research instrument to explore how integrating domains can stimulate students' ISL. A variety of tools — including pre-/post-questionnaires, field notes, worksheets, and interviews — were utilized to collect comprehensive data throughout the iterations.

The following two chapters present the findings of each design iteration. Chapter 4 details the research design and results of Iteration 1, including the participants, research instruments, process, and key findings related to the initial implementation of the interdisciplinary course.

Chapter 4 Iteration 1

This chapter documents the first implementation of the interdisciplinary course designed to integrate acoustical science into choral practice. Conducted as part of a DBR framework, Iteration 1 served as an initial trial to explore the course's feasibility, refine its structure, and assess its impact on students' understanding and engagement. The course was co-developed and delivered by the researcher and a choral conductor, and implemented in a senior high school chorus setting.

The following sections describe the research participants, instructional design, data collection tools, and implementation process. Results from both quantitative and qualitative data are presented to evaluate learning outcomes across cognitive, affective, and psychomotor domains. Reflections on course effectiveness and research design are included to inform future iterations and broader applications of science-infused music education.

4.1 Research Participants

Iteration 1 involved a collaborating teacher and 25 high school students from a choral ensemble. This section introduces their backgrounds.

4.1.1 Collaborating Teacher – Teacher Z

Teacher Z holds a master's degree in choral conducting. With over 16 years of experience in choral singing and seven years in conducting, he has led Chorus A for more than three years. In addition to working with high school students, he also conducts elementary school, women's, and community choruses. His familiarity with both the students and the researcher provided a strong foundation for implementing the course.

4.1.2 High School Students in Chorus – Chorus A in School A

School A is a public senior high school for female students located in a metropolitan area in northern Taiwan. With a student body of approximately 2,400, it is one of the largest and most academically competitive secondary schools in the region. The school is well-regarded for its emphasis on both scholastic achievement and well-rounded personal development, providing a variety of extracurricular opportunities alongside a demanding academic curriculum.

Chorus A is a female chorus consisting of students from different grade levels. Students participate voluntarily and rehearse outside of regular class hours, typically for several hours each week. The chorus is led by Teacher Z and supported by music teachers who assist in vocal training and repertoire preparation. Chorus A has a strong tradition of excellence, having received numerous awards in both national and international choral competitions. Their high level of performance, commitment, and collaboration make them an ideal case for exploring interdisciplinary curriculum implementation in a music education context.

Although 25 students participated in this group, a total of 10 matched pre- and post-questionnaires were collected and included in the analysis. All 10 participants were female, with ages ranging from 15 to 17 (M = 16.0). The majority were 11th-grade students (n = 6), followed by 10th-grade students (n = 4). In terms of academic track, three students were from the first track (Humanities and Social Sciences), four from the second track (STEM: Science, Technology, Engineering, and Mathematics), and three from the third track (Life Sciences, Agriculture, and Medicine).

Regarding their involvement in the chorus, the students had varied lengths of participation: four students had joined the chorus for two semesters, while six had been involved for four semesters. Their prior choral experience also ranged widely: one student had less than one year of experience, two had 1–2 years, two had 2–3 years, one had 3–4 years, three had 4–5 years, and one had 8–9 years.

4.2 Course Design

The interdisciplinary course was co-developed by the researcher and Teacher Z through informal discussions, with a focus on integrating vocal acoustics into chorus instruction. Although Teacher Z lacked a formal science background, he actively collaborated to ensure conceptual accuracy and instructional clarity. After two weeks of development, the finalized version was implemented as a 3-hour workshop.

4.2.1 Learning Objectives.

The course was developed in response to students' limited understanding of voice acoustics, which often hindered their ability to improve vocal performance. Observations during rehearsals suggested that vocal training in the chorus heavily relied on experiential rules, with little reference to underlying physical principles. To address this, the course aimed to blend scientific understanding with practical application in choral singing.

Three learning objectives guided the instructional design:

- **Cognitive Objective:** Students can explain the physical mechanisms of voice production, including concepts such as overtones, standing waves, and resonance.
- **Affective Objective:** Students can demonstrate increased ISL through engagement with acoustics concepts and their relevance to singing.
- **Psychomotor Objective:** Students can apply vocal techniques for resonance adjustment to shape timbre.

These objectives ensured that learning outcomes were aligned with both science and music domains.

4.2.2 Course Structure

To ensure alignment with the intended learning objectives, the course was structured to integrate acoustical concepts with practical vocal exercises in a high school chorus context. It consisted of four 50-minute lessons (200 minutes in total), which could be implemented weekly or biweekly, or condensed into a single 3-hour workshop format. For this study, the 3-hour workshop format was adopted to ensure sufficient participant availability.

The instructional design followed a PhBL approach, in which each session began with a real-world vocal phenomenon and progressed toward scientific explanation and vocal application. Students were guided through observations, discussions, hands-on vocal experiments, and reflection via worksheets. The four lessons were structured as follows:

- **Lesson 1:** The Nature of Human Voice
- **Lesson 2:** The Principle of Overtones
- **Lesson 3:** The Causes of Timbre
- **Lesson 4:** The Selection of Resonance

This structure aimed to bridge the gap between students' intuitive, experiential chorus learning and the underlying scientific principles. Through progressive exposure to concepts—

from vocal fold vibration to overtone manipulation and resonance control—students were encouraged to connect theory with practice and develop both their vocal technique and interest in science. For details of the instructional design in Iteration 1, see **Appendix A**.

4.2.3 Lesson 1: The Nature of Human Voice

This lesson introduced the fundamental principles of vocal sound production by drawing parallels between the human voice and wind instruments. Through multimedia demonstrations and interactive activities, students explored how sound is generated by airflow, modulated by the vocal folds, and shaped by resonant structures. The instructional goal was to help students recognize the physiological basis of vocal production and to spark curiosity about the scientific underpinnings of choral singing.

1. Engagement-1: Overtone Singing. To engage students at the start of the course, the teacher played a video of overtone singing (Video 1-1), in which a performer sang a low, sustained note while simultaneously producing a high, melodic overtone. After viewing the clip, students were prompted to respond to two questions via Slido: “What did you hear?” and “How did he do it?” Responses were displayed as a word cloud and discussed collectively. The teacher then introduced the four-lesson structure and the overarching question of the unit: “How can understanding overtones help us sing better?”

This activity adopted a PBL approach by presenting an unfamiliar yet authentic vocal phenomenon without prior explanation. The aim was to elicit curiosity and initial hypotheses from students before introducing formal scientific content. The Slido platform enabled anonymous participation and fostered inclusive engagement, while also serving as a formative assessment tool to gauge students’ prior understanding.

2. Development-1: Review of the Three Elements of Sound. To assess students' prior knowledge, the teacher used Slido to ask: “What are the three elements of sound?” Students submitted keywords describing concepts such as volume, pitch, and timbre, which were visualized in a word cloud. The teacher then reviewed the responses and clarified the correct scientific concepts.

This segment combined direct instruction with interactive technology. The goal was to ensure that all students shared a foundational understanding of core acoustic concepts, which would be further developed in subsequent lessons.

3. Development-2: Mechanisms of Voice Production and Tuning. Next, the teacher posed two multiple-choice questions: “What is the mechanism behind voice production?” and “What is the mechanism behind pitch tuning?” Students first voted individually, then discussed their ideas in small groups, followed by a second vote. Students holding differing views were invited to share their reasoning. The teacher paraphrased their responses neutrally before presenting two videos—one showing vocal fold vibration during pitch shifts (Video 1-2), and another featuring the vocal folds of four chorus members while singing (Video 1-3). After the videos, a final round of voting was conducted, followed by a summary of the scientific principles.

This sequence combined collaborative learning, guided inquiry, and direct instruction. Peer discussion reduced the anxiety of public sharing and helped scaffold understanding, while multimedia resources provided rare visual insights into internal vocal mechanisms.

4. Recap-1: Everyday Phenomena and Human Voice. To conclude the lesson, students responded in writing to two questions: “What is the connection between the pipe organ and the human voice?” and “Why does our voice sound lower after staying up late or just waking up?” These questions encouraged students to connect scientific concepts to everyday experiences. Their answers were submitted via worksheets and used as prompts for the next lesson's discussion.

This recap activity reinforced the lesson’s key concepts through familiar phenomena, promoting knowledge transfer. The worksheet format supported the written organization of ideas and prepared students for future verbal sharing.

4.2.4 Lesson 2: The Principle of Overtones

This lesson focused on the concept of overtones and standing waves. Through a hands-on rope activity, students explored how vibration patterns form when both ends of a string are fixed. The concept of harmonic frequencies was introduced, emphasizing how integer multiples of a fundamental frequency generate overtones. By connecting these principles to both musical instruments and the human voice, the lesson helped students develop a scientific understanding of how different overtones are produced and how they relate to a human voice.

1. Engagement-2: Different Sizes of Eggs. The teacher posed a question: “Which length of an egg placed in a box is less likely to break when shaken?” This question, though seemingly unrelated, guided students toward thinking about boundary conditions and oscillation.

This activity introduced a hypothetical scenario to create cognitive dissonance and foster curiosity, preparing students for the conceptual learning ahead. Slides were used to guide the questioning.

2. Engagement-3: Review and Connection. The teacher revisited students’ responses to the previous worksheet and guided a discussion. Two takeaways were emphasized: (1) both pipe organs and the human voice produce sound through air-driven mechanisms, and (2) relaxed vocal folds produce deeper sounds. These served as a bridge to the current lesson.

This activity supported connection-building through PhBL and allowed the teacher to consolidate understanding using student-generated reflections. Worksheets facilitated organized thinking.

3. Development-3: Exploring Vibrations Through Jump Rope. To illustrate vibrational modes, the teacher used a jump rope to demonstrate how standing waves form when a string is fixed at both ends. Students experimented with creating the fundamental mode and its harmonics.

This tangible, kinesthetic activity grounded abstract physics principles in physical experience. It is linked to vocal fold behavior and highlights interdisciplinary connections.

4. Development-4: Fundamental Frequency, Overtones, and Harmonics. The teacher introduced and defined three terms: fundamental frequency, overtones, and harmonics. These definitions helped interpret the rope activity and laid the groundwork for later lessons.

This direct instruction segment clarified distinctions and consolidated terminology. Slides provided a visual reference.

5. Recap-2: Identifying and Interpreting Waveforms. Students viewed waveform diagrams and classified each as fundamental, overtone, or non-harmonic. Cold-calling was used to elicit reasoning. A follow-up question asked students how real-world strings vibrate.

This activity reinforced understanding through guided interpretation. The worksheet helped students record and reflect on their ideas.

4.2.5 Lesson 3: The Causes of Timbre

This lesson explored why different instruments can produce distinct sounds when playing the same pitch. Students examined how differences in overtone composition contribute to timbre. Through listening exercises, waveform analysis, and simulations, students deepened their understanding of how waveforms are shaped.

1. Engagement-4: Recognizing Timbre Differences. The teacher played sound clips of piano, flute, and saxophone playing the same pitch and asked the students to identify each instrument. The teacher then posed the question: “Why do they sound different despite having the same pitch?”

This phenomenon-based activity triggered curiosity by presenting a perceptual contradiction. Audio clips made the phenomenon tangible and engaging.

2. Engagement-5: Review and Connection. The teacher reviewed student responses from the previous worksheet question on string vibration. Students voted, discussed in heterogeneous groups, voted again, and shared insights. The teacher paraphrased the ideas neutrally.

This cooperative activity supported reflection and social learning. Worksheets helped organize thoughts and scaffolded discussion.

3. Development-5: Vibration and Overtone Selection. The teacher explained overtone selection using a fruit-sorting analogy. When strings vibrate, all harmonics are generated, but only specific ones are amplified. The teacher related this to the jump rope experience, explaining that higher frequencies are harder to produce.

Direct instruction was used to clarify overtone filtering. A fruit-sorting machine video illustrated the analogy.

4. Development-6: Understanding Timbre through Waveform Composition. The teacher asked: “Why do different timbres exist if the pitch is the same?” Students discussed, and the teacher summarized that waveforms differ due to overtone proportions. A simulation demonstrated how harmonic waves combine into different waveforms.

This direct instruction segment clarified abstract ideas with visual aids. Simulation tools and graphing software made overtone composition visible and concrete.

5. Recap-3: Linking Overtone Composition to Timbre Differences. The teacher provided waveform graphs of various instruments and asked: “What difference do you observe in timbre based on overtone content?” Students recorded their answers on a worksheet.

This recap session used PhBL. The worksheet scaffolded independent thinking and helped consolidate understanding.

4.2.6 Lesson 4: The Selection of Resonance

This lesson focused on how resonance affects vocal timbre and how singers can adjust resonance spaces to shape their sound. Students explored resonance principles using instrument comparisons, anatomical diagrams, and overtone singing.

1. Engagement-6: Review and Connection. The teacher summarized the previous lesson’s reflection responses, highlighting that high-frequency overtones lead to brighter timbres, while fewer high overtones produce warmer tones. This review reinforced students’ prior understanding.

Direct instruction helped consolidate key concepts. Worksheets from the previous lesson were used for reference.

2. Engagement-7: Can We Change Our Timbre? The teacher asked: “Can we change our vocal timbre?” After students agreed, the teacher asked: “Since it is difficult to change our vocal folds, how can we adjust our timbre?” This guided students to consider the resonance space.

The teacher used guided questioning to promote critical thinking. The activity encouraged verbal participation without specific instructional materials.

3. Development-7: How Resonance Shapes Timbre. The teacher compared ukuleles and guitars to explain how size affects resonance. A vocal tract diagram was shown to illustrate human resonance spaces. The teacher replayed the overtone video and asked students to interpret the phenomenon.

PhBL was employed to link familiar instrument examples to vocal mechanisms. Videos and diagrams helped visualize resonance effects.

4. Recap-4: Applying Knowledge of Overtones. Students were asked: "How can understanding overtones help us sing better?" They wrote their thoughts on worksheets and shared them with the class.

Direct instruction guided reflection. The worksheet provided a structure for organizing ideas.

5. Conclusion: Extending More Science Behind Music Phenomena. The teacher concluded the course by introducing other sound phenomena, such as just intonation vs. equal temperament and harmonic balance. Students watched a video of glass breaking due to resonance.

This phenomenon-based closing aimed to extend learning and spark curiosity. News articles and videos illustrated the broader applications of acoustics.

4.2.7 Learning Assessments

To evaluate students' learning outcomes aligned with the three instructional objectives—cognitive, affective, and psychomotor—this study employed a combination of written work, self-report measures, and qualitative interviews.

- **Cognitive Objective:** Students completed worksheets with open-ended questions after each lesson. Their responses were analyzed for accuracy and depth of conceptual understanding. Items covered key topics such as overtone ratios, waveform interpretation, and voice production mechanisms.
- **Affective Objective:** The Science Learning Interest Scale was administered before and after the course. This validated instrument measured five dimensions of learning interest, and Wilcoxon Signed-Rank Tests were used to detect any

statistically significant shifts.

- **Psychomotor Objective:** The collaborating teacher was interviewed after the course to assess whether students applied scientific understanding to their vocal practice. The teacher reported increased awareness of timbre and more responsive rehearsal behavior, indicating successful knowledge transfer to singing contexts.

Together, these assessments provided a multi-faceted picture of students' learning across cognitive understanding, attitudinal shifts, and skill development.

4.3 Research Instruments

To address the research questions and evaluate the course's effectiveness, a mixed-methods approach was adopted. Four types of instruments were used: pre-/post-questionnaires, field notes, student worksheets, and a teacher interview. These tools were designed to capture learning outcomes and answer the three research questions.

4.3.1 Pre-/Post-Questionnaires

The pre-/post-questionnaires were designed to take approximately 10 minutes to complete. These questionnaires were not part of the formal course content but were administered by the researcher as external data to evaluate the effectiveness of the course.

The pre-questionnaire was distributed at the beginning of the first session, immediately after the study was introduced to the students. The post-questionnaire was administered after the final session, following the course summary. To enable paired comparison between pre- and post-responses, students were asked to write a self-generated code name on their response sheets. Although responses were matched using these identifiers, all data remained anonymous.

For details of the pre-/post-questionnaires in Iteration 1, see **Appendix B**. In Iteration 1, the pre-/post-questionnaires are roughly the same, consisting of several sections, each designed to assess different aspects of students' experiences and learning outcomes. The following subsections describe the structure and purpose of each section in detail.

1. Demographic Information: The pre-questionnaire would first collect a student's age, grade, gender, academic division, years of participating in the chorus, and years of being a chorister. The items were chosen by the researcher, aiming to provide more details about the students so that we could use these materials to explain the data further.

Since the data type of the demographic information was mostly nominal and the distribution mattered, we used descriptive statistics to analyze the demographic information, including the ratio of different grades, the average of years of being a chorister, and so on.

2. Science Learning Interest Scale. To answer RQ2 concerning students' ISL, this study adapted a self-report instrument originally developed by Cheng et al. (2013), the Science Learning Interest Scale, for use in the pre-/post-questionnaires. The scale includes two major dimensions—personal interest and situational interest—comprising five subscales: *latent interest* and *actualized interest* (representing personal interest), and *triggered situational interest*, *maintained situational interest-feeling*, and *maintained situational interest-value* (representing situational interest).

Specifically, latent interest captures students' inherent but undeveloped tendency to be curious about science topics even when not explicitly exposed to them, whereas actualized interest reflects students' stable and ongoing engagement with science learning in their daily life. For situational interest, triggered situational interest measures the initial spark or curiosity provoked by new scientific phenomena or learning contexts; maintained situational interest-feeling assesses the positive emotions, enjoyment, and excitement students experience during science learning activities; and maintained situational interest-value gauges the perceived personal value and usefulness students attach to the science content they are learning.

Each subscale contains four items, making a total of 20 items, rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), with higher scores indicating greater interest.

The scale was developed based on prior theoretical frameworks of interest by Hidi and Ann Renninger (2006), who proposed that situational interest plays a foundational role in the development of personal interest. The three situational subscales were adapted from Linnenbrink-Garcia et al. (2010), Measuring Situational Interest in Academic Domains, while the two personal interest subscales were based on Mitchell's (1993) Personal Interest Scale. Cheng et al. (2013) localized and validated the instrument through expert review and pilot testing with 144 junior high school students in southern Taiwan. Principal component analysis confirmed the five-factor structure, explaining 74.26% of total variance. Internal consistency reliability coefficients (Cronbach's α) ranged from .868 to .942 across subscales, with an overall reliability of .962, indicating high reliability above the standard criterion of .70 (George & Mallery, 2010).

To align with the purpose of the pre- and post-questionnaires in this study, minor wording adjustments were made to the situational interest items in the pre-questionnaire, following guidance from Lo (2016). Specifically, the phrase "this course" was modified to "previous science classes" in the pre-questionnaire to reflect better students' prior learning experiences rather than their responses to the current interdisciplinary intervention.

3. Music Learning Interest Scale. In addition to measuring students' ISL, Iteration 1 also incorporated the Music Learning Interest Scale in the pre-/post-questionnaires to assess whether the interdisciplinary course could positively influence students' interest in music learning. This instrument was included to address RQ3. If the course not only enhances science learning interest but also promotes students' interest in music, it could strengthen its practical value for music teachers. Demonstrating such dual benefits would make the curriculum more attractive and increase its applicability in formal music education settings.

This instrument was adapted from the study of Lai (2011) on high school students' music learning interest and self-determination needs. All 25 original items were retained without modification. The scale used a 5-point Likert format (1 = strongly disagree to 5 = strongly agree), and was designed to evaluate students' affective engagement with music education.

The scale consists of five subscales, each comprising five items: *latent interest*, *actualized interest*, *text-based interest*, *task-based interest*, and *knowledge-based interest*. Latent interest refers to students' stable, long-term preference for learning music. Actualized interest describes students' internal motivation that drives them to seek out music-related content outside of class actively. The remaining three dimensions represent situational interest: text-based interest is triggered by how music content is presented (e.g., visual aids, layout); task-based interest reflects students' engagement in classroom activities, especially when they relate to personal life experiences; and knowledge-based interest is influenced by students' prior familiarity with the subject matter.

According to Lai (2011), the internal consistency reliability of each subscale, measured by Cronbach's α, ranged from .814 to .904: latent interest (α = .881), actualized interest (α = .904), text-based interest (α = .892), task-based interest (α = .814), and knowledge-based interest (α = .898). These values indicate satisfactory reliability (George & Mallery, 2010).

4. Choral Learning Attitude Scale. To address RQ3 from another aspect, Iteration 1 also measured students' learning attitudes toward choral music in both the pre- and post-questionnaires. Since chorus participation is elective in most schools, students who join a chorus club typically already possess a relatively high level of interest in choral singing. As such, Iteration 1 focused on evaluating changes in learning attitudes rather than baseline interest. From a music educator's perspective, if an interdisciplinary course can improve students' learning attitudes toward chorus participation, it may enhance the course's practical value and increase its likelihood of adoption in real-world choral settings.

The Choral Learning Attitude Scale used in this study was adapted from the Music Learning Attitude Scale developed by Cheng (2004), which was originally designed to measure junior high school students' attitudes toward music learning within an integrated curriculum framework. The original scale contains 32 items, divided into four subscales: *learning motivation* (Items 1–8), *learning habits* (Items 9–15), *learning behaviors* (Items 16–21), and *learning cognition* (Items 22–32). Each item is rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). In Cheng's study, the internal consistency reliability (Cronbach's alpha) for the full scale was .822. The subscale reliabilities were .838 for learning motivation and .827 for learning cognition, indicating that the instrument met acceptable standards of reliability (George & Mallery, 2010).

For this study, the original scale was adapted by replacing all references to "music class" with “choral class” to better align with the context of the choral-based curriculum. No changes were made to the item structure, phrasing, or subscale organization beyond this contextual adjustment. This revision preserved the psychometric integrity of the instrument while ensuring that the items reflected the learning environment of the participating students.

4.3.2 Field Notes

During Iteration 1, the researcher observed the classroom and recorded field notes throughout the instructional process. The primary focus of the observation was on the teacher’s instructional delivery, students’ on-task behaviors, and the overall classroom atmosphere. These notes provided descriptive records of how the lesson was implemented in practice and served as qualitative data to support the collaborating teacher interview, contributing to the analysis of RQ1 regarding the feasibility and reception of the course.

The field notes were recorded in an open-ended and descriptive format, without a predetermined coding scheme. The researcher recorded the progression of classroom events, capturing details such as teacher instructions, student reactions, moments of engagement or confusion, the pace of the lesson, and the tone of classroom interactions. Due to the researcher's supporting role during student small-group discussions, detailed records of peer interactions were not consistently captured in the notes.

Notably, two Slido-based word cloud activities at the beginning of Lesson 1 were also included in the field notes. The first was an Engagement activity involving overtone singing: after watching a video of a singer performing a single sustained note with a moving overtone melody (Amazing Grace), students were asked, “What did you hear?” and “How did he do it?” They submitted their responses anonymously via Slido, and the resulting word cloud offered insight into their initial perceptions and curiosity. The second Slido prompt was designed to review students’ prior knowledge of sound. Students were asked to recall the three elements of sound—volume, pitch, and timbre—based on their junior high school experiences. Their answers were displayed as another real-time word cloud, allowing the teacher to assess students’ conceptual readiness and provide targeted clarification. These interactions, along with the classroom dynamics they revealed, were recorded in the field notes to enrich the contextual analysis of instructional implementation.

4.3.3 Student Worksheets

To assess students' conceptual understanding and gather their reflections on each lesson, a worksheet was developed and implemented across all four lessons. This instrument served two primary purposes: (1) to evaluate how well students grasped the scientific concepts embedded in the course, thus addressing RQ1, and (2) to capture students' engagement and feedback, contributing to RQ3.

The worksheet was distributed at the end of each lesson as a recap activity. Each lesson included two to three open-ended questions: one or two focused on science-related concepts covered in the lesson (e.g., the connection between vocal timbre and overtone ratios, or the principle behind resonance control), and one invited students to reflect on their learning experience for that particular session. In the final lesson, students were also asked to respond to broader questions about the overall course structure and insights gained. For details of the student worksheets in Iteration 1, see **Appendix C**.

All worksheet responses were handwritten and collected immediately at the end of each class. After the course, students' submissions were scanned and archived as part of their learning portfolio. The open-ended format allowed for a range of student expressions, from factual recall to personal reflections, providing valuable qualitative data for triangulating other sources of evidence, such as interviews and classroom observations.

4.3.4 Teacher Interview

To supplement the classroom observations and provide additional insights into the instructional process and course feasibility, a semi-structured interview was conducted with the collaborating teacher (Teacher Z) following the completion of Iteration 1. This interview served two purposes: first, to explore the teacher's reflections on course design and specific instructional moments during the course, which addressed RQ1; and second, to gather the teacher's feedback on the instruction, which addressed RQ3.

The interview took place five days after the course and was conducted face-to-face in a private setting. It lasted approximately 100 minutes. With the participant's consent, the conversation was audio-recorded and later summarized by the researcher into interview notes. A semi-structured interview guide was used, covering the following thematic areas: course design, material preparation, teaching activities, student responses, and post-course observations. The questions were developed in advance by the researcher, with supplementary prompts derived from field notes to probe specific classroom events further and elicit broader reflections on the course's impact.

All responses were anonymized using pseudonyms to protect the participants' identities. The transcribed data were summarized and organized thematically for analysis. While the interview questions were not developed based on a specific theoretical model, they were aligned with the instructional focus of the course and aimed at capturing both in-the-moment and reflective pedagogical insights.

4.4 Research Process

This section outlines the procedures involved in the design, implementation, and data collection of the study. The research process was structured to ensure alignment between the instructional goals and the methodological framework, while also maintaining flexibility to accommodate the dynamics of a real classroom setting. The following subsections describe each phase of the process in chronological order, from initial preparation through data collection and ethical considerations.

4.4.1 Course Development Timeline

This section describes the preparation and execution of the course during Iteration 1, which served as the first formal implementation of the instructional design. The course was co-developed by the researcher and a collaborating teacher, and carried out in a real classroom setting to examine the feasibility of interdisciplinary teaching in a choral environment. The process is divided into two phases: the preparation phase, which outlines the instructional planning and logistical setup, and the implementation phase, which details how the course was delivered, who participated, and how instructional responsibilities were shared.

1. Preparation Phase. Before the course implementation, several preparatory steps were undertaken to ensure alignment between the instructional design and research goals. The researcher first engaged in collaborative discussions with the collaborating teacher (Teacher Z) to co-develop the teaching plan. These informal meetings focused on clarifying the scope of scientific content, sequencing the lessons, and identifying appropriate pedagogical strategies for integration within a choral rehearsal setting. The first version of the teaching plan was completed after two weeks of collaborative work and subsequently refined based on Teacher Z's feedback.

Given that the collaborating teacher did not have a background in physics, the researcher provided targeted support to help him become familiar with the scientific concepts embedded in the course, such as overtones, standing waves, and resonance. Instructional content was adjusted to ensure accessibility while preserving conceptual accuracy, so that it could be taught effectively by a music teacher without formal training in science.

In addition, all research instruments were prepared in advance, including the pre- and post-questionnaires, student worksheets, and interview guidelines. Multimedia teaching materials, such as video demonstrations of overtone singing and vocal fold vibrations, were also selected and reviewed to ensure clarity and appropriateness for the target student population. The entire course, including learning objectives, lesson flow, and materials, was finalized before the start of the implementation.

Once all preparations were in place, the course was implemented in the designated setting. The following section outlines the implementation process in detail, including instructional delivery, classroom environment, and the division of instructional and observational roles.

2. Implementation Phase. The course was implemented in the form of a single three-hour workshop, held in the music classroom of School A. This format was chosen to ensure that all lessons could be completed within a single session, considering the students' limited availability during the academic term. The classroom provided appropriate teaching equipment, and students were already familiar with the environment, which supported a comfortable and focused learning atmosphere.

The course was held in March 2024, after the National Student Competition of Music in Taiwan, which means that most of the choristers had performance experience at least twice. Implementing the course at this time could avoid some novel issues, and most of the students had decided on their academic division. Therefore, this timing is good for instruction and analysis.

The instruction was primarily delivered by the collaborating teacher, Teacher Z, who had previously rehearsed the lesson flow and scientific content with the researcher. However, due to a temporary schedule conflict, the researcher assumed the teaching role for part of the workshop. Specifically, the researcher conducted the course from the end of Lesson 1 to the end of Lesson 2, and from the middle of Lesson 3 to the middle of Lesson 4. During these segments, classroom observation was not recorded, as the researcher was directly engaged in instructional delivery.

The course was conducted with 23 students from Chorus A, all of whom had prior experience singing under the guidance of Teacher Z. This familiarity facilitated smoother communication and classroom interaction. Throughout the workshop, students engaged in group discussions, multimedia-based activities, and worksheet-based reflections, following the designed lesson sequence.

4.4.2 Data Collection

Multiple sources of data were collected to address the research questions and to triangulate findings across cognitive, affective, and behavioral dimensions. These data sources included pre-/post-questionnaires, student worksheets, field notes, and a teacher interview.

- **Pre-/Post-Questionnaires:** The Science Learning Interest Scale, Music Learning Interest Scale, and Choral Learning Attitude Scale were administered before and after the course to assess changes in students' interest and attitudes. The pre-questionnaire was distributed at the beginning of the workshop, after the study was explained to participants. The post-questionnaire was completed immediately following the final course summary. Students used a self-generated code on both instruments to allow paired comparisons while maintaining anonymity.

- **Student Worksheets:** Open-ended worksheets were distributed at the end of each lesson segment. These worksheets served both as a formative assessment and a data source for examining students' conceptual understanding and engagement. In the workshop format, all worksheets were collected at the end of the session.
- **Field Notes:** The researcher recorded detailed field notes throughout the course implementation, focusing on instructional fidelity, student reactions, and overall classroom dynamics. However, during the segments when the researcher assumed the teaching role (i.e., part of Lessons 2, 3, and 4), observation was not recorded, resulting in partial gaps in the field notes.
- **Teacher Interview:** A semi-structured interview with the collaborating teacher was conducted five days after the course. The interview lasted approximately 100 minutes and was held in a cafe. It aimed to capture the teacher's in-the-moment reflections on classroom events (addressing RQ1) and his subsequent observations during regular rehearsals (addressing RQ3). With consent, the interview was recorded and later transcribed for analysis.

Together, these instruments provided a multi-perspective understanding of students' learning processes, instructional implementation, and the overall feasibility of the interdisciplinary course.

4.4.3 Ethical Consideration

To ensure the ethical conduct of the study, all data collection procedures adhered to standard research ethics guidelines, with an emphasis on anonymity, informed consent, and voluntary participation.

Students were informed of the study's purpose, procedures, and their right to withdraw at any time without penalty. Prior to participation, verbal consent was obtained from each student.

All data were collected anonymously. To enable paired comparisons between pre- and post-questionnaires, students were asked to create and write a self-generated code on their answer sheets. These codes were not linked to students' real names, ensuring participant confidentiality. Worksheets and questionnaire responses were stored securely by the researcher and were only accessible to the research team.

To express appreciation and encourage participation, students who completed both the pre- and post-questionnaires received a small token of appreciation—a gift card valued at 50 NTD. This incentive was disclosed in advance and was not tied to performance or answer quality.

The study was reviewed and approved by the researcher's academic advisor and followed institutional research protocols for studies involving human participants.

4.5 Analysis and Findings

This section evaluates the first implementation of the course using both quantitative and qualitative data. Three pre-/post-questionnaires were administered to assess changes in students' science learning interest, music learning interest, and choral learning attitudes. Additional data, including field notes, student worksheets, and a teacher interview, were analyzed to provide contextual insights. The findings are presented in the following four subsections.

4.5.1 Pre-/Post-Questionnaires

In this implementation, we collected 20 pre-questionnaires and 15 post-questionnaires from 25 students. However, only 10 paired questionnaires were counted.

Given the small sample size (n = 10) and the non-normal distribution typically associated with Likert-scale data, the Wilcoxon Signed-Rank Test was employed to examine whether there were statistically significant differences in students' ISL before and after the course. This non-parametric method is appropriate for paired ordinal data and offers a robust alternative to the paired-samples t-test under these conditions. Descriptive statistics and test results for Iteration 1 are presented in **Table 4.1** and **Table 4.2**.

Table 4.1

Descriptive Statistics of Chorus A's Science Learning Interest Scale in Iteration 1

Subscale	Pre			Post		
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Latent Interest	16.1	3.9	16.0	16.1	3.5	16.0
Actualized Interest	16.2	3.0	16.0	16.5	2.0	16.0
Triggered SI	13.1	2.6	14.0	13.6	3.7	14.0
Maintained SI-Feeling	15.1	4.1	15.5	15.8	3.9	16.0
Maintained SI-Value	16.4	2.5	16.0	17.0	2.2	16.0

Note. $n = 10$ refers to the number of matched questionnaires collected for analysis.
SI = Situational Interest.

The results showed that among the five subscales in the Science Learning Interest Scale, only the maintained situational interest-feeling demonstrated a statistically significant increase ($p < .05$), with five students showing higher post-course scores compared to pre-course scores and none showing a decrease. This indicates an enhancement in students' emotional engagement with the learning activity after the course. No significant differences were found in latent interest, actualized interest, triggered situational interest, or maintained situational interest-value.

Table 4.2

Results of the Wilcoxon Signed-Rank Test on Chorus A's Science Learning Interest Scale in Iteration 1

Subscale	Ranks	*n*	Mean Rank	Sum of Ranks	*z*	*p*	Effect Size
Latent Interest	Neg.	3	2.5	7.5	0.00	1.000	.00
	Pos.	2	3.8	7.5			
	Ties	5					
Actualized Interest	Neg.	3	2.7	8.0	-0.53	.598	-.17
	Pos.	3	4.3	13.0			
	Ties	4					
Triggered SI	Neg.	2	2.0	4.0	-0.96	.336	-.30
	Pos.	3	3.7	11.0			
	Ties	5					
Maintained SI-Feeling	Neg.	0	0.0	0.0	-2.07	.038*	-.65
	Pos.	5	3.0	15.0			
	Ties	5					
Maintained SI-Value	Neg.	1	2.0	2.0	-1.51	.131	-.48
	Pos.	4	3.3	13.0			
	Ties	5					

Note. $n = 10$ refers to the number of matched questionnaires collected for analysis.

SI = Situational Interest; Neg. = Negative; Pos. = Positive.

*p < *.05.* **p < *.01.* ***p < *.001.*

The same statistical method was applied to analyze students' music learning interest before and after the course, given the small sample size and the ordinal nature of the Likert-scale responses. Descriptive statistics and test results are presented in **Table 4.3** and **Table 4.4**.

Table 4.3

Descriptive Statistics of Chorus A's Music Learning Interest Scale in Iteration 1

Subscale	Pre			Post		
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Latent Interest	18.8	3.5	19.5	18.6	3.9	19.0
Actualized Interest	17.9	3.8	18.0	18.3	4.1	18.0
Text-Based Interest	19.0	3.8	19.0	19.7	3.6	19.5
Task-Based Interest	15.9	2.2	16.5	16.5	2.6	16.0
Knowledge-Based Interest	20.4	3.3	20.5	20.0	3.1	19.5

Note. n = 10 refers to the number of matched questionnaires collected for analysis.

SI = Situational Interest.

The results indicated that none of the subscales showed statistically significant changes. Specifically, there were no significant differences in latent interest, actualized interest, text-based interest, task-based interest, or knowledge-based interest. These findings suggest that the course had a limited measurable effect on students' reported interest in music learning across the five interest dimensions.

Table 4.4

Results of the Wilcoxon Signed-Rank Test on Chorus A's Music Learning Interest Scale in Iteration 1

Subscale	Ranks	*n*	Mean Rank	Sum of Ranks	*z*	*p*	Effect Size
Latent Interest	Neg.	3	4.2	12.5	-0.43	.671	-.14
	Pos.	3	2.8	8.5			
	Ties	4					
Actualized Interest	Neg.	3	3.0	9.0	-0.86	.391	-.27
	Pos.	4	4.8	19.0			
	Ties	3					
Text-Based Interest	Neg.	4	2.5	10.0	-1.14	.256	-.36
	Pos.	4	6.5	26.0			
	Ties	2					
Task-Based Interest	Neg.	2	2.5	5.0	-1.56	.119	-.49
	Pos.	5	4.6	23.0			
	Ties	3					
Knowledge-Based Interest	Neg.	4	3.4	13.5	-0.63	.527	-.20
	Pos.	2	3.8	7.5			
	Ties	4					

Note. n = 10 refers to the number of matched questionnaires collected for analysis.

SI = Situational Interest; Neg. = Negative; Pos. = Positive.

*p < *.05.* **p < *.01.* ***p < *.001.*

The same statistical method was applied to analyze students' choral learning attitudes before and after the course, given the small sample size and the ordinal nature of the Likert-scale responses. Descriptive statistics and test results for Iteration 1 are shown in **Table 4.5** and **Table 4.6**.

Table 4.5

Descriptive Statistics of Chorus A's Choral Learning Attitude Scale in Iteration 1

Subscale	Pre			Post		
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Learning Motivation	32.5	4.2	30.5	32.2	3.9	32.0
Learning Habits	25.8	4.6	23.5	24.5	4.3	23.5
Learning Behaviors	22.8	2.7	23.5	22.6	2.4	22.5
Learning Cognition	43.4	6.0	42.0	43.5	5.2	42.5

Note. n = 10 refers to the number of matched questionnaires collected for analysis.

The results showed that none of the subscales demonstrated statistically significant differences. Specifically, no significant changes were found in learning motivation, learning habits, learning behaviors, or learning cognition. These findings suggest that the course had a limited impact on students' self-reported attitudes toward learning in the choral setting. However, it is worth noting that in the learning habits subscale, the majority of students (n = 9) exhibited lower scores after the course. This pattern will be further explored in the reflection section of this chapter.

Table 4.6

Results of the Wilcoxon Signed-Rank Test on Chorus A's Choral Learning Attitude Scale in Iteration 1

Subscale	Ranks	*n*	Mean Rank	Sum of Ranks	*z*	*p*	Effect Size
Learning Motivation	Neg.	3	4.0	12.0	-0.32	.752	-.10
	Pos.	3	3.0	9.0			
	Ties	4					
Learning Habits	Neg.	7	4.3	30.0	-1.71	.087	-.54
	Pos.	1	6.0	6.0			
	Ties	2					
Learning Behaviors	Neg.	2	3.3	6.5	-0.55	.581	-.17
	Pos.	2	1.8	3.5			
	Ties	6					
Learning Cognition	Neg.	5	4.3	21.5	-0.12	.905	-.04
	Pos.	4	5.9	23.5			
	Ties	1					

Note. n = 10 refers to the number of matched questionnaires collected for analysis.

Neg. = Negative; Pos. = Positive.

$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

4.5.2 Field Notes

This section summarizes key observations from the field notes, organized into four areas: (1) student thinking and prior knowledge, (2) group interaction and classroom dynamics, (3) instructional conditions and contextual challenges, and (4) noteworthy student engagement.

1. Student Thinking and Prior Knowledge (Slido Prompts). At the beginning of the first lesson, students engaged in a Slido word cloud activity after watching a video demonstrating overtone singing. In response to the prompt "What did you hear?", the most frequently mentioned words included “whistling sound” (n = 6), “Amazing Grace” (n = 4), and “overtone” or “harmonics” (total n = 6). Additional responses included analogical descriptions such as “sounds like a flute” (n = 3), “human voice” (n = 2), and remarks noting the presence of both high and low tones (n = 2). Some students submitted imaginative or humorous responses, such as “magical feeling,” “cow sound,” and “mosquito sound” (each n = 1).

Following this, students were asked a second question: “How did he do it?” The most common response was “I do not know” (n = 9). Other responses included general descriptions such as “singing” (n = 5), “just do it” (n = 3), and “use strength” (n = 4). Some students provided more specific answers, such as “changing mouth shape” (n = 3), “frequency” (n = 3), and “vocal cord vibration” (n = 2).

In a third Slido prompt, students were asked to identify the three elements of sound. Reported responses included “frequency” (n = 13), “timbre” (n = 10), and “loudness/amplitude” (n = 8). Six responses explicitly listed a complete combination of the three elements. Additional responses included related terms such as “waveform” (n = 3), “medium” (n = 2), and “wavelength” (n = 1). Some students entered unrelated or off-topic responses, including humorous comments or remarks referencing difficulty with physics content.

Throughout the Slido activities, responses were displayed in real time via word clouds visible to the entire class. Several entries appeared to repeat or closely resemble earlier responses, and several entries were similar in wording, suggesting that students referred to earlier visible responses when composing their own.

2. Group Interaction and Classroom Dynamics. Later in the first lesson, the teacher conducted a peer discussion activity using a multiple-choice question: “What is the principle of vocal sound production?” Students first responded individually, then engaged in group discussion before voting again. Students formed groups by self-selection rather than through pre-assigned heterogeneous grouping. During the follow-up sharing, only a small number of students volunteered to speak. The teacher restated students’ contributions in a neutral tone.

In several instances during the lesson, the teacher provided the correct answer shortly after posing a question, particularly when students did not respond immediately. Some questions were phrased in a way that indicated a specific correct answer. During these moments, few students offered responses or initiated discussion.

Overall, student responses during these discussion segments were limited, with participation observed from only a few individuals.

3. Instructional Conditions and Contextual Challenges. Due to temporary external obligations assigned on short notice, the collaborating teacher was unavailable for parts of the course. As a result, the researcher assumed teaching responsibilities from the end of Lesson 1 to the end of Lesson 2, and from the middle of Lesson 3 to the middle of Lesson 4. During these periods, the researcher was unable to take field notes, resulting in incomplete observational records.

The collaborating teacher, who also served as the conductor of Chorus A, was familiar with the students. Interactions during the sessions led by the collaborating teacher were characterized by a relaxed and informal atmosphere. Students occasionally responded to questions or smiled during instruction, but did not frequently initiate discussion or display overt enthusiasm without prompting.

Attendance varied across sessions. The first two lessons were conducted during regular club time; however, students who were not on the official roster of the club were unable to attend. The final two lessons were held after school, and several students left early due to private tutoring or other commitments.

4. Noteworthy Student Engagement. While most students demonstrated moderate levels of participation, a few exhibited notably high interest. One student, in particular, consistently demonstrated strong engagement throughout the lessons, frequently asking questions, responding actively to prompts, and showing curiosity about the subject matter. After class, this student, along with another peer, voluntarily approached the researcher to express interest in the topic. They inquired about the possibility of conducting further research.

These field notes provided insight into classroom dynamics, student engagement, and the implementation context of the course in Iteration 1.

4.5.3 Student Worksheets

In Iteration 1, we collected 23 pieces of worksheets, which roughly align with the number of students. The average completion rate of worksheets was .91 (SD = 0.14), while the average accuracy rate of worksheets was .54 (SD = 0.27).

Table 4.7 presents the completion and accuracy rates for each item on the worksheet. Overall, the completion rates were relatively high across all items, ranging from .83 to 1.00, indicating that most students attempted nearly all questions. Items 2 and 3-1 had the highest completion rates at 1.00, followed by items 1-2, 4-1, and 3-2 (all ≥ .87).

Table 4.7

Chorus A's Completion Rate and Accuracy Rate of Each Item on The Worksheet in Cycle 1

	1-1	1-2	2	3-1	3-2	4-1	4-2
Completion Rate	.87	.96	1.00	1.00	.87	.87	.83
Accuracy Rate	.40	.73	.30	.65	.30	.80	.74

Note. n = 23 refers to the number of worksheets collected for analysis.

1-1 refers to the first item of Lesson 1, 3-2 refers to the second item of Lesson 3, and Lesson 2 includes only one item.

In contrast, accuracy rates varied more widely, ranging from .30 to .80. Notably, items 4-1 and 4-2 showed the highest accuracy rates (.80 and .74, respectively), suggesting stronger student understanding on those tasks. Meanwhile, items 2 and 3-2 had the lowest accuracy rates (.30), indicating that although these items were completed, students may have struggled with the concepts or reasoning required.

To further examine students' engagement with the course, we analyzed two types of qualitative data: open-ended worksheet responses and written reflections from each lesson. Four worksheet items were selected for thematic analysis based on accuracy patterns and conceptual demands. In addition, students' comments were grouped by lesson to identify recurring impressions, conceptual shifts, and emotional responses. The following sections present findings from these analyses.

1. Inference-Based Reasoning: Item 3-2. Item 3-2 had a relatively low accuracy rate (.30), indicating that many students encountered difficulty when asked to reason about a phenomenon that had not been explicitly addressed through direct instruction. The item asked: "*Why do overtone ratios differ?*" and required students to infer factors that influence the distribution of overtones in different sound sources. The expected response included one or more of the following: differences in material, sound production mechanisms, or the shape and structure of the resonating body.

Student responses varied widely. A portion of students mentioned only one of the expected factors, such as "material" or "vibration method," without further explanation. These responses were coded as incomplete. Another common type of response framed the question in reverse causal order. Many students wrote that overtone ratios differ because the timbre is different, using expressions such as "different timbre," "the sound is brighter or darker," or "the waveform is different." In these cases, students appeared to explain the cause of overtone variation in terms of its perceptual outcome, rather than identifying the physical properties that determine the overtone content itself.

2. Conceptual Interpretation of Vibrating Systems: Item 2. Item 2 also showed a low accuracy rate, as students were asked to explain how a real string vibrates in practice. The item appeared after a set of images used to distinguish between fundamental frequency, harmonic modes, and non-harmonic motion. Students were then prompted to record their ideas in response to the question: *"How does a real string vibrate?"* This open-ended task preceded any formal explanation and was designed to elicit students' intuitive models of vibration.

The expected answer was that the vibration of a real string is a combination of multiple standing wave patterns—i.e., a superposition of the fundamental and its harmonics. Students could demonstrate this understanding through either a verbal explanation or a drawing showing overlapping waveforms. However, most students provided only a single vibration pattern, typically depicting either the fundamental mode or a simplified curve without further elaboration. In many cases, there was no indication that students updated their answers after the correct explanation was introduced at the beginning of the following class.

3. Analogical vs. Physiological Reasoning: Items 1-1 and 1-2. Items 1-1 and 1-2 were both presented during the first lesson and addressed sound production mechanisms. The contrast in student performance on these two items highlights differences in how students responded to analogy-based prompts versus everyday physical phenomena.

Item 1-1 asked: *"The word 'organ' refers to both the pipe organ and human body parts. What connection do you think exists between them?"* The expected answer was that both share a similar sound production principle, involving airflow that causes vibration. While some students provided partially correct responses, such as noting the presence of air passages or referencing airflow, many responses misrepresented the mechanism. For example, some wrote that both have "space for resonance" or that "air flows through a pipe," framing the similarity in terms of physical form or resonance rather than the source of vibration.

Item 1-2, in contrast, asked: *"Why does the voice tend to sound lower when you are tired or have just woken up?"* The expected explanation was that the vocal folds are in a relaxed state, leading to slower vibrations and thus a lower pitch. Most students provided responses aligned with this idea, mentioning vocal fatigue or lack of muscle tension. However, a few students described only the preceding condition (e.g., "just woke up" or "overused") without explicitly stating the resulting change in the vocal fold's state. For example, some wrote that the voice is low because the vocal folds were "not yet warmed up" or "exhausted," without linking this to reduced tension or slower vibration.

4. High-Accuracy Conceptual Recall with Misapplied Mechanism: Item 4-1. Item 4-1 yielded the highest accuracy rate (.80), suggesting that most students were able to recall the central concept emphasized during the lesson. Following an overtone singing demonstration video, students were prompted to explain how the performer achieved the distinctive sound. The expected response was that the singer adjusted the size or shape of the resonating cavity, such as the oral cavity or vocal tract—a concept explicitly addressed during instruction.

Most students referred directly to this idea, using expressions such as “changing the oral space” or “adjusting the resonance cavity.” Because the scoring criterion focused solely on identifying this core concept, the majority of responses were considered correct, resulting in a high accuracy rate. A small number of students extended their answers by attempting to explain the mechanism behind the phenomenon. These responses often described the action as a way to control or produce overtones. Some wrote that changing the shape of the mouth “controls the overtones,” or that “manipulating the space creates the overtones.” These responses did not match the intended mechanism but showed attempts to elaborate beyond the expected answer.

5. Student Reflections on the Lessons. To complement the worksheet analysis, we collected open-ended feedback from students after each lesson. The following section summarizes recurring themes based on students’ written comments, categorized by lesson.

Lesson 1: The Nature of Human Voice. Many students commented on the novelty and visual impact of the vocal fold video. Several described it as “very interesting,” “cute,” or even “a bit uncomfortable,” reflecting a strong affective response. Responses such as “first time seeing vocal folds,” and “watching how the vocal cords work was very special” suggest that the anatomical perspective sparked interest. A few students also noted that the discussion helped them address personal curiosities, with one stating, “This answered a question I have had for a long time!”

Several responses also mentioned that the lesson encouraged them to think about sound production in new ways, including how instruments work, or how sound originates in the body.

Lesson 2: The Principle of Overtones. A recurring theme in this lesson was the use of jump ropes as a physical model for wave behavior. Students described the demonstration as “fun,” “vivid,” or “a good way to visualize textbook physics.” Many explicitly referred to the experience of “seeing standing waves,” or noted that “swinging the rope helped me understand how standing waves form.”

While many found the activities engaging, a few students expressed confusion regarding key distinctions, such as between fundamental and overtone frequencies. One student wrote, "I still do not quite understand the difference between fundamental and overtone." Others commented that the lesson felt similar to a science subject review, with one writing, "It feels like a subject-based review, and physics is not fun—it is hard."

Lesson 3: The Causes of Timbre. Several students highlighted the demonstrations with different instruments, particularly guitars, as helpful in illustrating how timbre changes. One student noted, "The theme was lively with different guitars." Others remarked that they were surprised to learn that "timbre comes from differences in overtones," and that they "never knew overtones could explain why instruments sound different."

Some responses also reflected personal engagement with musical aesthetics. For example, one student remarked, "I realized I do not like the sound of the trumpet," while another wrote, "It was interesting to hear different tones from the same type of instrument."

Lesson 4: The Selection of Resonance. Students frequently mentioned the overtone singing video and the guest instructor's demonstration, using expressions such as "the old man was amazing" or "the conductor was impressive." These responses suggest that the live demonstration had a strong impact, both cognitively and emotionally.

One student wrote, "I finally understood how overtones are produced—this answered the question from the first class," linking this lesson back to an earlier conceptual gap. Another response proposed a practical classroom application: "When teaching choral music, we could let students first feel the emotional effect of different harmonies to build interest."

Overall Course Reflections. In the course-end feedback, students frequently used words like "interesting," "new," or "magical." Many appreciated learning about overtones and resonance, particularly how these concepts linked physics with music. One student commented, "I learned things we never covered in music class before," while another wrote, "Now I better understand the relationship between physics and music."

Some students expressed cognitive overload from the course pacing, noting that a short break might be helpful in a three-hour session. Others reflected on their limitations, writing, for example, "There was much new knowledge, and I now see that I need to improve my science ability."

A few students asked follow-up questions, such as: "So does being able to sing overtones mean that you are singing in tune?"—suggesting that the course stimulated ongoing curiosity.

Summary. The analysis of worksheet responses and student reflections revealed varied patterns in recall and reasoning. Students were generally able to reproduce key terms and concepts when these were directly emphasized in instruction. Items requiring inference, explanation of mechanisms, or application to unfamiliar contexts showed lower accuracy rates and more diverse responses.

In written reflections, students frequently commented on specific demonstrations, hands-on activities, or new concepts they encountered. Comments included expressions of interest, novelty, and in some cases, confusion or difficulty. Some students highlighted elements they found enjoyable or memorable, while others noted challenges in understanding or sustaining attention across longer sessions.

4.5.3 Teacher Interview

This section presents findings from the post-lesson interview with Teacher Z, organized by key themes. These reflections provide insight into how the course was perceived and experienced from the teacher's perspective, informing both the evaluation of Implementation 1 and the refinement of subsequent course designs. Although the interview protocol included a question about teaching material preparation, Teacher Z did not offer substantive comments on that topic; therefore, it is not discussed in the following sections.

1. Course Design. Teacher Z expressed that the overall course design required stronger continuity between lessons. Although worksheets were originally intended to serve as a bridge from one session to the next, their connective function was not sufficiently clear to students. Z suggested that transitions should be made more deliberate to reinforce coherence.

Additionally, Z emphasized the value of incorporating interactive activities, noting that students, especially those in the chorus, responded more enthusiastically to participatory tasks such as the jump rope swinging activity. These experiences seemed to enhance engagement, particularly because chorus members are typically more reserved and reluctant to stand out. Z believed that embedding similar interactive elements in each lesson could help sustain students' interest, even if adjustments to the teaching materials are necessary.

However, Z also raised concerns about the depth of the course content, observing that for students from the first academic track, some of the scientific concepts felt too abstract or lacked personal relevance. While recognizing the challenge of meeting the needs of diverse learners, Z pointed out that the majority of chorus students belong to the first academic track, and future curriculum design should take this into account.

2. Teaching Activities. When it came to discussion-based activities, Teacher Z observed that students often tended to limit themselves. They were less likely to express their thoughts if they heard others speak first, suggesting a concern about conforming or not wanting to stand out. In response, the researcher suggested using strategies that prevent students from answering the same question or being influenced by peers' responses too early in the process. This approach could encourage more independent thinking and reduce the pressure to follow others' ideas.

3. Students' Responses. Teacher Z observed that the classroom atmosphere was livelier than in regular chorus rehearsals. Without the usual emphasis on vocal technique, students appeared more at ease and participative. Z also shared that on the day of the lesson, some students showed genuine interest—two of them even approached the researcher afterward, expressing a desire to pursue further research related to the topic.

4. Post-Course Observations. In post-lesson rehearsals, Teacher Z noted that while improvements in vocal technique are often difficult to observe immediately, students demonstrated a clearer understanding of musical terminology. When discussing concepts like overtones or chords, they appeared more confident and attentive. Z also reported that students responded more effectively to feedback, such as adjusting dynamics or balance during rehearsals.

Regarding timbre, students showed heightened awareness of how changes in mouth shape and resonance space affect vocal quality. This increased sensitivity was seen as an outcome of the course's focus on acoustic concepts.

5. Others. Teacher Z and the researcher both noted that late arrivals and early departures affected learning and data collection. Z emphasized the need for full student participation in future lessons. The researcher also remarked that while a single three-hour session reduced scheduling complexity, it risked losing student attention. They discussed the possibility of splitting the course into two shorter sessions and adjusting the content accordingly.

The lessons were conducted in a noisy environment, with disturbances from nearby wind band and honor guard practices. Although a theater space had been considered, it lacked essential teaching equipment.

Teacher Z also pointed out that some students struggled with course content, and that the challenge might be even greater at other schools. The researcher, however, argued that since the topic was new for everyone, prior knowledge was not a major barrier. Both agreed that students at School A had been conditioned by exam-oriented training and might require more support to engage in open-ended thinking.

Additionally, they discussed the challenges of separating course design and delivery roles. While Teacher Z was familiar with the materials, unexpected classroom disruptions hindered the lesson flow. The researcher proposed preparing a detailed teaching script or conducting trial lessons to help instructors gain confidence and improve continuity. Teacher Z supported this idea, suggesting that a teacher's manual that included key instructions and anticipated student responses would be especially useful for less experienced educators.

Both parties reflected on teaching consistency and responsiveness. The researcher noted that their questioning style became more directive after re-entering the classroom following an interruption, which may have discouraged student participation. Teacher Z affirmed the importance of maintaining professional presence and flexibility.

In discussing teaching style, Z reflected on how traditional choral training had deprioritized spontaneous engagement:

"I have kind of tucked that part away. However, if I become more aware of it, maybe I

can bring it back out. It is not that I do not know how to use it—it is just that I do not use it often anymore. My current job does not call for it, so I have locked it away.”

(Teacher Z, personal communication, April 3, 2024)

In moments of realization, Z observed that students became visibly more engaged. As Z described:

“Some of them were engaged—when they noticed something they had not realized before. Once you pointed it out, their eyes lit up. It is like they always knew it, but never really saw it until then.”

(Teacher Z, personal communication, April 3, 2024)

These moments underscored the course's goal of making scientific ideas feel familiar and personally relevant. Both teacher and researcher emphasized the importance of helping students connect new knowledge to their existing experiences and expressed interest in making complex ideas more accessible without oversimplification.

Summary. The interview with Teacher Z provided valuable insights into both the strengths and limitations of the first implementation. Z affirmed the overall value of the course, particularly its emphasis on interactive learning and its focus on timbre, which aligned well with the needs of chorus students. However, Z also noted the need for stronger continuity between lessons and raised concerns about the accessibility of certain scientific concepts for students in the first academic track.

Throughout the interview, both the teacher and the researcher emphasized the importance of balancing depth and accessibility. Several instructional strategies—such as the use of interactive activities, relatable examples, and gradual conceptual scaffolding—were identified as effective in maintaining student engagement. Z also reflected on the students' improved understanding of musical concepts such as overtones and resonance, which became more evident in post-lesson rehearsals.

Contextual challenges such as inconsistent student attendance, environmental noise, and the division of course design and instruction roles were also acknowledged. These factors influenced both the implementation process and the perceived effectiveness of the lessons. Moreover, the discussion highlighted the value of detailed teaching scripts and trial runs to support instructors with less formal pedagogical training.

Finally, the interview revealed moments of strong student engagement, especially when students discovered new connections between abstract concepts and their prior experiences. These observations reinforced the course's goal of making scientific ideas feel tangible, relevant, and applicable to students' musical practice. In the latter part of the interview, Teacher Z also engaged in a collaborative review of the lesson design. This portion of the discussion focused on identifying areas for improvement and exploring ways to adapt the instructional flow, which will be further elaborated in the following reflection section on Iteration 1.

4.6 Reflection

This section provides a comprehensive reflection on the first iteration of the interdisciplinary course. Drawing from multiple sources—including student work, classroom observations, field notes, and a post-course teacher interview—it examines both the instructional design and the research implementation. The reflection is structured into three main areas: course design (4.6.1), research design (4.6.2), and additional insights (4.6.3). Each subsection highlights lessons learned and identifies opportunities for improvement, laying the foundation for the refinement of future iterations.

4.6.1 Course Design

This section provides a comprehensive reflection on the design and implementation of the interdisciplinary course developed for Iteration 1. Drawing on multiple data sources—including student worksheet responses, classroom observations, and a post-course interview with the collaborating teacher—the analysis focuses on five key aspects of the course design: content appropriateness, instructional methods, instructional activities and teaching materials, time allocation, and teacher preparation. Each subsection highlights areas of success, identifies instructional challenges, considers contextual factors, and proposes directions for improvement. The goal is to refine the curriculum for future iterations and to explore how such interdisciplinary teaching strategies can be made more accessible and scalable for music educators.

1. Content Appropriateness. A key strength of the Iteration 1 course design was its clear thematic focus on timbre, which proved highly relevant to students in a chorus setting. Unlike pitch or volume—commonly emphasized in chorus training—timbre is often underexplored, despite being critical to ensemble blending and expression. By centering the course on how resonance shapes timbre and using overtone singing as an anchor phenomenon, the lessons offered students a fresh lens to understand their voices. Timbre, as both a perceptual and physical construct, offered a unique interdisciplinary bridge, allowing students to explore how abstract acoustical principles shape real-world artistic expression. Evidence of successful knowledge retention appeared in students' written responses (e.g., high accuracy on Worksheet Item 4-1), and Teacher Z reported noticeable improvements in students' attentiveness to timbre and resonance during post-course rehearsals.

However, some of the scientific concepts embedded in the course, such as waveform superposition and overtone ratios, proved too abstract for many students. Tasks that required students to infer physical causes (e.g., Worksheet Item 3-2) or reason beyond direct instruction often resulted in low accuracy or vague explanations. While the course succeeded in introducing basic concepts such as pitch, loudness, and timbre, it became evident that deeper understanding was limited when students were asked to make causal connections or apply knowledge to unfamiliar contexts.

Teacher Z initially attributed this difficulty to the large proportion of students from the first academic track, who are generally perceived as less exposed to scientific content. However, demographic data showed that students were evenly distributed across all three academic tracks. A more plausible explanation, proposed by the researcher, was that most acoustics-related topics in the national physics curriculum, such as standing waves or overtones, are introduced only in the first semester of Grade 12. Since the participants were in Grades 10 and 11, likely, they had not yet encountered these concepts in formal instruction, contributing to their struggle with more abstract content.

Despite efforts to make the content accessible through analogies, demonstrations (e.g., jump rope activities), and visual aids, these strategies were not always sufficient. The complexity of some topics, particularly those requiring conceptual transfer, remained a challenge for many. Moving forward, future iterations should retain the timbre-centered framework but simplify the conceptual trajectory. For example, instead of introducing mathematical explanations of harmonic series, the curriculum could prioritize multisensory comparisons (e.g., listening to different instruments) and draw from students' everyday experiences (e.g., the echo in a bathroom vs. a closet). Furthermore, reviewing foundational concepts like pitch and volume before diving into timbre may help students better differentiate the three and build a more coherent understanding of voice production.

2. Instructional Methods. In the initial design of the course, a variety of instructional strategies were incorporated, including group discussions, peer collaboration, anonymous response tools, and visual aids. Some of these methods proved effective, especially the use of Slido, which allowed students to share ideas without pressure and provided insight into their intuitive understandings of vocal phenomena.

However, during implementation, it became clear that student participation was limited during open-ended discussions and group tasks. In several instances, questions posed by the teacher or researcher were met with silence or minimal response, often dominated by a few outspoken students. When questions seemed to imply a "correct" answer or when the instructor revealed the solution too quickly, students were less inclined to offer their thoughts. While collaborative learning can theoretically promote deeper engagement, it may not be effective when students lack confidence or background knowledge, leading instead to cognitive disengagement.

The instructor's professional background also shaped this challenge. In the post-course interview, Teacher Z admitted feeling unfamiliar with teaching methods that involved student-led discussion, exploratory questioning, or indirect instruction. He explained that choral conducting training typically emphasizes rehearsal techniques and musical interpretation, but rarely includes formal pedagogical training. From the researcher's perspective, this reflects a broader pattern: chorus conductors are not required to have formal education credentials, and many have limited exposure to instructional strategies or educational theory. As a result, when placed in teaching contexts that demand facilitation, scaffolding, and adaptive questioning, they may feel underprepared or uncertain.

In light of these challenges, the next iteration of the course will shift from a collaborative learning approach to a more structured, teacher-centered model of direct instruction. In practice, this will involve explaining scientific concepts, supporting them with videos and demonstrations, and guiding students through increasingly complex ideas. This shift is intended to reduce students' anxiety about being "wrong," improve conceptual clarity, and provide a more manageable framework for instructors without a science background. Ultimately, this adjustment enhances both the feasibility of implementation and the potential for future adoption by music educators in similar contexts.

To further support instructors, future iterations should include clear teacher scripts and visual guides that outline key moments for explanation, demonstration, and check-for-understanding. Rather than relying on open-ended group inquiry, the revised model will focus on structured questioning and guided responses to scaffold students' learning process.

3. Instructional Activities and Teaching Materials. The instructional activities in Iteration 1 demonstrated a commendable level of variety and coherence. Hands-on experiences such as the jump rope demonstration and sound comparison tasks effectively transformed abstract acoustic concepts into tangible learning experiences. For instance, when introducing standing waves and overtones, the jump rope activity helped students visualize nodes and waveforms while also increasing engagement. Teacher Z noted that these types of interactive activities were particularly effective in drawing interest from chorus students, who are typically more reserved in classroom settings.

However, certain activities did not achieve the intended learning outcomes. For example, while the "fruit-sorting machine" video was a creative analogy for overtone selection, students struggled to understand its underlying mechanism and how it related to sound filtering. Similarly, the visualizations of waveform superposition and frequency spectra, though scientifically accurate, were difficult for students to comprehend in a short time. Many were unable to connect these representations to their auditory experience, and worksheet performance suggested this was one of the most challenging sections of the course.

One key takeaway from the qualitative analysis of worksheet responses was that abstract content needed to be paired with more concrete and tactile experiences. While the design initially included several visual simulations, these were not always sufficient to support students' conceptual understanding. Students' written reflections revealed that they felt more engaged and understood the content better when activities involved movement, physical interaction, or direct auditory comparison.

To improve the effectiveness of instruction, future iterations will emphasize the use of physical teaching aids and hands-on interactive activities. Compared to purely visual simulations or lecture-based explanations, physical interaction allows students to engage with concepts through bodily movement and multisensory input. This approach aligns well with the learning preferences of chorus students, who often learn through experiential and sensory means. For example, manipulatives could include overtone resonance models, sound masking challenges, or physical resonance box comparisons. These tools can help students transition from intuitive perception to conceptual understanding, building a concrete foundation for grasping complex acoustic principles. By making learning "doable, feelable, and explainable," such activities are expected to enhance both conceptual depth and motivation for application.

4. Time Allocation. The course was implemented in a three-hour workshop format, which allowed for the full integration of the originally designed four-lesson structure. This approach offered the advantage of covering a broader range of content and presenting conceptual progression in a single session. However, several challenges emerged during implementation. First, many students exhibited signs of decreased attention and fatigue in the latter part of the course, which affected both their participation and the quality of their worksheet responses. Observational data and worksheet analysis indicated that responses during the final lesson were noticeably more concise, with reduced engagement during discussions. Teacher Z also reported that students required repeated prompting to stay focused, suggesting that the continuous three-hour schedule posed a substantial cognitive load.

Moreover, the three-hour format did not align with the school's existing chorus schedule, which is limited to two class periods. To accommodate the extended lesson, the course had to continue after regular school hours, resulting in some students leaving early and missing key instructional segments. This scheduling mismatch not only compromised the consistency of student participation but also created additional challenges for classroom management and data collection.

Although the full content of the original four lessons was retained, it was difficult for both the instructor and students to maintain a coherent instructional rhythm. Transitions and recaps between lesson segments were compressed, which disrupted the natural flow of teaching and made it harder for students to grasp the connections between ideas. Teacher Z noted that some learning activities were rushed or skipped due to time constraints, limiting opportunities for reflection and consolidation.

Based on these observations, the course structure will be revised in future iterations to a two-lesson, 100-minute version. This more manageable format will focus on reorganizing the core content and integrating key hands-on activities, while aligning with the school's standard class schedule. It is expected that this adjustment will enhance student attendance and engagement, improve instructional pacing, and strengthen conceptual connections without overburdening either students or teachers.

5. Teacher Preparation and Support. Throughout the design and implementation of the course, the researcher and Teacher Z maintained close communication and collaboration. Before the course, they engaged in multiple discussions to align the instructional focus, structure, and pacing. After the lessons, they conducted a reflective interview, establishing a reciprocal and developmental dialogue. Although Teacher Z came from a music background and had no formal training in education, he demonstrated adaptability and a strong willingness to collaborate. He was familiar with the context of choral teaching, provided practical suggestions for activities suitable for the students, and quickly grasped the overall structure of the course.

However, during implementation, the researcher observed some challenges in applying specific teaching strategies, particularly in areas such as classroom questioning techniques, guiding student responses, and addressing more abstract concepts like waveform superposition and overtone filtering. In the interview notes, the researcher frequently explained the instructional rationale behind various strategies to Teacher Z—for instance, why the course began with a Slido activity, why student questions were sometimes redirected to peers, or why certain ideas were intentionally left unresolved to carry over into the next lesson. These conversations not only helped Teacher Z clarify how to use the materials but also prompted him to reflect on his teaching style and students' reactions.

Additionally, the more difficult parts of the course, such as the relationship between standing waves and overtone proportions, were frequently discussed by the teacher and researcher. Together, they explored ways to simplify terminology, substitute teaching tools, or reorder activities to reduce the teacher's cognitive load during instruction. Teacher Z expressed that while he had strong motivation to teach, content with a heavier emphasis on scientific theory could be daunting without someone to help break it down, reframe it, and align it with student thinking.

These experiences highlight that the success of an interdisciplinary course depends not only on the feasibility of the lesson design but also on the availability of structured support for instructors. For future implementations, it is recommended to develop a visually supported teacher's manual that includes sample student responses, common misconceptions, key moments for classroom interaction, and suggested language for guiding discussions. When resources allow, opportunities for rehearsal or access to recorded model lessons could further enhance teacher confidence and their ability to adapt instruction in real time, ultimately supporting broader scalability of the curriculum.

Summary. In summary, the first iteration of the course demonstrated strong conceptual coherence and relevance to chorus students, particularly through its focus on timbre as an interdisciplinary anchor. While hands-on activities and structured materials enhanced engagement, challenges emerged in facilitating abstract scientific understanding, sustaining attention in a condensed format, and supporting instructors unfamiliar with science pedagogy. These findings underscore the need for simplified content trajectories, direct instruction models, and enhanced teacher support materials. Insights from this iteration not only informed key revisions for future implementations but also highlighted broader considerations for adapting interdisciplinary instruction to music education contexts.

4.6.2 Research Design

Beyond the course design itself, the first iteration of the study offered valuable insights into the research instruments and implementation strategies used for data collection and evaluation. While many tools proved useful, particularly the science interest scale and student worksheets, others revealed limitations in their sensitivity or alignment with the course objectives. This section reflects on the methodological aspects of the study, including participant composition, the utility of various instruments, and opportunities for improving data quality and relevance. These reflections not only inform the next iteration of this interdisciplinary course but also offer broader implications for conducting classroom-based educational research in music and science integration.

1. Participant Scope and Implementation Frequency. The first iteration of this study was conducted within a single high school chorus, led by the collaborating teacher with whom the researcher has established a working relationship. This context allowed for smooth coordination and detailed data collection, as the researcher was familiar with the students' learning environment, group dynamics, and instructional culture. Such conditions were beneficial for piloting a new interdisciplinary course, as they provided a stable and responsive setting for observing how students engaged with science-infused vocal instruction.

However, the participant sample was relatively homogeneous, comprising only female students from a single public high school in northern Taiwan, all members of the same extracurricular chorus. This limited diversity restricts the generalizability of findings. It hinders the evaluation of the course’s adaptability across other student populations, such as mixed-gender groups and those with differing levels of musical training. Similarly, the course was implemented only once, which limited the researcher's ability to assess whether any modifications to the course design would lead to improved outcomes. Without iterative testing, it is difficult to determine whether specific changes in content, pacing, or instructional strategy contribute to enhanced student engagement or understanding.

These constraints were shaped by the practical realities of school scheduling and the need for the collaborating teacher, who had no formal science background, to become familiar with the materials. Nonetheless, from a DBR perspective, the course would benefit from implementation across a more heterogeneous sample and under the guidance of different choral instructors. This would allow researchers to examine how teacher background and instructional style interact with the course content. Furthermore, multiple iterations would support the core DBR cycle of design, enactment, analysis, and refinement. Future studies should aim to implement the course in diverse school settings, with varied student demographics, and across at least two instructional rounds. Doing so would strengthen both the empirical robustness and practical applicability of the curriculum.

2. Instrument Refinement: Pre-/Post-Questionnaires. Three self-report instruments were used in this study: the Science Learning Interest Scale, the Music Learning Interest Scale, and the Choral Learning Attitude Scale. All were adapted from validated instruments with established reliability and construct validity. Minor modifications were made to contextualize the items for this interdisciplinary course.

Among the three, the Science Learning Interest Scale proved most informative. One of its subscales—maintained situational interest-feeling—showed a statistically significant increase after the course, suggesting that the curriculum had a positive emotional impact on students' engagement with science. This aligns well with the affective objective of the course.

In contrast, none of the subscales in the Music Learning Interest Scale and the Choral Learning Attitude Scale showed statistically significant changes, and the differences between pre- and post-scores were minimal across all dimensions. One plausible explanation is the small sample size, which limits the statistical power to detect meaningful progress. Another explanation is that students already exhibited moderately high levels of interest before the course. For example, the pre-course average scores on the Music Interest Scale ranged from 15.9 (task-based interest) to 20.4 (knowledge-based interest) out of a maximum of 25 points, indicating generally favorable attitudes toward music learning. With such high baseline levels, there was limited room for further improvement, suggesting that the instruments may have been subject to a ceiling effect—particularly within a highly motivated and self-selected chorus population.

Furthermore, the content of the music and choral attitude items had only partial overlap with the interdisciplinary focus of the course. Since the instructional emphasis was on acoustics and voice science rather than general music appreciation or choral rehearsal routines, students may have found it difficult to relate their course experience to the constructs measured in the questionnaires.

Based on these observations, future iterations of the study should retain the Science Learning Interest Scale as the primary quantitative instrument, while removing or replacing the other two. Open-ended questions or brief feedback surveys may serve as more appropriate tools for capturing students' evolving perspectives on music and chorus learning. For example, questions like "How has this course changed your understanding of singing?" or "Can scientific knowledge help you sing better?" may yield more specific and relevant insights aligned with the course's objectives.

3. Instrument Refinement: Field Notes. During the course implementation, the researcher took concurrent field notes to document teacher-student interactions, student responses, instructional flow, and situational factors. These notes offered rich firsthand data that contributed to contextualizing classroom dynamics and interpreting the effectiveness of various teaching activities. They were particularly helpful in identifying moments of high student engagement and areas where instructional difficulties emerged, thereby supporting later stages of interview analysis and curriculum revision.

However, the field notes were not organized using a predetermined structure or coding scheme. Entries were largely descriptive and open-ended, requiring substantial post-hoc interpretation and synthesis by the researcher. Additionally, although the researcher originally intended to act solely as an observer, an unanticipated scheduling conflict required them to temporarily assume teaching duties, resulting in gaps in observation during parts of the course.

In preparation for future iterations of the course, field note documentation will adopt a more structured approach, using the lesson plan as a guiding framework. The focus will shift toward observing the teacher's instructional execution, such as delivery style, scaffolding techniques, and classroom language. At the same time, student responses will be noted as supplementary indicators to assess implementation fidelity and instructional clarity.

To enhance the analytical utility of the notes, a semi-structured recording template is recommended, with predefined observation categories for each teaching segment, including teacher prompts, student engagement levels, and common misconceptions. Given ethical considerations and the realities of classroom settings, this study does not employ video or audio recordings. Instead, future implementations may incorporate a secondary observer to assist with documentation and ensure more comprehensive coverage when the researcher is actively teaching.

4. Instrument Refinement: Student Worksheet. In this study, open-ended worksheets were administered after each lesson to evaluate students' conceptual understanding and encourage reflection. Overall, the worksheets served as an effective tool for prompting students to organize their thoughts, record their ideas, and provide the researcher with valuable insight into both cognitive progress and affective responses. Some items, such as Item 4-1 (overtone singing), elicited accurate and focused answers, indicating students had grasped the core concepts emphasized during instruction.

However, other items—particularly Items 3-2 and 2-1—showed low accuracy rates. These questions required students to infer mechanisms that were not explicitly taught or to extend abstract ideas beyond familiar contexts. Analysis of student responses revealed common misconceptions, such as explaining outcomes in reverse causal order (e.g., "the overtone ratio is different because the timbre is different") or failing to connect sensory experiences to physical principles (e.g., misunderstanding the superposition of standing waves). These difficulties suggest that item complexity should be more closely aligned with students' prior knowledge and the instructional trajectory.

Beyond conceptual questions, the qualitative feedback collected through worksheet reflections provided additional insight. Many students commented on the emotional and sensory impact of specific activities. For example, some described the vocal fold video as "interesting" or "a little gross," and others called the jump rope demonstration "fun" or "a good way to understand textbook physics." Responses to instrument demonstrations and overtone singing videos included remarks such as "I finally understood" and "I learned something never taught in music class before," illustrating how experiential learning elements helped foster engagement and cross-domain connections. Still, some students expressed difficulty keeping up with the lesson pace or grasping the scientific content, writing that "there was much new information" or that "physics is still hard," offering useful feedback for adjusting lesson depth and pacing.

In future implementations, worksheet design should adopt a scaffolded structure that separates observational description from conceptual explanation. Visual cues, multiple-choice scaffolds, or comparative prompts may help students bridge the gap between experience and theory. Additionally, reflection-based prompts might be better integrated with in-class discussions or peer-sharing sessions to enhance students' motivation and willingness to express ideas. Ultimately, to maximize the effectiveness of worksheets, their design must be tightly coordinated with lesson activities to support both conceptual clarity and learner engagement.

5. Instrument Refinement: Teacher Interview. This study originally adopted a semi-structured interview protocol to explore the teacher's perspectives on course design, instructional activities, student responses, and post-lesson observations. However, during the actual interview, it became apparent that the original questions, though comprehensive in scope, were too general to elicit detailed teaching recollections or implementation experiences. When faced with abstract or open-ended prompts, the teacher tended to offer brief or generalized responses, limiting the researcher's ability to reconstruct the classroom context in depth.

In the latter part of the interview, when the conversation shifted to reviewing the lesson materials in sequence, the teacher was able to recall more specific instructional steps and student reactions. This approach facilitated more concrete reflections, and the researcher was able to clarify what occurred in the classroom by referencing both the instructional slides and field notes. These contextual cues helped the teacher provide richer descriptions and offer targeted suggestions for improvement.

As a result, future iterations of the teacher interview process will adopt a revised structure. Rather than beginning with general reflection questions, interviews will be organized around a lesson-by-lesson walkthrough of the teaching materials, supported by classroom observation notes to prompt memory, and only after this step-by-step review will the discussion shift to broader topics such as instructional effectiveness, course adjustments, and feedback on teaching strategies. This sequencing is expected to enhance teacher engagement and improve the quality and specificity of interview data.

Summary. The first iteration revealed both the strengths and limitations of the research design. While instruments such as the Science Learning Interest Scale and student worksheets provided valuable data, others, like the music interest and choral attitude scales, suffered from ceiling effects or misalignment with course content. Field notes and teacher interview generated rich insights, but would benefit from more structured protocols and sequencing. The homogeneous participant group and single implementation round also limited generalizability. Future iterations should aim for broader sampling, repeated implementation, and refined data collection tools that better align with the interdisciplinary goals of the course. These adjustments will enhance both the validity of findings and the transferability of the instructional model.

4.6.3 Others

In addition to the core aspects of the course and research design, Iteration 1 revealed two unexpected yet insightful areas of reflection. First, the collaborating teacher began to reconsider his professional role, gradually shifting from a conductor-centric perspective toward that of an educator. Second, a noticeable decline in students' self-reported choral learning habits emerged, suggesting a recalibration of their self-perceptions rather than a regression in behavior. Though not the primary focus of the study, these developments highlight the broader influence of interdisciplinary course implementation and underscore the value of attending to peripheral yet meaningful changes in participants' identities and attitudes.

1. Teacher's Evolving Professional Identity. During the implementation of the course, an unexpected yet noteworthy shift was observed: the collaborating teacher began to reflect on and gradually embrace the role of an "educator." Teacher Z, who was trained as a choral conductor, possessed extensive experience in music performance but had never received formal pedagogical training. As a result, he initially positioned himself primarily as a rehearsal leader and performance coach rather than a classroom instructor. However, through repeated discussions with the researcher, particularly regarding instructional strategies, activity sequencing, and presentation methods, he not only became more familiar with the rhythm of teaching but also started to consider how students were processing the material and engaging with the lessons.

In the follow-up interview, Teacher Z mentioned that he had rarely thought about "how to teach" in the past. However, this collaboration prompted him to seriously consider how students' understanding developed and how their classroom responses could inform instructional decisions. He even began to imagine ways to incorporate simple teaching strategies into regular rehearsals. Although the primary focus of this study was not teacher professional development, the collaborative process appeared to foster a shift in Teacher Z's professional identity and instructional mindset. This suggests that co-designing interdisciplinary courses may hold potential for supporting the growth of music teachers and expanding their pedagogical practices.

2. Reframing the Decline in Choral Learning Habits. The second point of reflection concerns the observed decline in students' post-test scores on the "learning habits" subscale of the Choral Learning Attitude Scale. Nine students showed lower scores after the course. Rather than interpreting this as a negative outcome, the researcher views this shift as a result of students' increased self-awareness and recalibration of their self-assessment. Through the course, students' perception of their learning behavior became more grounded, shifting from idealized self-evaluations to more realistic and reflective judgments.

Items in the learning habits subscale—such as "I actively seek out extracurricular resources related to choral singing" and "I ask the teacher questions based on my interests"—require both initiative and depth of engagement. The interdisciplinary nature of the course, which introduced scientific content, teaching activities, and reflective worksheets, prompted students to examine their choral learning from a new perspective. In doing so, many came to realize their limitations in proactively exploring or inquiring beyond the standard repertoire.

This interpretation is supported by students' qualitative feedback on the worksheets. Several students noted that they had "never thought about the science behind the voice," that "overtones affect timbre," or that they were "still not good at controlling resonance spaces." These reflections suggest that the course sparked a recognition of previously overlooked dimensions of their learning. As a result, students approached the post-course self-assessment with greater caution and self-honesty. While the shift in scores may appear negative at first glance, it in fact reveals an important developmental opportunity: although learning attitudes cannot be transformed overnight, the course successfully initiated a process of self-reflection and deeper awareness, laying the groundwork for future growth.

Summary. Though peripheral to the study's main objectives, the developments observed in Iteration 1 reveal broader impacts on both teacher identity and student self-perception. The collaborating teacher's evolving view of himself as an educator points to the transformative potential of interdisciplinary co-design in professional development. Simultaneously, the apparent decline in students' learning habit scores likely reflects a shift toward more honest self-evaluation, catalyzed by the course's novel content and reflective structure. These findings suggest that interdisciplinary instruction may serve as a platform not only for cognitive learning but also for personal and professional growth.

Chapter 5 Iteration 2

Three rounds for Iteration 2 were conducted with Chorus A, Chorus B, and Chorus C in the Fall semester of 2024. Iteration 2-1 was held with Chorus A around the middle of December 2024, while Iteration 2-2 and Iteration 2-3 were held two weeks later. Because that was the first semester of the school year, there was a certain ratio of new members in each chorus. Fortunately, there was a City Preliminary Round of the National Student Competition of Music and the same round of the National Competition of Folk Song for Teachers and Students before the implementations, so that all the students had at least one performance experience, which was less ideal than Iteration 1 but still acceptable.

5.1 Research Participants

To better understand how different educational contexts influence the implementation and outcomes of the interdisciplinary course, this study involved two collaborating teachers and three high school choruses in Iteration 2. The participating teachers brought distinct professional backgrounds and roles, ranging from direct instruction to observational support, offering varied perspectives on course delivery and classroom dynamics. The student groups represented a range of demographic, academic, and musical profiles, enhancing the study's capacity to explore how diverse learner characteristics interact with the instructional design. The following sections provide detailed descriptions of both the collaborating teachers and the student participants.

5.1.1 Collaborating Teacher – Teacher L

There were two collaborating teachers in Iteration 2, who were Teacher Z and Teacher L. Both of them are around 35 years old, and they both conduct more than three choruses, including high school clubs, social choruses, and church choruses. Teacher Z is the conductor of Chorus A and the teacher of each implementation, while Teacher L is the conductor of Chorus B and Chorus C.

Unlike Teacher Z, who taught the course, Teacher L only observed the course and accepted the interview, which could give opinions from an outsider's perspective. Teacher L does not have an academic background in Music, but he has been involved in choral music for a long time. Besides being a chorister, Teacher L has worked in a famous chorus in Taipei, organizing many concerts and activities. Chorus C is the first chorus that Teacher L guides in his conducting journey, and this year is the sixth year since Teacher L met Chorus C. On the other hand, Teacher L used to be the student conductor of Chorus B, and he was asked to be the conductor of Chorus B as an alumnus four years ago. Teacher L views students as peers rather than subordinates, so that his teaching style is unconventional yet more empathetic.

5.1.2 High School Students in Chorus

In Iteration 2, the interdisciplinary course was implemented in three different high school choruses across Taipei. These groups were selected to enhance contextual diversity and to examine the course's adaptability across varying educational environments. Each chorus differed in gender composition, school culture, and students' prior musical experience, allowing for a more nuanced analysis of how background variables might influence the effectiveness of the instruction. The following subsections introduce the three participant groups in detail.

1. Chorus A from School A. Considering the accessibility and the comparability, we chose the same chorus in Iteration 1, but the demographic information was different. The details are below:

Fifteen students participated in this group, and a total of 14 matched pre- and post-questionnaires were collected for analysis. All participants were female, with ages ranging from 15 to 16 (M = 15.9). The majority were 11th-grade students (n = 10), while the rest were in 10th grade (n = 4). In terms of academic track, five students were from the first track, three from the second track, three from the third track, and three were undecided.

Regarding their involvement in the chorus, four students had joined for one semester, two for two semesters, and eight for three semesters. Notably, some of them had taken the course in Iteration 1. As for their prior choral experience, one student had less than one year of experience, five had 1–2 years, one had 2–3 years, two had 3–4 years, three had 4–5 years, and two had 6–7 years.

2. Chorus B from School B. School B is a prestigious all-boys public senior high school located in Taipei City. With an enrollment of approximately 2,800 students, it is renowned for its academic rigor and selective admissions process. The school places a strong emphasis on holistic education, encouraging students to engage actively in extracurricular activities alongside their academic pursuits.

Chorus B is a male chorus, directed by Teacher L and supported by the school's music faculty. Rehearsals are held regularly after school, with additional practices scheduled before major events. The ensemble is known for its disciplined approach to both vocal technique and musical interpretation. Over the years, Chorus B has received numerous awards in regional and national choral competitions. This group provided a meaningful setting for exploring interdisciplinary teaching practices that blend scientific concepts with choral instruction.

Although 18 students participated in this group, a total of 14 matched pre- and post-questionnaires were collected and included in the analysis. All participants were male, with ages ranging from 15 to 17 ($M = 15.9$). The majority were 10th-grade students ($n = 8$), followed by 11th-grade students ($n = 6$). In terms of academic track, one student was from the first track, two from the second track, five from the third track, and six were undecided.

Regarding their involvement in the chorus, nine students had joined for one semester, two for two semesters, and three for three semesters. As for their prior choral experience, six students had less than one year of experience, one had 1–2 years, two had 2–3 years, two had 3–4 years, two had 4–5 years, and one had 7–8 years.

3. Chorus C from School C. School C is a co-educational public combined junior and senior high school located in a residential area of Taipei City. The school serves approximately 1,300 students and is recognized for its emphasis on student autonomy, interdisciplinary learning, and the cultivation of diverse talents. With a balanced focus on academics and the arts, the school encourages students to explore a wide range of interests through elective courses and extracurricular programs.

Chorus C is a mixed chorus composed of students with varied musical backgrounds. The chorus operates as an extracurricular club and is led by Teacher L. Rehearsals take place regularly after school, often intensifying before performances. Chorus C has participated in various local choral events and public performances and is characterized by its open and inclusive atmosphere.

Although 14 students participated in this group, a total of 9 matched pre- and post-questionnaires were collected and included in the analysis. The group consisted of seven females and two males, with ages ranging from 15 to 17 (M = 16.2). The majority were 11th-grade students (n = 8), with one student in 10th grade. In terms of academic track, three students were from the first track, one from the second track, four from the third track, and one was undecided.

Regarding their involvement in the chorus, three students had joined for one semester and six for three semesters. As for their prior choral experience, one student had less than one year of experience, four had 1–2 years, one had 2–3 years, one had 3–4 years, and two had 7–8 years.

5.2 Course Design

The revised interdisciplinary course for Iteration 2 was co-designed by the researcher and Teacher Z in response to the instructional challenges identified in the first implementation. Drawing on student performance data, teacher reflections, and logistical constraints, the new version aimed to simplify scientific content while enhancing physical engagement and instructional clarity. To increase feasibility and alignment with the school's schedule, the course was condensed from a four-lesson, three-hour workshop to a two-lesson, 100-minute structure. This shortened format allowed for better classroom integration and more focused delivery.

5.2.1 Learning Objectives

The core learning goals remained consistent with Iteration 1, emphasizing interdisciplinary outcomes across cognitive, affective, and psychomotor domains:

- **Cognitive Objective:** Students can analyze how physical principles such as airflow, frequency, and resonance apply to vocal production and tone modification.
- **Affective Objective:** Students can demonstrate increased ISL through active engagement with vocal acoustics.

- **Psychomotor Objective:** Students can apply techniques for adjusting vocal resonance, such as modifying the shape and size of resonance spaces, to improve timbre in singing.

Although the affective objective remained unchanged, the cognitive and psychomotor goals were slightly reinterpreted to emphasize practical application and reduce theoretical complexity.

5.2.2 Course Structure

To ensure feasibility within the constraints of a regular school schedule, the course structure for Iteration 2 was revised from a four-lesson (three-hour) format to a streamlined two-lesson (100-minute) model. While the thematic focus on timbre and vocal acoustics remained unchanged, the instructional content was reorganized to emphasize clarity, pacing, and hands-on engagement. Each lesson was designed to align with the updated learning objectives and to build directly on the experiences and challenges identified in the first implementation.

The revised structure retained the use of PhBL but replaced extended group discussions and theoretical explanations with guided demonstrations, analogical reasoning, and embodied learning experiences. Each lesson opened with an observable vocal phenomenon and proceeded through concrete analogies and scaffolded teacher-led explanation, culminating in opportunities for students to reflect on their vocal practice.

The two revised lessons were described as follows.

Lesson 1, Voice and Overtones, introduced the analogy between human vocal production and wind instruments using video demonstrations and a physical model of a trumpet mouthpiece. This was followed by a series of structured activities, including overtone labeling on keyboard diagrams and a hands-on jump rope demonstration to visualize standing wave patterns and overtone relationships.

Lesson 2, Resonance and Timbre, focused on the effect of resonance on timbre. It used comparisons between instruments of different body sizes (e.g., violin vs. double bass) to illustrate how resonance amplifies specific frequency ranges. Anatomical diagrams of the vocal tract were used to help students visualize internal resonance spaces, and overtone singing videos were revisited to prompt students to connect resonance manipulation with changes in vocal timbre.

This restructured course sequence aimed to maximize accessibility, reduce cognitive overload, and provide students with intuitive and practical entry points into vocal acoustics. The simplified progression allowed more instructional time to be spent on direct engagement, while still preserving the interdisciplinary instruction between physics and choral singing. For details of the instructional design in Iteration 2, see **Appendix A**.

5.2.3 Lesson 1: Voice and Overtones

The first lesson in Iteration 2 introduced the basic principles of vocal sound production and the concept of overtones. Building on insights from the first implementation, this version of the lesson placed greater emphasis on tangible analogies and kinesthetic experiences to reduce cognitive load and enhance student engagement. Instead of leading with theoretical explanations, the lesson opened with practical demonstrations and guided observations, gradually linking these to core scientific ideas.

1. Engagement-1: Reframing Common Vocal Challenges. The lesson began with a brief introduction to the rationale behind the course design. The teacher explained that traditional chorus training often relies on experiential trial-and-error—doing more and hoping to find what works—which may not be effective for every student. This course aimed to offer an alternative perspective: to begin from observable vocal phenomena, introduce supporting scientific principles, and integrate these insights into vocal practice. In doing so, it encouraged students to develop a more structured and intentional approach to singing.

After this preface, the teacher turned to a more familiar tone. Imitating the critical voice of a typical chorus conductor, he delivered three recognizable rehearsal complaints: “Why are you singing so softly? Why is your pitch so off? Why does it sound so bad?” These deliberately exaggerated remarks prompted both laughter and immediate recognition from the students.

Without pausing for answers, the teacher acknowledged that these are common—but often unhelpful—questions in the rehearsal setting. He then rewrote them as positive, actionable prompts: “How can we sing with more presence?” “How can we sing more in tune?” “How can we make our singing sound better?” This simple rhetorical shift was both a pedagogical gesture and a reflective cue, encouraging students to think of voice-related problems not as faults to be fixed, but as processes to be understood and improved.

This opening served several design purposes. First, it replaced the abstract overtone-singing video from Iteration 1 with a more effectively grounded approach. Rather than beginning with an unfamiliar acoustic phenomenon, the teacher drew from students’ direct experience, increasing emotional relevance and accessibility. Second, each of the three rephrased questions corresponded to one of the fundamental acoustic elements—volume, pitch, and timbre—core concepts that had previously been introduced through a review of “the three elements of sound.” However, unlike in Iteration 1, where those concepts were surfaced via a general recall of science class content, Iteration 2 grounded them in the lived language of vocal coaching. This shift enabled students to approach scientific ideas not as external knowledge to be remembered, but as explanatory tools for solving familiar performance challenges.

Finally, the choice to reframe negative conductor phrases into constructive questions modeled an important value for future chorus educators. By the researcher’s observation, many chorus conductors tend to rely on deficit-based feedback, often unaware of its cumulative impact on students’ confidence. By beginning with humor and then modeling an affirming approach, the teacher not only engaged the students effectively but also introduced a meta-message: how we talk about sound matters, and so does how we teach it.

2. Development-1: Vocal Mechanism through Trumpet Analogy. To help students understand the mechanism of human voice production, the teacher began by introducing an external analogy: the trumpet. A video explaining how trumpets produce sound was played, and students were asked to extract key points to complete a guided worksheet. The teacher then brought out a physical trumpet mouthpiece and demonstrated how it produces vibrations when air is blown through it. Several students were invited to try it themselves, providing a tangible experience of the airflow-vibration relationship.

Rather than immediately explaining the relevance, the teacher posed an open-ended question: “Why do we need to know how a trumpet works?” Without offering an answer, he allowed the question to linger. This pause served to activate curiosity and encourage students to consider the parallel on their terms.

The lesson then transitioned to a video showing how human vocal folds operate during sound production. By comparing the mechanical vibration of the mouthpiece with the biological vibration of vocal folds, students were guided to perceive structural and functional similarities. These observations were then consolidated into a comparative chart summarizing how both trumpet and human voice generate and adjust sound, emphasizing shared principles such as airflow-driven vibration, and methods for modifying volume and pitch.

The teacher returned to the earlier question— “Why compare a trumpet to the human voice?”—and answered it explicitly: both rely on airflow to generate vibrations, and both control volume through breath pressure and pitch through tension adjustments. The lesson concluded this segment with a second chart comparing how singers and trumpet players adjust loudness (via air pressure) and pitch (via tension). For singers, more airflow means louder sound, and relaxed vocal folds help access lower pitches. Demonstrations were provided to reinforce these points.

Compared to Iteration 1, which presented multiple instrument analogies and guided students through small group discussions to infer voice mechanisms, this version focused solely on the trumpet as a dual analogy for both sound production and pitch control. The approach in Iteration 2 favored clarity and efficiency over exploration, sacrificing opportunities for peer prediction and debate in exchange for streamlined explanation and direct modeling. Although student interaction was limited, the use of physical models and targeted questioning helped anchor understanding and ensured that the core conceptual link was not lost in a shorter time.

3. Development 2: The Concept of Overtones. Building on the previous comparison between the trumpet and the human voice, the teacher introduced three key terms that had surfaced during the discussion: fundamental frequency, overtone, and overtone series. These terms were presented not as abstract equations but as auditory experiences. The teacher first played the overtone series featured in the trumpet video, paired with a keyboard diagram that allowed students to visually and aurally locate each note. Students then labeled overtone positions on a printed keyboard chart while listening to corresponding sound clips, preparing them for later activities focused on timbre and resonance.

To help students make sense of these new terms, the teacher introduced two analogies that linked the physical structure of sound to familiar sensory domains. First, the teacher described sound as a bowl of ramen: the broth represents the fundamental frequency. In contrast, the toppings represent the overtones—different ingredients layered on top of a base to create a specific flavor. Then, the teacher shifted to a visual example, referencing Georges Seurat's pointillist painting style. Just as Seurat's paintings appear unified from a distance but are composed of individually colored dots on the background color up close, a vocal tone may sound like a single entity but is made up of layered overtones on the fundamental frequency.

These analogies were deliberately selected not just for familiarity, but for conceptual precision. Unlike other common examples, such as adding sugar to tea, which can mislead students into thinking overtones are optional or adjustable, the ramen and pointillism metaphors reflect the fixed and proportional nature of overtone structures. The broth-to-topping and base-to-dot relationships allow for discussions of overtone ratios and harmonic structure, without oversimplifying the physics. Moreover, the pointillism metaphor captures a key perceptual insight: what we hear as a single vocal color is, in fact, a composite of distinct, traceable elements.

In contrast to Iteration 1, where overtone concepts were introduced through explanations of standing waves and resonance theory, Iteration 2 omitted these theoretical frameworks entirely. Time constraints partly drove this shift, but also by feedback from the first implementation, which revealed that students and the teacher found the abstract science content too difficult. While the lesson no longer included detailed explanations of wave behavior, the analogies retained the core conceptual accuracy, providing students with a clear and accessible entry point into timbre analysis. The simplification was thus not a compromise of correctness, but a considered pedagogical decision to prioritize intuitive learning without misrepresenting scientific principles.

4. Development-3: Constraints of Overtone Production. To deepen students' understanding of why only specific overtones occur with a given fundamental, the teacher introduced a surprising and engaging demonstration using a long flexible plastic tube known as a whirly tube—or "magic tube" (as shown in **Figure 5.1**), as referred to in class. Before revealing how the tube worked, the teacher asked students to guess how it might produce sound. Once spun through the air, the tube emitted a clear pitch, drawing expressions of curiosity and amusement from the class.

Figure 5.1

Teaching Aid in Development 3 of Lesson 1

Note. This plastic tube, also known as a "whirly tube" or "magic tube," was used in class to demonstrate how specific overtones are selectively produced based on resonant frequency.

Students quickly noticed that different spinning speeds resulted in different pitches, but always within a discrete set. The teacher highlighted that, unlike a sliding pitch instrument, the whirly tube could only produce specific notes—those that corresponded to fixed points in the overtone series. This observation led to a rephrased version of an earlier question: "Why are the overtones fixed once the fundamental is set?" Rather than providing a theoretical explanation, the teacher allowed this question to linger, setting up the next demonstration.

To explore the answer, the teacher brought out a jump rope and asked for a student volunteer to hold one end. With a few experimental flicks of the rope, the teacher demonstrated how certain rhythms of movement produced stable wave loops, while others failed to produce any regular pattern. Some attempts were deliberately "wrong" to show that without the right frequency, no standing wave—or "loop"—would appear. This tactile demonstration gave students a concrete sense of physical constraints in vibration systems.

The teacher then connected the number of loops in the rope to the overtone series, explaining that just as the rope can only support certain vibrational modes, the human vocal folds can only produce overtones that fit specific resonance conditions. A summary comparison between the rope and the vocal folds reinforced the concept that overtones are not arbitrary additions, but physically constrained results of the fundamental frequency's properties.

While Iteration 1 had introduced these ideas through diagrams and theoretical explanations of standing waves, the revised lesson in Iteration 2 replaced theory with embodied analogy. The jump rope activity, which had left a strong impression on students in the first implementation, was retained, but this time framed more intentionally as an experiential response to a real acoustic mystery. By pairing the novel magic tube with the familiar jump rope, the lesson combined curiosity-driven observation with kinesthetic modeling, achieving the goal of helping students grasp the constraints of overtone production without relying on abstract physics terminology.

5. Recap-1: Human Voice, Instruments, and the Overtone Series. To conclude the first lesson and consolidate learning, the teacher led a review activity that invited students to synthesize what they had learned about voice production, instrumental analogies, and the overtone series. The task was structured around two central comparison questions designed to reinforce key ideas while maintaining student engagement.

First, the teacher asked, "Which instrument is most similar to the human voice in terms of how sound is produced?" To support informed reasoning, the teacher briefly explained how each of the three candidate instruments—clarinet, violin, and timpani—produces sound: the clarinet uses a vibrating reed, the violin uses a bowed string, and the timpani relies on a struck membrane. Students were invited to raise their hands and share their thoughts, followed by a discussion of the correct answer: the clarinet, which, like the human voice, produces sound via airflow through a vibrating structure.

The second question shifted focus to pitch modulation: "Which instrument is most similar to the human voice in terms of how pitch is adjusted?" Again, the teacher briefly described the pitch control mechanisms of each instrument. While the clarinet changes pitch by altering the length of the air column using different fingerings, and the violin adjusts pitch by changing string length and tension, the timpani modifies pitch by tightening or loosening the drumhead membrane. The teacher explained that the human voice adjusts pitch by changing the tension of the vocal folds—tightening them to raise pitch and loosening them to lower it, making the timpani the closest match in this regard. The teacher emphasized that analogies serve to simplify complex ideas, and while none are perfect, each can highlight specific aspects of how the voice works.

To close the lesson, students revisited the overtone series. On their worksheet, they were asked to write the first seven overtones of D2 using a blank keyboard diagram. The teacher guided them through the answers, using either interval names or semitone counts, and played each corresponding sound. Two additional overtones were introduced to align with the overtone singing video that would be featured in the next lesson. This preview created a conceptual link between abstract structure and the upcoming musical experience.

This summary activity was designed with several pedagogical goals in mind. The first two comparison questions were retained from Iteration 1 but enhanced with a key revision. Each instrument option was now accompanied by a concise explanation of its sound production and pitch control mechanism. This ensured that students could make informed comparisons based on accurate conceptual cues, rather than relying on superficial associations or prior familiarity.

The use of structured voting and class discussion promoted active participation, while also modeling a process of scientific reasoning grounded in everyday musical experience. Rather than simply recalling textbook definitions, students were encouraged to apply what they had just observed and discussed, thereby reinforcing the voice-instrument analogies introduced earlier in the lesson.

The final task on the overtone series served a dual purpose: it provided a review of content introduced in Development 2 and established a conceptual bridge to the next lesson. Specifically, the choice of D2 as the reference pitch mirrored the fundamental tone used in the overtone singing video that would follow. In addition to revisiting the first seven overtones, the teacher introduced two additional overtones that had not been previously calculated, ensuring that students would be able to recognize and map the sung pitches to the overtone structure they had already encountered. This deliberate alignment of content across lessons was intended to promote continuity, transfer, and readiness for deeper analysis of timbre and resonance.

5.2.4 Lesson 2: Resonance and Timbre

The second lesson in Iteration 2 revisited the phenomenon of overtone singing—not as a novelty, but as a familiar yet still captivating entry point for deeper exploration. Drawing on students' prior exposure to overtones in the first session, this version of the lesson repositioned the video as a conceptual bridge rather than an introductory hook. With a clearer foundation already established, the engagement activity focused on sharpening students' perceptual awareness and prompting targeted observation. Instead of providing immediate explanations, the teacher used subtle prompts and open-ended questions to sustain curiosity, setting the stage for inquiry into resonance and timbre grounded in prior understanding.

1. Engagement-2: The Mystery of Overtone Singing. After a ten-minute break, the second lesson began with a familiar yet still captivating video clip of overtone singing. Unlike in Iteration 1, where the video served as the opening phenomenon of the entire unit and its explanation became the central thread across multiple lessons, in this version, the video was placed at the start of Lesson 2. By this point, students had already been introduced to the concepts of overtones and overtone series, allowing them to approach the phenomenon with a more informed and focused perspective.

Before playing the video, the teacher gave a subtle prompt: “This time, try to ignore the low note and listen carefully to the high melodic tones riding above it.” Without directly stating that these were overtones, the teacher encouraged students to tune into the structure of the sound and observe with curiosity. After viewing, the teacher asked, “What notes did you hear in the melody?” Students were expected to respond in a variety of ways—naming solfège syllables (Do, Re, Mi, Sol, flat Ti), absolute pitches (A5, C6, D6, etc.), or identifying the overtone series of D3. The teacher then confirmed that the melody was indeed formed by the overtones of D3, reinforcing the connection to the previous lesson’s worksheet and playing each overtone pitch again for auditory confirmation.

Next, the teacher posed a more challenging question: “How does the singer control which overtones are heard?” Students responded with intuitive ideas such as “mouth shape,” “facial expression,” or simply “feeling.” Rather than providing a direct answer, the teacher paused and replied, “That is something we can explore using science.” This moment was designed to create cognitive tension and sustain attention, not by confusion, but by planting a specific, solvable question in the students’ minds.

Only then did the teacher reveal the day’s focus: resonance and timbre. By connecting the mystery of overtone control to previously learned concepts, the teacher framed the lesson not as a new topic but as a continuation of the question left unanswered from the previous session. The goal was to invite students to use science as a tool to unpack something they had already heard, found fascinating, and tried to explain on their own.

2. Development-4: Resonance Box Size and Overtone Emphasis. To explore how resonance affects which frequencies are emphasized in sound production, the teacher introduced the concept of the resonance box using examples from familiar string instruments. A brief explanation was provided: instruments like violins, guitars, and pipas use resonance chambers to amplify sound. The teacher pointed out that while all these instruments have resonance boxes, their sizes vary, and that this size difference plays a role in what parts of the sound are strengthened.

To prompt student reasoning, the teacher posed a playful but purposeful question: “If shortening the string produces higher notes, why can’t a double bass just play violin melodies by shifting hand positions? Wouldn’t that save us the need for violins in an orchestra?” The question invited students to confront an apparent contradiction: the double bass can technically reach higher finger positions, but the sound produced does not carry in the same way.

Students then watched a video comparing two guitars that were nearly identical except for the size of their resonance chambers. The teacher instructed students to pay close attention to the differences in sound when the same pitch was played on each guitar. This setup—narrowing the variable to just resonance box size—replaced the more complex multi-instrument comparisons used in Iteration 1 and was designed to focus students’ attention on a single acoustic factor.

After the video, the teacher presented a comparison chart showing the key differences between large and small guitars. Rather than discussing general timbre, the focus remained on the overtone response: which frequencies were more pronounced in each case, the higher notes or the lower notes. The teacher explained that larger resonance boxes tend to reinforce lower overtones, while smaller ones allow higher overtones to be more audible. Students were invited to contribute their observations, and the teacher synthesized the comparison based on class discussion.

Returning to the opening question, the teacher concluded: “Even if a double bass can reach high pitches, those notes do not sound good—not because of pitch, but because the resonance box does not amplify those higher overtones. That is why the sound is weak or thin.” To strengthen the analogy, the teacher added that just as larger instruments favor low frequencies, vocalists with smaller resonance spaces—like sopranos—naturally amplify higher frequencies better than lower ones.

In contrast to Iteration 1, which featured a wider array of instrument comparisons, this version deliberately focused on a tightly controlled contrast—two guitars differing only in resonance box size. This simplification was intended to guide students more precisely toward the concept that different resonance structures selectively enhance specific parts of the overtone series.

3. Development-5: Human Resonance Spaces and Overtone Control. Building on the previous discussion of resonance box size in instruments, the teacher now redirected attention to the human voice. “So where is the resonance box in our body?” he asked, inviting students to apply what they had learned to their vocal mechanism. The question sparked curiosity and opened a transition into the anatomical basis of vocal resonance.

To support the discussion, the teacher presented a sagittal cross-section of the human head and vocal tract. He explained that after the vocal folds generate sound, it travels through a series of cavities—most notably the pharynx, oral cavity, and nasal passages—before exiting the mouth. These anatomical spaces serve as resonance chambers, much like those in musical instruments. However, unlike fixed physical boxes, these human structures are malleable and responsive to subtle muscular adjustments.

The teacher then returned to a key question posed at the beginning of the lesson: “How do we control which overtones are heard?” This time, a direct answer was given: by altering the size and shape of the resonance chambers, especially the oral cavity, singers can selectively amplify specific overtones. To illustrate this, the teacher explained that creating a larger oral space tends to emphasize lower overtones, while narrowing the cavity enhances higher ones. A practical example was given: “To sing a darker, lower-sounding overtone, you will likely open your mouth more; to bring out a brighter, higher one, you will shape the space differently—even if it is not visible from the outside.”

To reinforce this explanation, the class rewatched the overtone singing video. Students were instructed to focus closely on the singer’s facial expressions and overall stillness, and to consider what internal changes might be occurring even if the mouth appeared motionless. The teacher clarified that most of the adjustments happen in the inner oral cavity and pharynx—areas not visible on the surface. This helped explain why overtone singing, despite its acoustic complexity, seems effortless.

This activity served a second purpose: it resolved the mystery raised at the start of the lesson, giving students a scientifically grounded explanation for a phenomenon that initially seemed magical. In Iteration 1, student worksheet responses revealed a common misconception: some students thought that altering the size of the resonance chamber changed the overtone series itself. In this revised lesson, the teacher explicitly corrected this misunderstanding by emphasizing that the overtone series remains constant for a given fundamental; what changes is which overtone is selectively amplified through vocal tract shaping.

4. Development-6: The Cause of Timbre. The third development activity of Lesson 2 centered on a simple question: Why do different sounds, even at the same pitch, still feel distinct? To approach this, the teacher returned to a moment from earlier in the lesson—the comparison between large and small guitars—and recalled that students had already noticed differences not just in volume, but also in timbre. This became a natural entry point to a deeper discussion on the acoustic causes of vocal uniqueness.

To build perceptual awareness, the teacher played recordings of a flute, trumpet, and piano, all producing the same note. Despite identical pitch, the class immediately recognized the distinctive qualities of each sound. A second set of examples featured the recorder, clarinet, and oboe—three instruments with more similar construction and sound production mechanisms. Nevertheless, again, students were able to tell them apart. The teacher pointed out that even small variations in how sound is produced can result in noticeable differences in timbre.

The focus then shifted to the human voice. The teacher noted that even when two people sing the same note, listeners can easily tell their voices apart. Referencing real-world applications such as voice-activated personal assistants, the teacher posed a question to the class: if we each have fingerprints, could we also have unique "voiceprints"?

Rather than answering immediately, the teacher guided students to revisit the foundational concepts they had already explored: voice production, overtone structure, and resonance. Students were reminded that sound begins with a vibrating source, that this vibration produces a fundamental frequency along with a structured set of overtones, and that the surrounding space modifies which frequencies are amplified. Together, these components lay the groundwork for understanding what causes timbre.

The teacher explained that timbre arises from the relative prominence of different overtones. A sound with stronger high-frequency overtones may be perceived as bright or sharp, while one with more dominant low-frequency overtones may be described as warm or dark. These overtone patterns are consistent enough that listeners can use them to distinguish between instruments or between human voices.

To make this principle more concrete, the teacher presented simplified spectrograms comparing the overtone distribution of different instruments playing the same pitch. Visualizing the frequency content helped students see how distinct overtone balances define the "sound fingerprint" of each instrument. These comparisons helped consolidate the link between the physical behavior of sound and the perceptual experience of timbre.

In contrast to Iteration 1, where similar frequency analyses were used, the emphasis in Iteration 2 was on using students' perceptual observations to build toward the scientific explanation. The use of spectrograms supported, not replaced, the students' logical reasoning based on earlier discussions about overtones and resonance.

5. Development-7: The Key to Changing Timbre. With the concept of timbre now grounded in the overtone structure and resonance behavior of each instrument or voice, the final development activity returned the focus to a practical and personal question: can we change our timbre—and if so, how?

The teacher posed this as a rhetorical challenge: "As human singers, how can we change our timbre?" Rather than offering immediate suggestions, the teacher let the question settle, inviting students to reflect on what aspects of their vocal sound might be adjustable. The answer, when it came, was structured around a key limitation. While we cannot fundamentally alter the physical nature of our vocal instrument, we do have some degree of control over how it resonates.

The teacher explained that the "identity" of an instrument—what was previously referred to as its acoustic nature—cannot be changed easily. In humans, this would be akin to changing the properties of the vocal folds themselves, something that might only occur through biological changes such as puberty, disease, or surgical intervention. In normal singing practice, however, our instrument's core characteristics remain constant.

What we can change, the teacher emphasized, is the resonance space. To make this idea concrete, the teacher returned to the earlier anatomical diagram of the human vocal tract. With a brief recap of how sound passes from the vocal folds through various resonating chambers, the teacher highlighted which parts of the system singers can consciously control. Students were reminded that, unlike a violin or trumpet, the human instrument allows for subtle, moment-to-moment reshaping of internal spaces.

To illustrate this, the teacher demonstrated different vocal techniques—such as altering mouth shape, tongue position, or pharyngeal openness—to show how resonance adjustments could modify timbre without changing pitch. Students were invited to try simple variations, like humming with a more closed or open mouth, or slightly shifting their jaw position while sustaining a tone. These small exercises helped them connect physical sensation with the acoustic outcomes they had been analyzing.

By synthesizing prior knowledge about overtone selection and resonance, this segment guided students to a practical conclusion: while we cannot rebuild our voice, we can learn to shape it. In doing so, singers can develop greater awareness of their vocal instrument and learn how to make deliberate, responsive choices to influence the sound they produce.

6. Recap-2: Music with Science. As the lesson approached its end, the teacher returned to the overarching goal of the course: to understand the scientific principles behind sound in order to improve one's singing. Rather than launching into a monologue, the teacher invited students to participate in a collective review, asking them to recall and summarize the four main topics covered across the two sessions—voice production, overtones, resonance, and timbre.

Students were encouraged to share just one sentence or a single key point from any of the four areas. The teacher used each contribution as a springboard to reinforce, clarify, or expand on the core concepts. This open-ended recall approach allowed students to revisit earlier learning through their language while keeping the summary dynamic and engaging. In cases where student responses were limited or time was short, the teacher provided the summary themselves, ensuring that all essential ideas were covered.

After reviewing the four topics, the teacher returned to the very first questions that opened the course: How can we sing louder? How can we sing more in tune? How can we make our voices sound better? These questions, initially posed with a touch of humor, were now revisited with deeper understanding. The teacher invited students to offer revised answers based on what they had learned, highlighting how scientific knowledge could transform vague frustrations into actionable insights.

At this point, the teacher introduced a reflective prompt, offering a transition from science to artistry: "Throughout this course, we have not only integrated scientific knowledge—we have also touched on the spirit of science. Each 'why?' and 'how?' we explored reflects a desire to understand, to question, to improve. However, as singers, we do not just seek better technique—we also ask: what is the spirit of music? What is the spirit of the chorus?" This moment opened space for students to consider the broader meaning of their learning, beyond technical mastery.

Compared to Iteration 1, which concluded with speculative thinking and a list of four directions for extended learning—including acoustics, vocal pedagogy, musical acoustics, and recording analysis—this version opted for a more concentrated reflection, using philosophical questions to anchor students' takeaways. The shift represented a trade-off: less emphasis on breadth, more on internalization and thematic coherence.

To close, the teacher shared a quote from French musicologist Jules Combarieu: "Music is the art of thinking with sounds." This quote offered a final affirmation that the intersection of science and music is not a contradiction but a deepening—an invitation to think, feel, and sing with greater awareness.

5.2.5 Learning Assessments

The assessment framework for Iteration 2 followed the same structure as in Iteration 1, evaluating learning outcomes across cognitive, affective, and psychomotor domains.

Cognitive understanding was assessed through open-ended worksheets completed after each lesson. These items prompted students to describe mechanisms of sound production, identify overtone patterns, and explain how resonance influences vocal output. Question design was adjusted from Iteration 1 to improve clarity and better match the revised lesson flow.

Affective outcomes were measured using the Science Learning Interest Scale, administered before and after the course. This validated instrument captured changes in students' engagement with science-related content, particularly as applied to singing.

Psychomotor learning was evaluated through a post-course teacher interview. The collaborating teacher provided feedback on students' ability to apply scientific concepts during rehearsals, such as referring to resonance adjustments or overtone awareness in vocal practice.

This combination of written responses, self-report measures, and instructor observations offered a balanced view of the course's instructional effectiveness.

5.3 Research Instruments

To investigate the effectiveness and feasibility of the revised interdisciplinary course, a mixed-methods approach was again adopted in Iteration 2. Four types of instruments were employed: pre-/post-questionnaires, field notes, student worksheets, and teacher interview. These tools were designed to address the three research questions from multiple perspectives, capturing both quantitative and qualitative evidence. While the overall structure of the research instruments remained consistent with Iteration 1, several modifications were made to better align with the revised course format and to address limitations identified in the first iteration. The following sections describe each instrument in detail.

5.3.1 Pre-/Post-Questionnaires

For details of the pre-/post-questionnaires in Iteration 2, see **Appendix B**. The instruments in Iteration 2 largely followed the structure established in Iteration 1, with selective modifications aimed at enhancing conceptual alignment and data quality.

1. Open-Ended Pre-Class Questions. To probe students' prior knowledge and prime their curiosity, three open-ended questions were included in the pre-questionnaire: “How do you adjust the volume?”, “How do you adjust the pitch?”, and “How do you adjust the timbre?”. These questions were designed by the researcher and reviewed with Teacher Z to align with the course’s three major scientific dimensions.

The expected correct answer to the first question was adjusting the amount of airflow, while a common misconception involved tensing or squeezing the throat. For the second question, the correct answer was adjusting the tension of the vocal folds, although some students might mention external references such as tuning with others or using a piano. The third question addressed the concept of resonance adjustment, although students were more likely to rely on intuition or vague imagery.

By considering these questions in advance, students were expected to approach the lesson with heightened curiosity and attentiveness.

2. Demographic Information. The demographic items remained identical to those in Iteration 1, including student age, grade level, gender, academic division, and years of chorus experience. These data were used to characterize the sample and support further analysis.

3. Science Learning Interest Scale. The Science Learning Interest Scale was adapted from Iteration 1, with minor wording refinements for clarity and consistency. The scale maintained its original structure, comprising 20 items across five subscales, based on the theoretical model of situational and personal interest (Cheng et al., 2013; Hidi & Ann Renninger, 2006). Items were rated on a 5-point Likert scale, with higher scores indicating greater ISL.

4. Learning Satisfaction Scale. To further address RQ3 regarding the course’s feasibility and appeal, Iteration 2 measured students’ learning satisfaction. Because this interdisciplinary course emphasized the integration of scientific knowledge into chorus-based singing instruction, rather than direct improvement of singing skills, it was important to examine how students perceived the course’s value and relevance. In particular, satisfaction is often regarded as a key indicator of student engagement and acceptance, which can inform educators’ willingness to adopt a new instructional approach.

The research instrument was adapted from Huang's (2023) Learning Satisfaction Scale, originally designed to evaluate elementary students' experiences in music creation courses using digital audio workstation software. The original scale consisted of three subscales—course satisfaction (Items 1–4), learning outcomes (Items 5–8), and peer interaction (Items 9–12)—each rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Cronbach's α values in Huang's study indicated acceptable internal consistency (George & Mallery, 2010): .824 for course satisfaction, .748 for learning outcomes, and .873 for the full scale.

In the current study, all references to "music composition" or "software use" were modified to "choral singing" and "scientific knowledge," reflecting the content and goals of the interdisciplinary curriculum. Because the course was not explicitly designed to promote peer interaction, the corresponding subscale was excluded, and only the two relevant subscales—*course satisfaction* and *learning outcomes*—were retained, resulting in a total of eight items.

5.3.2 Field Notes

The field notes in Iteration 2 followed the same observational focus as those in Iteration 1, documenting the teacher's instructional delivery, students' on-task behaviors, and the overall classroom atmosphere. In this iteration, the researcher incorporated the lesson plan as a reference framework for observational alignment. This adjustment was made in response to prior interview feedback, which highlighted the lesson plan's utility in clarifying the timeline and pedagogical decisions. By using the teaching plan as a reference during observation, the researcher was able to capture key instructional moments better and align them with intended teaching strategies.

Unlike Iteration 1, in which classroom-based prompt questions were recorded as part of the field notes, Iteration 2 moved those prompts to the pre-questionnaire. This change allowed for more systematic data collection and statistical analysis. The rest of the observation approach remained descriptive and open-ended, with field notes capturing the flow of classroom events, instructional pacing, student responses, and episodes of engagement or confusion.

5.3.3 Student Worksheets

In Iteration 2, the worksheets were redesigned to fit the revised course format better. Rather than being distributed at the end of each lesson as reflective prompts, the worksheets were transformed into in-class materials that functioned more like guided note-taking and embedded practice activities. Students completed the worksheets during the lesson, responding to questions while learning and applying new concepts. This change was made in response to the structural shift of the course, from a four-part modular design in Iteration 1 to a more continuous two-session workshop in Iteration 2. As a result, the worksheets no longer needed to serve as transitions between sessions.

In addition, the individual reflection questions originally included at the end of each lesson in Iteration 1 were removed due to low response rates (ranging from 22% to 43%). Only the final section for overall course feedback was retained, while the rest of the worksheet focused on content-based tasks that aligned directly with classroom instruction.

The worksheet content was structured around five key topics aligned with the course: trumpet sound production, human voice, overtones, resonance, and timbre. The first three topics were addressed in the first session, while the remaining two were covered in the second. Each topic was supported by questions directly linked to in-class explanations. For example, the overtone section was supplemented with a keyboard diagram based on feedback from the trial run, which helped students visualize the concept more clearly. A final reflection section was retained at the end of the worksheet to collect students' overall impressions of the course. All responses were handwritten and collected at the end of the two sessions. For details of the student worksheets in Iteration 2, see **Appendix C**.

5.3.4 Teacher Interviews

Teacher interviews in Iteration 2 were conducted similarly to those in Iteration 1: face-to-face, semi-structured, and audio-recorded with participant consent. Although the exact timing varied, all interviews took place within a few days after the course and aimed to capture reflective insights from the instructors. The interview procedure was refined based on previous experience. In Iteration 2, the interview began with an open-ended discussion on the teacher's most memorable impressions, followed by a review of the teaching process using the lesson plan and field notes as reference. This scaffolded approach helped facilitate more detailed recall and targeted discussion on teaching effectiveness.

Interviews were conducted with two teachers across different implementations. Teacher Z participated in three interviews following each implementation. The first focused on modifications made in Iteration 2; the final one invited more holistic reflections on the course design and its overall trajectory. In contrast, Teacher L was interviewed only once, after teaching the course to Chorus B and Chorus C. His interview covered student responses, instructional flow, and general impressions of the interdisciplinary curriculum.

5.4 Research Process

This section outlines the research process for Iteration 2, which extended and deepened the initial design established in Iteration 1. To examine the effectiveness and adaptability of the interdisciplinary course across different learning contexts, the implementation was expanded to three choral groups. The process involved a revised instructional design phase, multiple implementations, systematic data collection, and a final round of instructional refinement.

The main stages of course development—preparation, implementation, and consolidation—are presented chronologically in Section 5.4.1. This timeline traces how the instructional design evolved across multiple contexts and iterations, guided by ongoing analysis and feedback. Section 5.4.2 describes the data collection procedures used to evaluate each implementation, while Section 5.4.3 outlines the ethical safeguards maintained throughout the study.

5.4.1 Course Development Timeline

This section details the second iteration of the interdisciplinary course, which involved a broader implementation scope and continued refinement of the instructional design. Building on the outcomes of Iteration 1, the course was revised, tested, and applied across three different choral groups to evaluate its adaptability and effectiveness in varied educational settings. The development process is described in three phases: preparation, implementation, and consolidation, each reflecting a distinct stage in the DBR cycle. These phases collectively contributed to the emergence of a more robust, transferable instructional model.

1. Preparation Phase. The teaching plan for Iteration 2, referred to as *Version 2.0*, was revised based on reflections and findings from Iteration 1. Drawing on both quantitative and qualitative data, the researcher refined the lesson sequence, clarified key concepts, and added scaffolding strategies to support student understanding better. Prior to the first formal implementation, the revised lesson plan underwent a trial teaching session followed by a structured lesson rehearsal with the collaborating teacher. Feedback from these sessions led to a further round of modifications, resulting in *Version 2.1*, which was used in Iteration 2-1.

In addition to continuing work with Chorus A and Teacher Z, the researcher expanded the implementation scope by recruiting two additional choruses—Chorus B and Chorus C—led by Teacher L. This expansion enabled multiple implementations of the same instructional design under varied classroom contexts, thereby strengthening the robustness of the design research process.

All instructional materials and research instruments were finalized prior to the first implementation. These included video and audio resources, physical teaching aids, and student worksheets, as well as the pre-/post-questionnaires, field notes, and teacher interviews protocols.

2. Implementation Phase. Iteration 2 was implemented in the form of three single-session workshops, each held at a different school site and involving one of three choruses: Chorus A, Chorus B, and Chorus C. These were referred to as Iteration 2-1, Iteration 2-2, and Iteration 2-3, respectively. The three implementations took place in December 2024, with Iteration 2-1 occurring in mid-December and the latter two following approximately two weeks later.

Iteration 2-1 used Version 2.1, the result of the initial revision and rehearsal. Following this first implementation, the teaching plan was further updated based on classroom observations and teacher reflections, resulting in *Version 2.2*, which was then used in Iteration

2-2. A final round of minor adjustments produced *Version 2.3*, which was used in Iteration 2-3.

Because the implementations were conducted in the first semester of the school year, each chorus included a proportion of newly joined members. Nevertheless, all participating students had recently taken part in either the City Preliminary Round of the National Student Competition of Music or the corresponding round of the National Competition of Folk Song for Teachers and Students. Although this level of experience was not as extensive as in Iteration 1, it was sufficient to provide students with the choral foundation needed to engage meaningfully with the course content.

All sessions followed the same general structure and instructional flow. After Iteration 2-1, the teaching plan was further updated based on classroom observations and teacher reflections, and this revised version was used in Iteration 2-2 and Iteration 2-3. Each workshop lasted approximately 100 minutes and was led by the same collaborating teacher (Teacher Z), who had rehearsed the updated materials beforehand. Unlike in Iteration 1, the researcher remained in an observer role throughout all three implementations, allowing for uninterrupted data collection and a consistent record of instructional delivery.

Across the three sessions, class sizes ranged from 12 to 17 students. Participation in each chorus was voluntary, and not all students were formal members. Meanwhile, their levels of engagement and familiarity with the teacher varied, and these diverse teaching contexts offered valuable insight into how the curriculum functioned across different school cultures, classroom environments, and teacher-student dynamics.

3. Consolidation Phase. This phase took place after all instructional implementations and data collection activities for Iteration 2 had been completed. Drawing on insights from pre-/post-questionnaires, student worksheets, field notes, and teacher interviews, the researcher conducted a comprehensive analysis to evaluate the instructional effectiveness and identify remaining areas for improvement. Based on these findings, the teaching plan was refined one final time, resulting in *Version 2.4*—a consolidated version that integrated adjustments from all three sub-iterations.

Version 2.4 represents the most complete and field-tested edition of the interdisciplinary course. It addressed instructional gaps observed during earlier implementations, streamlined activity flow, and included revised materials tailored to support both student understanding and teacher facilitation. Although not implemented in a formal classroom session, *Version 2.4* serves as the culminating product of the DBR process and a resource for future application.

In parallel with the final design work, the researcher began composing the thesis to document the development and outcomes of the study. This writing process aimed to synthesize theoretical insights with practical findings and articulate a set of domain-specific design principles for integrating science and music in high school chorus settings. To further disseminate the findings, selected course materials and research insights were prepared for sharing with educators to support teacher training and inspire future curriculum innovation in interdisciplinary science learning.

5.4.2 Data Collection.

Data collection in Iteration 2 followed the same structure as in Iteration 1, using the same types of instruments administered at comparable points in time. These included pre- and post-questionnaires, student worksheets, field notes, and teacher interviews, all designed to answer the three research questions.

Teacher interviews were conducted shortly after each course implementation to capture timely reflections and feedback. Specifically, the interview with Teacher Z in Iteration 2-1 took place one day after the lesson; the Iteration 2-2 interview occurred two days after implementation; and the Iteration 2-3 interview was conducted two weeks after the course. Additionally, an interview with Teacher L, who participated in the final implementation, was held in mid-April 2025. This variation in timing allowed the researcher to collect both immediate and more reflective insights into the instructional process and course feasibility.

5.4.3 Ethical Consideration

All ethical procedures for Iteration 2 were consistent with those established in Iteration 1. Students were informed of the study’s purpose and procedures, and verbal consent was obtained prior to participation. Participation was voluntary, and students were assured of their right to withdraw at any time without consequence. To protect anonymity, participants used self-generated codes on all written responses, and no identifying information was collected. All data were securely stored and accessible only to the research team.

As in Iteration 1, a small token of appreciation (a gift card valued at 50 NTD) was offered to students who completed both the pre- and post-questionnaires. The study continued to follow institutional research ethics guidelines and was reviewed and approved by the researcher's academic advisor.

5.5 Analysis and Findings

This section presents the findings from the three sub-iterations of the revised interdisciplinary course, referred to as Iteration 2-1, 2-2, and 2-3. Data were collected through multiple instruments designed to address the three research questions. To provide a more integrated and tool-based analysis, the results are organized by instrument rather than by implementation cycle. This approach enables cross-comparison among the three implementations and highlights how each instrument contributed to evaluating the effectiveness, engagement, and feasibility of the course design.

5.5.1 Science Learning Interest Scale

To evaluate changes in students' ISL, the Science Learning Interest Scale was administered before and after the course in each of the three implementations of Iteration 2. The instrument included five subscales: latent interest, actualized interest, triggered situational interest, maintained situational interest-feeling, and maintained situational interest-value. Each subscale consisted of four Likert-type items rated on a 5-point scale. Given the small sample sizes (n = 9–14) and the ordinal-level data, the Wilcoxon signed-rank test was used to assess differences between pre- and post-course scores. Descriptive statistics are summarized in **Table 5.1**.

Table 5.1

Descriptive Statistics for the Science Learning Interest Scale Across Iteration 2

Subscale	Chorus	Pre			Post		
		M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Latent Interest	A	11.3	4.6	11.0	12.1	4.5	12.0
	B	15.5	4.8	16.0	15.5	4.9	16.0
	C	12.2	4.5	15.0	13.0	4.0	16.0
Actualized Interest	A	14.4	3.3	15.5	15.3	2.6	15.5
	B	15.6	3.3	16.0	16.0	3.8	16.0
	C	13.8	3.3	14.0	15.0	2.9	16.0
Triggered SI	A	12.8	3.7	12.0	15.9	2.8	16.0
	B	13.9	4.7	15.0	17.9	2.6	19.0
	C	13.3	4.7	16.0	17.1	2.6	17.0
Maintained SI-Feeling	A	12.7	4.3	13.0	15.9	2.6	16.0
	B	15.0	4.2	15.5	17.0	3.0	17.5
	C	12.3	4.9	14.0	16.0	2.7	16.0
Maintained SI-Value	A	15.4	2.3	15.5	17.0	2.5	17.5
	B	16.1	3.6	17.0	18.5	1.7	19.0
	C	14.0	4.0	15.0	16.3	2.7	16.0

Note. Iteration 2-1: $n = 14$; Iteration 2-2: $n = 14$; Iteration 2-3: $n = 9$ refers to the number of matched questionnaires collected for analysis.

SI = Situational Interest.

Across the three implementations, students demonstrated improvements in several subscales, though the pattern of significant changes varied by group:

1. Iteration 2-1: Chorus A. The Wilcoxon Signed-Rank Test results are presented in **Table 5.2**, revealing statistically significant improvements in four of the five subscales. In latent interest, nine students reported higher scores after the course ($p < .05$). In triggered situational interest, 10 students showed improvement ($p < .05$). For maintained situational interest-feeling, 11 students demonstrated increased scores ($p < .05$). Similarly, in maintained situational interest-value, nine students scored higher after the course ($p < .05$). No statistically significant change was observed in actualized interest. These findings indicate that the course in Iteration 2-1 was effective in enhancing students' situational engagement and in stimulating their latent interest in science, yet actualized interest, which reflects students' sustained personal involvement, appeared less responsive to the instructional intervention in this sub-iteration.

2. Iteration 2-2: Chorus B. The Wilcoxon Signed-Rank Test results are presented in **Table 5.3**, showing statistically significant improvements in two subscales. In triggered situational interest, 10 students reported higher scores after the course ($p < .05$). In maintained situational interest-value, all 10 students who showed change reported gains ($p < .01$). No statistically significant differences were observed in latent interest, actualized interest, or maintained situational interest-feeling. These results suggest that the course in Iteration 2-2 was particularly effective in stimulating curiosity and helping students perceive value in science learning, even though emotional engagement and sustained personal interest remained unchanged.

3. Iteration 2-3: Chorus C. The Wilcoxon Signed-Rank Test results are presented in **Table 5.4**, showing statistically significant differences in two of the five subscales. In actualized interest, six students reported higher scores after the course ($p < .05$). In maintained situational interest-feeling, six students also showed improvement ($p < .05$), indicating gains in both sustained personal engagement and emotional involvement. No significant differences were observed in latent interest*,* triggered situational interest*, or* maintained situational interest-value, although all three subscales exhibited positive trends. These findings suggest that while some dimensions of interest improved significantly, others did not reach statistical significance within this iteration.

Table 5.2

Results of the Wilcoxon Signed-Rank Test on Chorus A's Science Learning Interest Scale in Iteration 2-1

Subscale	Ranks	*n*	Mean Rank	Sum of Ranks	*z*	*p*	Effect Size
Latent Interest	Neg.	1	4.5	4.5	-2.48	.013*	-.66
	Pos.	9	5.6	50.5			
	Ties	4	-	-			
Actualized Interest	Neg.	4	4.0	16.0	-1.56	.120	-.42
	Pos.	7	7.1	50.0			
	Ties	3	-	-			
Triggered SI	Neg.	3	5.8	17.5	-1.96	.050*	-.52
	Pos.	10	7.4	73.5			
	Ties	1	-	-			
Maintained SI-Feeling	Neg.	1	6.5	6.5	-2.56	.011*	-.68
	Pos.	11	6.5	71.5			
	Ties	2	-	-			
Maintained SI-Value	Neg.	2	5.5	11.0	-1.97	.049*	-.53
	Pos.	9	6.1	55.0			
	Ties	3	-	-			

Note. n = 14 refers to the number of matched questionnaires collected for analysis.

SI = Situational Interest; Neg. = Negative; Pos. = Positive.

*p < .05. **p < .01. ***p < .001.

Table 5.3

Results of the Wilcoxon Signed-Rank Test on Chorus B's Science Learning Interest Scale in Iteration 2-2

Subscale	Ranks	*n*	Mean Rank	Sum of Ranks	*z*	*p*	Effect Size
Latent Interest	Neg.	1	7.0	7.0	-1.26	.206	-.34
	Pos.	6	3.5	21.0			
	Ties	7	-	-			
Actualized Interest	Neg.	4	4.9	19.5	-0.36	.720	-.10
	Pos.	5	5.1	25.5			
	Ties	5	-	-			
Triggered SI	Neg.	2	4.5	9.0	-2.36	.018*	-.63
	Pos.	10	6.9	69.0			
	Ties	2	-	-			
Maintained SI-Feeling	Neg.	4	2.8	11.0	-1.69	.091	-.45
	Pos.	6	7.3	44.0			
	Ties	4	-	-			
Maintained SI-Value	Neg.	0	0.0	0.0	-2.83	.005**	-.76
	Pos.	10	5.5	55.0			
	Ties	4	-	-			

Note. n = 14 refers to the number of matched questionnaires collected for analysis.

SI = Situational Interest; Neg. = Negative; Pos. = Positive.

*p < .05. **p < .01. ***p < .001.

Table 5.4

Results of the Wilcoxon Signed-Rank Test on Chorus C's Science Learning Interest Scale in Iteration 2-3

Subscale	Ranks	*n*	Mean Rank	Sum of Ranks	*z*	*p*	Effect Size
Latent Interest	Neg.	0	0.0	0.0	-1.84	.066	-.61
	Pos.	4	2.5	10.0			
	Ties	5	-	-			
Actualized Interest	Neg.	0	0.0	0.0	-2.23	.026*	-.74
	Pos.	6	3.5	21.0			
	Ties	3	-	-			
Triggered SI	Neg.	1	3.5	3.5	-1.78	.075	-.59
	Pos.	6	4.1	24.5			
	Ties	2	-	-			
Maintained SI-Feeling	Neg.	1	1.0	1.0	-2.20	.028*	-.73
	Pos.	6	4.5	27.0			
	Ties	2	-	-			
Maintained SI-Value	Neg.	1	3.0	3.0	-1.58	.114	-.53
	Pos.	5	3.6	18.0			
	Ties	3	-	-			

Note. $n = 9$ refers to the number of matched questionnaires collected for analysis.

SI = Situational Interest; Neg. = Negative; Pos. = Positive.

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Summary. Taken together, the findings suggest that the interdisciplinary course had a consistent impact on students' situational interest across all three implementations, particularly in stimulating curiosity and reinforcing perceived value. However, effects on sustained personal interest were more variable, highlighting opportunities for further instructional refinement.

5.5.2 Learning Satisfaction Scale

To evaluate students' satisfaction with the interdisciplinary course, the Choral Learning Satisfaction Scale was administered at the end of each implementation in Iteration 2. The scale consisted of two subscales—Course Satisfaction and Learning Outcomes, each comprising four Likert-type items rated from 1 (strongly disagree) to 5 (strongly agree). A total score of 12 (4 × 3) was used as the neutral benchmark for comparison.

Given the ordinal nature of the data and the small sample sizes, Wilcoxon signed-rank tests were employed to determine whether students' post-course scores were significantly higher than the neutral value. As shown in **Table 5.5**, the average scores across all three choruses exceeded the benchmark on both subscales.

Table 5.5

Descriptive Statistics of the Learning Satisfaction Scale in Iteration 2

Subscale	Chorus	*M*	*SD*	*Mdn*
Couse Satisfaction	A	15.7	3.1	15.5
	B	16.5	3.5	18.0
	C	14.6	3.0	15.0
Learning Outcomes	A	13.9	2.5	13.5
	B	16.1	4.3	17.5
	C	15.0	3.5	16.0

Note. Iteration 2-1: $n = 14$; Iteration 2-2: $n = 14$; Iteration 2-3: $n = 9$ refers to the number of matched questionnaires collected for analysis.

The results of the Wilcoxon signed-rank tests are presented in **Table 5.6**. In all three implementations, students' ratings on both subscales were significantly higher than the benchmark. Chorus B in Iteration 2-2 reported the highest levels of satisfaction and learning outcomes ($p < .01$ for both subscales). In Iteration 2-1, Chorus A also showed significant results ($p < .01$ for course satisfaction; $p < .05$ for learning outcomes). Despite the smaller sample size, Chorus C demonstrated consistent positive outcomes in Iteration 2-3 ($p < .05$ for both subscales). These results provide robust evidence of students' positive perceptions of the interdisciplinary course across all participating groups.

Table 5.6

Results of the Wilcoxon Signed-Rank Test on the Learning Satisfaction Scale in Iteration 2

Subscale	Chorus	Ranks	*n*	Mean Rank	Sum of Ranks	*z*	*p*	Effect Size
Course Satisfaction	A	Neg.	2	2.5	5.0	-3.00	.003**	-.80
		Pos.	12	8.3	100.0			
		Ties	0	-	-			
	B	Neg.	1	4.5	4.5	-2.88	.004**	-.77
		Pos.	12	7.2	86.5			
		Ties	1	-	-			
	C	Neg.	1	3.5	3.5	-2.04	.042*	-.68
		Pos.	7	4.6	32.5			
		Ties	1	-	-			
Learning Outcomes	A	Neg.	2	6.0	12.0	-2.36	.018*	-.63
		Pos.	11	7.2	79.0			
		Ties	1	-	-			
	B	Neg.	2	6.0	12.0	-2.55	.011*	-.68
		Pos.	12	7.8	93.0			
		Ties	0	-	-			
	C	Neg.	2	2.5	5.0	-2.10	.036*	-.70
		Pos.	7	5.7	40.0			
		Ties	0	-	-			

Note. Iteration 2-1: n = 14; Iteration 2-2: n = 14; Iteration 2-3: n = 9 refers to the number of matched questionnaires collected for analysis.

Neg. = Negative; Pos. = Positive; Benchmark value for comparison = 12 (4 items × Likert midpoint 3).

*p < .05. **p < .01. ***p < .001.

5.5.3 Open-Ended Pre-Class Questions

To explore students' prior conceptions of vocal production, three open-ended questions were included in the pre-questionnaire: "How do you adjust the volume?", "How do you adjust the pitch?", and "How do you adjust the timbre?". A total of 39 valid responses were collected for each question. Student responses were coded using a semi-structured thematic coding approach. The analysis began with a predefined set of five general categories applicable to all three questions:

- **Code 0**: "Do not know", unclear, or irrelevant
- **Code 1**: Scientifically aligned explanations (target answers)
- **Code 2**: Intuitive or affective strategies, such as relying on feeling, imagination, or listening
- **Code 3**: Use of scientific terms or conceptual references (e.g., frequency, amplitude, resonance)
- **Code 9**: Other, uncategorizable, or ambiguous responses

The numeric labels were assigned solely for coding purposes and do not imply any ordinal meaning. The predefined codes were determined based on anticipated response types: students might give irrelevant or unclear answers (Code 0), provide scientifically accurate explanations aligned with target concepts (Code 1), describe intuitive or feeling-based strategies commonly observed in the chorus context (Code 2), or mention scientific terms indicating the use of scientific knowledge (Code 3). Code 9 was reserved for responses that did not fit the other categories.

Additional codes were inductively generated for each question to capture specific language patterns and reasoning that emerged frequently. Multiple codes were allowed per response to account for the complexity of students' thinking.

1. Question 1: How do you adjust the volume? The expected scientific explanation was adjusting the amount of airflow or controlling the breath, often described in everyday terms such as "using more breath" or "controlling breath support". This reflects a basic physiological mechanism for amplitude modulation.

In addition to the general categories, two specific behavioral misconceptions were observed frequently and assigned unique codes:

- **Code 4**: Applying muscular force (e.g., "using abdominal strength", "pushing with the body")
- **Code 5**: Using the throat or squeezing the neck (e.g., "using the throat", "tensing the neck")

These reflect common misconceptions in vocal practice—namely, the assumption that volume comes from force or tension rather than airflow control.

The coding frequency for Question 1 is summarized in **Table 5.7**.

Table 5.7

Frequencies of Codes for Question 1: "How do you adjust the volume?"

Code	Description	Frequency	Percentage
0	Do not know/unclear/irrelevant	2	5.4%
1	Adjusting airflow*	10	27.0%
2	Relying on feeling/imagination/listening	6	16.2%
3	Scientific terms (e.g., amplitude)	5	13.5%
4	Using force/abdominal strength	19	51.4%
5	Using throat/neck tension	4	10.8%
9	Other/ambiguous	1	2.7%

Note: $n = 37$ refers to the number of matched questionnaires collected for analysis. Percentages may exceed 100% due to multiple codes per response.

*the expected correct answer.

Over half of the students (51.4%) associated volume adjustment with physical exertion (Code 4), frequently mentioning abdominal force or body strength. An additional 10.8% explicitly referred to throat tension (Code 5), indicating a belief that loudness is achieved through pressing or tightening the throat. Together, these two categories accounted for the majority of responses. By contrast, only 27.0% of students provided responses aligned with breath control (Code 1), the scientifically accurate mechanism for adjusting vocal volume. A small number used scientific terms (Code 3), and 16.2% relied on intuitive or affective strategies (Code 2), such as imagining the sound or singing “by feel.”

These results suggest that many students equate volume with force rather than airflow, a pattern consistent with common misconceptions observed in real-world vocal practice, where “singing louder” is often attempted through muscular strain rather than breath management.

2. Question 2: How do you adjust the pitch? The accurate scientific explanation involves adjusting the tension of the vocal folds, which directly affects the frequency of vocal fold vibration and thus the perceived pitch. Appropriate student responses might refer to “tightening or loosening the vocal cords” or “controlling the vocal muscles.”

This question did not result in the development of any additional codes beyond the original five-category scheme. The coding frequency for Question 2 is presented in **Table 5.8**.

Table 5.8

Frequencies of Codes for Question 2: “How do you adjust the pitch?”

Code	Description	Frequency	Percentage
0	Do not know/unclear/irrelevant	5	13.5%
1	Adjusting vocal fold tension*	4	10.8%
2	Relying on feeling/imagination/listening	25	67.6%
3	Scientific terms (e.g., frequency, airflow)	2	5.4%
9	Other/ambiguous	3	8.1%

Note: n = 37 refers to the number of matched questionnaires collected for analysis. Percentages may exceed 100% due to multiple codes per response.

*the expected correct answer.

Most students (67.6%) described perceptual or intuitive strategies (Code 2), such as listening to external references, matching pitch by feel, or imagining the target sound. These responses reflect a reliance on inner hearing or musical experience rather than an understanding of how pitch is physically controlled. Only a small number of students (10.8%) mentioned vocal fold adjustment (Code 1), the physiological mechanism most directly responsible for changing pitch. A few responses used scientific terms such as “frequency” or "airflow" (Code 3), but these were limited in both number and clarity.

Compared to the other two questions, this item revealed the strongest dependence on personal perception, suggesting that many students can execute pitch adjustments in practice, yet are less aware of how pitch is mechanically produced.

3. Question 3: How do you adjust the timbre? The expected response involves adjusting the shape and configuration of the resonance cavities, such as modifying the oral cavity, pharynx, or mouth opening. These changes influence the spectral characteristics of the voice and contribute to perceived timbre. Common descriptions may include "adjusting the mouth shape" or "changing the vocal tract."

In addition to the general categories, three recurring patterns were identified and coded separately:

- **Code 4**: Adjusting vocal placement or resonance position (e.g., "changing the place where I sing," "shifting where the sound vibrates")
- **Code 5**: Mimicking external sounds or people (e.g., "imitating the teacher's timbre," "copying another singer")
- **Code 6**: Engaging in exploratory or trial-based behaviors (e.g., "trying different ways," "experimenting with different tones")

These strategies reflect students' experiential engagement with vocal timbre, especially when direct explanations of resonance were absent.

The coding frequency for Question 3 is summarized in **Table 5.9**.

Most students (37.8%) referred to adjusting parts of the resonance cavity (Code 1), such as changing the shape of the mouth or throat. A notable number (21.6%) mentioned shifting vocal placement (Code 4), and 16.2% described mimicking a specific voice or sound (Code 5). Some students (8.1%) reported trying different vocal strategies (Code 6), while a small portion used scientific language (Code 3) or intuitive descriptions (Code 2). A few responses were unclear or did not relate to any specific mechanism (Code 0 or 9).

Table 5.9

Frequencies of Codes for Question 3: "How do you adjust the timbre?"

Code	Description	Frequency	Percentage
0	Do not know/unclear/irrelevant	2	5.4%
1	Adjusting the resonance cavity*	14	37.8%
2	Relying on feeling/imagination/listening	2	5.4%
3	Scientific terms (e.g., waveform, overtones, muscles)	2	5.4%
4	Adjusting vocal placement or resonance position	8	21.6%
5	Mimicking others or external models	6	16.2%
6	Trying out different vocal strategies	3	8.1%
9	Other/ambiguous	2	5.4%

Note: n = 37 refers to the number of matched questionnaires collected for analysis. Percentages may exceed 100% due to multiple codes per response.

*the expected correct answer.

Although this question had the highest proportion of scientifically accurate responses, it also involved the largest variety of additional codes, suggesting that students may hold divergent conceptions about how timbre is adjusted.

Summary. The analysis of students' responses to the three pre-class questions reveals varying degrees of conceptual clarity and strategy use across the dimensions of volume, pitch, and timbre. While the question on volume adjustment elicited the most physically oriented responses—often linking loudness to bodily force or throat tension—the question on pitch revealed a heavy reliance on perceptual strategies, with few students demonstrating awareness of how pitch is physiologically controlled. In contrast, the question on timbre produced the highest rate of scientifically accurate responses, yet also the widest variety of additional strategies, ranging from resonance placement to imitation and experimentation.

Across the three questions, the proportion of scientifically accurate responses (Code 1) remained low, ranging only from 10.8% to 37.8%. This result highlights a significant gap in students' conceptual understanding of vocal mechanisms prior to instruction, underscoring the importance and necessity of the interdisciplinary course in supporting more accurate and transferable knowledge of sound production.

5.5.4 Student Worksheets

In Iteration 2, a total of 44 worksheets were collected from three participating choruses: Chorus A (n = 15), Chorus B (n = 17), and Chorus C (n = 12). For each group, the completion rate and accuracy rate were calculated as the average of each student's individual worksheet performance across all items.

The average completion rate across all students was .93 (SD = .16), and the average accuracy rate was .85 (SD = .13), indicating that students generally engaged with the worksheet and performed well on most items.

When broken down by group:

- **Chorus A** showed the highest completion (M = .99, SD = .03) and accuracy (M = .89, SD = .08) rates;
- **Chorus C** also performed well (completion: M = .88, SD = .24; accuracy: M = .89, SD = .11);
- **Chorus B** exhibited lower average performance (completion: M = .90, SD = .16; accuracy: M = .79, SD = .16), with greater within-group variation.

Table 5.10 presents the completion and accuracy rates for each worksheet item across all groups. Completion rates were consistently high (ranging from .84 to .98), while accuracy rates showed more variation (ranging from .46 to 1.00). Items such as II-1, II-2, III-1, III-2, and V showed uniformly high accuracy (≥ .93), whereas I-1 and IV-1 had lower average accuracy, suggesting these may have been more challenging for students.

Table 5.10

The Completion Rate and Accuracy Rate of Each Item on the Student Worksheet in Iteration 2

Item	Completion Rate				Accuracy Rate			
	2-1	2-2	2-3	AVE	2-1	2-2	2-3	AVE
I-1	1.00	.94	.92	.95	.73	.38	.82	.62
I-2	1.00	.94	.92	.95	.73	.69	.91	.76
I-3	.93	.82	.92	.89	.93	.86	1.00	.92
II-1	1.00	.94	1.00	.98	1.00	.94	1.00	.98
II-2	1.00	.88	1.00	.95	.93	.87	1.00	.93
III-1	1.00	.94	.92	.95	1.00	1.00	1.00	1.00
III-2	1.00	1.00	.92	.98	1.00	1.00	1.00	1.00
IV-1	1.00	.82	.75	.86	.60	.50	.22	.46
IV-2	1.00	.76	.75	.84	.93	.69	.78	.80
V	1.00	.94	.75	.91	1.00	.94	.89	.95

Note. Iteration 2-1: *n* = 15; Iteration 2-2: *n* = 17; Iteration 2-3: *n* = 12 refers to the number of worksheets collected for analysis.

I-1 refers to the first item of Section I, III-2 refers to the second item of Section III, and Section V includes only one item.

1. Item I-1: How does a trumpet produce sound? This item was designed to assess students' understanding of the fundamental mechanism of sound production in wind instruments. The expected scientific response was that a trumpet produces sound by air passing through the lips, causing them to vibrate. This analogy allows the teacher to later relate it to the function of the human vocal folds, which also rely on airflow-induced vibration.

Across all groups, the average accuracy rate for this item was .62, with noticeable variation among the three choruses: .73 in Chorus A, .38 in Chorus B, and .82 in Chorus C. This makes it one of the lowest-scoring items on the worksheet, especially for Chorus B.

A large number of incorrect responses focused solely on the vibration of the lips, without mentioning the role of airflow. This omission suggests a partial understanding of the mechanism. Upon reviewing classroom footage, the researcher found that while lip vibration was explicitly emphasized during the activity, the explanation of air passing through was more implicit. This lack of emphasis likely led to the widespread omission in student responses.

These results indicate that although students may have retained the visible or emphasized aspect of the phenomenon (lip vibration), they did not always grasp or recall the invisible but essential component—airflow—as part of the mechanism.

2. Item I-2: How does a trumpet change its pitch? This item aimed to assess whether students could distinguish between the two mechanisms by which pitch is changed on a trumpet: (1) adjusting lip tension and airflow to select different harmonics within a given tubing length, and (2) changing the length of the tubing (via valve combinations) to shift the entire harmonic series. The expected answer included both components, highlighting that pitch control on the trumpet involves both embouchure technique and mechanical adjustment.

The average accuracy rate for this item was .76, with notable variation across groups: .73 in Chorus A, .69 in Chorus B, and .91 in Chorus C. While the overall performance was better than in Item I-1, the variation and response patterns suggest that students often had incomplete answers.

The most common incorrect or partially correct responses mentioned only the change in tubing length, reflecting the students' prior knowledge or assumptions about trumpet mechanics, namely, that pressing valves alters pitch. The newly introduced idea that airflow and lip tension also influence pitch was rarely incorporated, suggesting that students had not yet internalized or applied this new information to the trumpet-playing context.

These results indicate that while students were able to recall familiar mechanical aspects of pitch adjustment, they were less likely to integrate recently introduced concepts that involve the control of sound within a fixed physical structure.

3. Item IV-1: How do larger and smaller guitars differ in volume? This item was designed to assess students' understanding of how resonance cavity size interacts with frequency to influence perceived loudness. The expected response was that larger guitars produce louder low-frequency sounds, while smaller guitars tend to amplify higher frequencies more effectively. In other words, the difference in volume is frequency-dependent, not absolute.

The average accuracy rate for this item was .46, the lowest among all worksheet items, with particularly low performance from Chorus C (.22). This indicates that the majority of students did not identify the conditional nature of volume differences across pitch ranges.

Most incorrect responses stated simply that larger guitars are louder, treating "volume difference" as a general or absolute comparison rather than one that varies by frequency. This pattern suggests a potential misreading of the question, as the prompt asked about "differences in volume" but did not specify whether this referred to overall loudness or pitch-specific loudness.

Although the teacher had emphasized the correct interpretation during instruction, the widespread misunderstanding suggests that students may not have revised their initial assumptions. The way the question was phrased may have allowed students to default to pre-existing mental models about size equating to loudness, without activating the target concept of frequency-dependent resonance amplification.

4. Item IV-2: How do larger and smaller guitars differ in timbre? This item was designed to assess students' ability to describe qualitative differences in timbre between instruments of different sizes. The expected response was that larger guitars tend to have a fuller, warmer, or more resonant timbre, while smaller guitars sound brighter or more focused. These descriptions reflect differences in how the body size and resonance cavity shape influence sound quality, rather than measurable loudness or pitch.

The average accuracy rate for this item was .80, with moderate variation across groups: .93 in Chorus A, .69 in Chorus B, and .78 in Chorus C. While overall performance was higher than in Item IV-1, analysis of incorrect responses revealed a consistent pattern of misapplied reasoning.

Most incorrect responses stated that larger guitars amplify lower pitches and smaller guitars amplify higher pitches, which is the correct answer to Item IV-1. These students likely recalled the correct information from the previous question. However, they applied it in the wrong context, failing to shift from a discussion of volume to a discussion of timbre.

This suggests that although students had memorized the teacher's explanation, they did not fully grasp the distinction between timbre and frequency-specific loudness, leading to conceptual confusion between the two. The surface similarity of the two prompts may have further contributed to the error.

5.5.5 Field Notes

To better understand how students engaged with the interdisciplinary course and how instructional design influenced their responses, this section presents two sets of qualitative observations from the three implementations of Iteration 2. The first focuses on patterns of student participation and classroom dynamics across different choral groups. The second highlights recurring instructional features and challenges observed throughout the sessions, with particular attention to how specific teaching strategies, such as the sequencing of concepts, the use of analogies, and questioning techniques, affected student comprehension and engagement.

1. Classroom Observations. In Chorus A, student engagement was moderate and varied across activity types. Hands-on demonstrations, such as swinging the whirly tube and using a jump rope, successfully captured students' attention and generated some participation. However, classroom discussions revealed uneven involvement: while a few students responded when prompted, many were hesitant or struggled to articulate their understanding of key concepts like resonance and timbre. These patterns suggest that while the physical activities were effective in attracting attention, additional conceptual scaffolding may have been necessary to support deeper understanding and verbal expression. The overall atmosphere was respectful and comfortable, but lacked the dynamism seen in more interactive sessions.

Chorus B exhibited more polarized patterns of engagement. Some students were highly responsive—volunteering for demonstrations, answering questions, and contributing actively—while others remained passive or disengaged throughout the session. Individual differences were particularly noticeable: one student repeatedly interrupted with off-topic comments, while another demonstrated anxiety when asked to speak. Students who sat farther from the teacher tended to participate less, although at least one student demonstrated accurate musical recall despite limited verbal interaction. While the overall classroom tone was positive, these disparities in participation highlight the need for differentiated strategies to support a wider range of learners.

Student participation in Chorus C was generally lower than in the previous groups. Many students arrived late or left early, and several were not official members of the chorus, which may have affected their investment in the session. A few students responded well to demonstration-based activities, but most remained silent during class discussions. Even when invited to share their answers, no students volunteered, suggesting low confidence or motivation. Unclear instructional transitions may have compounded the muted peer interaction and flat classroom energy, but the overall participation trend points to challenges in engaging a less cohesive or transient group of learners.

2. Instruction Observations. Several recurring instructional issues emerged across the three implementations, offering insight into areas where the teaching design could be refined to better support student learning and classroom interaction.

One consistent challenge involved the sequencing of overtone-related concepts. In all three sessions, students were often asked to identify overtone pitches on a piano diagram before being given a formal explanation of what overtones are. This reversed instructional order led to observable confusion, especially among students with limited prior exposure to harmonic theory. The misalignment between concept introduction and task execution suggests a gap in scaffolding. A more effective strategy would begin with defining key terms, such as "fundamental frequency" and "overtone," and illustrating them with audio-visual examples before introducing application tasks like notation or comparison.

Another instructional pattern involved the use of analogies to explain abstract concepts such as timbre and harmonic structure. Examples like ramen broth and toppings, or Seurat's pointillism, were intended to make complex ideas more accessible. While these analogies were creative, they sometimes overshadowed the core scientific concepts or were extended without a clear explanatory focus. In several cases, students appeared more engaged with the metaphor than the intended physics principle. This highlights the need for well-structured analogies that are concise, explicitly mapped to target concepts, and followed by clarifying discussion to ensure accurate interpretation.

A third issue concerned spontaneous questioning and classroom response management. As the teacher became more confident, they increasingly incorporated impromptu questions meant to prompt critical thinking or connect to prior knowledge. While this flexibility reflected instructional growth, the execution was occasionally problematic. Questions were sometimes posed without sufficient wait time or clear signals for student response, leading to awkward silences or confusion, particularly in Chorus A and C. Fillers like "right?" further blurred whether a response was expected. These findings emphasize the importance of intentional questioning techniques that provide clarity and space for meaningful student participation.

5.5.6 Teacher Interviews

To deepen the understanding of how instructional adjustments affected student engagement and learning, this section synthesizes field notes and post-session reflections from the course instructor (Teacher Z) and an observing teacher (Teacher L). Across the three implementations of Iteration 2, each chorus presented distinct classroom dynamics, prompting adaptive teaching strategies and iterative refinement of the lesson design. By documenting these classroom interactions, instructional decisions, and observed student behaviors, this section highlights both the challenges and the affordances of implementing an interdisciplinary course in real-world choir settings. The following subsections offer a close look at how teaching unfolded in each context and how teachers made sense of student responses, instructional pacing, and the evolving role of science within choral practice.

1. Teacher Z in Iteration 2-1. Several modifications were made to the course design in this iteration to lower the threshold for understanding and increase student engagement. The overall duration of the course was shortened, and theoretical explanations were reduced in favor of example-based instruction, allowing students to follow the lesson flow more easily. The course was structured around three core themes—vocal and instrumental sound production, overtones and timbre, and resonance chambers—with a final review session to help students consolidate their understanding. The design also intentionally left conceptual gaps to encourage students to ask questions and engage in self-guided exploration beyond the lesson.

The instructional activities emphasized hands-on experiences and phased progression. Activities such as “tube swinging” and “jump rope” were designed to help students physically experience sound phenomena, which were then connected to scientific explanations. Differentiated instruction was applied by assigning extended observation or explanatory tasks to advanced students, while those who needed more help were guided by the teacher or supported by peers. Worksheets and videos were integrated with guiding questions to focus student attention. However, observations revealed that some teacher questions were phrased ambiguously, making it unclear whether student responses were expected. Future implementations could benefit from clearly distinguishing rhetorical prompts from actual questions to enhance classroom interaction.

Students showed generally positive engagement with the course. Those without prior background knowledge were able to grasp the content, indicating that the revised design effectively reduced the cognitive load. Meanwhile, students with backgrounds in chorus or physics demonstrated deeper thinking and asked follow-up questions, showing the course’s potential to support advanced learners as well. Hands-on activities noticeably improved student concentration, particularly after physically engaging tasks like “tube swinging.” Students’ understanding of overtones, resonance, and timbre varied depending on their musical experience, with those trained in chorus displaying quicker comprehension. Nevertheless, classroom interactions remained somewhat limited by the pacing and facilitation style; future adjustments could include more deliberate scaffolding during review sessions to encourage broader student participation.

2. Teacher Z in Iteration 2-2. The students in Chorus B exhibited noticeably different learning traits compared to those in previous iterations. Unlike Chorus A, where students tended to ask questions when encountering confusion, students in Chorus B showed a stronger tendency toward internal processing. Rather than seeking immediate clarification, they were more likely to engage in self-directed reflection when faced with cognitive dissonance. This made the lessons' built-in moments of inquiry and ambiguity especially impactful, stimulating deeper thought and engagement. Some students actively participated in discussions and even photographed key slides, indicating a strong interest in the content. As the teacher noted,

> *"I felt that their internal cognitive struggle was quite strong. Unlike students in Chorus A, who would ask questions whenever they did not understand, students in Chorus B tended to process things internally. As a result, the questions and uncertainties built into the lesson design had a greater impact on them."*
> (Teacher Z, personal communication, December 27, 2024).

However, not all students were equally involved. Several were more reserved or passive, and a few appeared disengaged, especially after the mid-session break. Although the classroom atmosphere remained generally respectful, the level of interaction was relatively low. Additionally, since students were allowed to choose their seats, more motivated students gravitated toward the front while others stayed in the back, resulting in uneven participation across the room.

To strengthen student engagement and reinforce key concepts, the second session of the lesson could incorporate more interactive activities. For instance, students could be invited to experiment with producing overtones themselves or to apply what they have learned about resonance and vocal mechanisms to adjust their timbre intentionally. These hands-on experiences would provide opportunities for embodied learning, deepen conceptual understanding, and help students make more explicit connections between scientific principles and their singing practices.

3. Teacher Z in Iteration 2-3. The implementation of Iteration 2-3 with Chorus C marked a turning point in the study, as both student reactions and instructional pacing revealed clearer patterns. While students initially appeared disengaged, their level of focus improved considerably as the session progressed, especially after interactive elements were introduced. The teacher noted that students responded well to singing activities and were better able to identify acoustic patterns when they actively vocalized rather than listened. This highlights the importance of embodied participation in helping students connect scientific principles with their own musical experience.

At this stage of the DBR process, the course had reached a relatively stable form. Iteration 2-3 demonstrated the growing coherence of the instructional design, with refinements based on earlier field trials yielding more consistent engagement and clearer learning outcomes. The shift to a phenomenon-based instructional strategy—presenting observable events first and then guiding students to uncover the underlying mechanisms—proved to be particularly effective. Rather than beginning with abstract theories, students were encouraged to investigate visible and audible phenomena, which better matched their intuitive learning processes.

The interdisciplinary theme of combining science and choral practice remained central to the curriculum's identity. According to the teacher, the success of this approach hinged on the choice of content: effective integration required topics that were strongly connected to both disciplines and relevant to students' experiences. While the fusion of acoustics and singing provided a meaningful foundation, it was suggested that more surprising or unconventional pairings could potentially spark even greater student curiosity in future iterations.

In terms of teaching context, the use of a chorus setting, rather than a general science or music classroom, proved to be a double-edged sword. On the one hand, students in the chorus were presumed to have stronger motivation and musical sensitivity, which supported deeper exploration of concepts like resonance and timbre. On the other hand, some students, especially in elective settings like Chorus C, participated with varying degrees of interest and preparation. Despite this, the course was viewed as highly feasible overall. With further streamlining of terminology, activity timing, and instructional scaffolds, the curriculum was seen as adaptable and implementable in similar chorus-based learning environments.

4. Teacher L. In this study, Teacher L served as the instructor for both Chorus B and Chorus C, providing firsthand observations of student characteristics and participation across two different groups. Importantly, Teacher L did not participate in the course design process and thus acted as an independent, external evaluator. This positioning allowed Teacher L to offer an objective assessment of the course's feasibility, usability, and relevance from the perspective of a typical chorus teacher. His feedback therefore reflects both insider knowledge of choral instruction and outsider detachment from the research team's design decisions, contributing valuable insights into how the curriculum could be adopted and adapted by other choral directors.

Teacher L observed that students in both Chorus B and Chorus C demonstrated a wide range of participation styles and personal characteristics, which influenced how they engaged with the interdisciplinary course. Some students remained quiet and peripheral during the lesson but still exhibited signs of understanding, such as offering corrections when something was misstated or responding nonverbally. One student, for example, often isolated himself during class yet showed intellectual engagement and later continued to attend rehearsals despite transitioning to a self-directed learning model. Another student, in contrast, frequently interjected with spontaneous thoughts that sometimes veered off-topic. While this behavior occasionally disrupted the lesson flow, it was also indicative of a more advanced and independent thought process. Teacher L reflected that such diversity in the classroom, though occasionally challenging, enriched the learning environment and revealed the chorus as a space where different identities and ways of thinking could coexist.

Regarding classroom questioning and student expression, Teacher L emphasized the importance of providing students with adequate time and scaffolding before expecting verbal responses. Some students, when called upon, found it difficult to articulate their thoughts on the spot, which sometimes led to awkward silences. Teacher L suggested that allowing students first to write down their thoughts, as was done in an earlier version of the course at Chorus A, could lower the pressure and make verbal sharing more accessible. He also pointed out that because traditional choral rehearsals rarely invite open discussion or student reflection, students may be unaccustomed to being asked for their input. This cultural gap between performance-based instruction and dialogic learning meant that teachers needed to develop more intentional strategies for drawing out student thinking.

After the lesson, Teacher L noticed meaningful changes in students' rehearsal behaviors. In particular, students began using more precise terminology during ensemble work, asking whether an issue was related to pitch or timbre and showing a greater awareness of vocal qualities. This demonstrated that students were not only retaining conceptual knowledge but were also beginning to apply it in practical, musically relevant ways. Although such changes were more apparent in some students than others, it affirmed the potential for interdisciplinary instruction to support long-term learning transfer beyond the immediate classroom context.

Teacher L regarded the curriculum as highly feasible and well-structured. The total duration of 100 minutes, divided across two sessions, was seen as manageable and compatible with the realities of high school scheduling. The materials—slides, worksheets, PVC tubes, jump ropes, and trumpet mouthpieces—were all considered accessible and easy to prepare. The lesson plan's clarity, with each activity mapped to corresponding slides and accompanied by detailed explanations, made it particularly useful. Teacher L recommended annotating scientific terms with optional extensions (e.g., "basic," "intermediate," or "advanced") so that teachers with different backgrounds could decide how much detail to include. This would also empower teachers to personalize the lesson based on their confidence and familiarity with the content.

Finally, Teacher L emphasized the curriculum's potential not only as a classroom resource but also as a teacher training tool. Many choral directors, he observed, have strong musical skills but limited training in pedagogy. This curriculum provided clear models for positive language use, student attention management, and lesson structure—all of which are crucial for effective instruction. He noted that many rehearsals, while instructional, lack planning around student engagement and conceptual progression. The design of this course, with its attention to student motivation, interactive pacing, and cognitive accessibility, could offer a valuable framework for both new and experienced teachers. He also suggested that the curriculum could be integrated into professional development workshops, especially for teachers preparing choruses for competitions, where a deeper understanding of vocal acoustics could enhance both teaching and performance outcomes.

When discussing the idea of positive behavioral support, Teacher L shared:

> *"I think this is helpful. Like, if I were teaching this course and also working as the chorus conductor, I honestly think it would be hugely beneficial to our regular rehearsals. Because usually, rehearsals are all about correcting mistakes. Furthermore, when you are correcting mistakes, you have to be fast and precise, so you end up negatively framing things. People tend to remember negative phrasing more clearly. Like, when I think about it now, what I remember most from before are all the 'don'ts' — do not do this, do not do that. However, I rarely remember the things we are supposed to do. So yeah, I think this part is helpful."*
>
> (Teacher L, personal communication, April 12, 2025)

This perspective highlights how the course's instructional style—especially its use of affirming language and constructive feedback—can directly enhance daily rehearsal practices by shifting attention from error correction to actionable, positive guidance.

5.6 Reflection

To refine the interdisciplinary course and enhance its applicability in real classroom contexts, Iteration 2 incorporated a range of design and research modifications based on insights gained from the first implementation. This section presents a multi-faceted reflection on these changes, focusing on both instructional revisions and research procedures. It begins by outlining the major shifts from Iteration 1 to Iteration 2, followed by smaller within-iteration adjustments made after each implementation. The section also reviews improvements in research design and explores how the course contributed to teacher learning and empowerment. Together, these reflections illustrate the iterative and adaptive nature of the DBR process.

5.6.1 Major Changes from Iteration 1 to Iteration 2

In the design of Iteration 2, the researcher made systematic revisions to the course's timing, instructional content, and teaching methods based on insights gained from the implementation and reflection of Iteration 1. These adjustments were aimed at responding to the practical needs of the teaching context and enhancing both the feasibility of the curriculum and student engagement.

1. Time Allocation. In terms of time allocation, the original structure of four sessions totaling 180 minutes was condensed into two sessions lasting 100 minutes in total. This change not only aligned better with school scheduling constraints and teachers' workload but also significantly improved students' learning conditions. According to feedback from Teacher Z in the Iteration 2-1 interview, the shorter duration helped students maintain focus and increased their level of participation. Worksheet data corroborate this: the completion rate for Chorus A in Iteration 2 reached 0.99, compared to 0.91 in Iteration 1. Teacher L similarly noted that 100 minutes was an appropriate length, given the limited attention span of high school students. Classroom observations also indicated that the three-hour session in Iteration 1 often led to student fatigue, particularly during the later stages involving discussion and hands-on activities. In contrast, the tighter pacing of Iteration 2, with a structured mid-session break, allowed for better maintenance of concentration and emotional regulation. Overall, although shortening the course necessitated trade-offs in content coverage and instructional strategies, it ultimately contributed to improved instructional quality and learning efficiency.

2. Instructional Content. Adjustments to instructional content focused on two main aspects: (1) reducing overly complex scientific theories and (2) increasing the use of real-life examples and interactive activities to lower abstraction and enhance accessibility. Teacher Z acknowledged that this simplification might feel shallow to students with prior knowledge or a science background, who might wish to explore the underlying mechanisms and theories more deeply. However, he also emphasized that the revised content allowed most students to more quickly grasp the core concepts, making it a reasonable trade-off. Teacher L added that the adjusted difficulty was more appropriate for chorus teachers and made implementation more manageable. Nonetheless, for academically advanced students such as those in Chorus B, who showed the highest pre-test scores across all five subscales of the Science Learning Interest Scale, it was suggested that the curriculum retain optional extensions for deeper exploration. Worksheet results also supported these content adjustments: Chorus A's average accuracy rate increased from 0.54 in Iteration 1 to 0.89 in Iteration 2, indicating stronger conceptual understanding. Student feedback further suggested that relatable examples from daily life facilitated their comprehension of acoustic phenomena. Although field notes revealed that the teacher's use of analogies was not yet fully refined, occasionally leading to unclear or tangential explanations, these examples generally helped foster a positive classroom atmosphere and boosted learning motivation.

On the other hand, the inclusion of interactive activities was another key direction of revision. Both Teacher Z and Teacher L affirmed that these activities were effective in capturing students' attention and sustaining classroom momentum. Teacher Z specifically noted that because Iteration 2 relied more on explanation and demonstration, it was even more important to incorporate interactive elements to distinguish the experience from typical school instruction. The researcher observed that while these additions raised the threshold for teaching preparation, requiring materials such as whirly tubes, jump ropes, and trumpet mouthpieces, they also demanded greater instructional competence, particularly in voice-related activities like overtone control and timbre adjustment. These tasks required vocal expertise and improvisational skill for in-class demonstration. Fortunately, Teacher Z possessed both the technical ability and enthusiasm to carry out these demonstrations, resulting in strong instructional outcomes. Therefore, the final version of the teaching plan included recommendations for other teachers to choose whether to implement such activities based on their confidence and capabilities, ensuring flexibility while maintaining instructional quality.

3. Teaching Methods. While Iteration 1 employed cooperative learning and inquiry-based instruction, encouraging students to think through peer discussions and open-ended questions, Iteration 2 adopted a more structured and teacher-centered approach. In response to limited instructional time and consideration of teachers' disciplinary backgrounds, direct instruction was chosen as the primary strategy for its efficiency and familiarity. Teacher Z noted that this method tended to place students in a passive role, and without planned activities, their attention might diminish within 15 minutes. Consequently, the revised teaching plan interspersed several interactive segments within lectures to enhance engagement. Although direct instruction may not be the most engaging method, it proved to be a pragmatic and effective choice for delivering essential scientific content within a constrained timeframe while making the curriculum more accessible to chorus teachers.

Summary. In sum, the design of Iteration 2 successfully integrated and responded to the reflections from the first phase of the study. Through practical revisions, it demonstrated improved relevance and feasibility in real classroom settings, enhancing student understanding and participation while also strengthening teacher confidence and willingness to adopt the curriculum. These outcomes underscore the value of DBR in iteratively refining instruction in response to contextual realities.

5.6.2 Minor Changes within Iteration 2

To clarify the progression of the course adjustments, each version of the teaching plan is named as follows: Version 2.0 refers to the initial design of Iteration 2. After a trial teaching session and discussions with Teacher Z, Version 2.1 was created and used in Iteration 2-1 with Chorus A. Following the implementation of Iteration 2-1, Version 2.2 was developed based on teacher interview feedback and used in Iteration 2-2. Similarly, Version 2.3 was produced after interviews for Iteration 2-2 and used in Iteration 2-3. After three implementations, the researcher added the last adjustment directions into Version 2.4, which is the version presented in Section 5.2 on course design.

1. Version 2.1. After the trial teaching session, the researcher reflected that Lesson 1's

"Development Activity 3: Constraints of Overtone Production" did not run smoothly. Originally, students were asked why overtone pitches are fixed, followed by a demonstration of the whirly tube. It became clear that the initial question was too abrupt, and the sequencing of the whirly tube and jump rope activities failed to capitalize on the peak of student attention. In Version 2.1, the whirly tube demonstration was moved before the question to allow students to observe the phenomenon first and then reflect on the cause, aligning better with the principles of PhBL and optimizing students' focus during the learning sequence.

Teacher Z also suggested that the piano keyboard diagram used in the slides for explaining overtone calculations should be included in the worksheet to help students identify pitch locations. Regarding the summary activity at the end of Lesson 1, Teacher Z noted that both the violin and timpani tuning mechanisms could be reasonably compared to vocal fold function, prompting revisions to the instructional explanation. Other unclear or supplementary areas were marked in blue within the lesson plan, such as added introductory explanations or the removal of potentially confusing text. These revisions were compiled into Version 2.1 for use in Iteration 2-1.

2. Version 2.2. In Lesson 2's "Development Activity 2: Human Resonance Spaces," the teacher originally replayed the overtone singing video first and then summarized how singers enhance overtones. However, classroom observations revealed that since overtone control largely involves internal mouth cavity adjustments, these changes were not externally visible in the video, making it difficult for students to deduce the method. In Version 2.2, the sequence was reversed: the teacher first explained the technique for amplifying specific overtones and then replayed the video to reinforce understanding. The video thus served as a recap rather than a discovery prompt, and students were warned that internal vocal tract movements may not be externally observable.

Additionally, in Iteration 2-1, the researcher observed that "Development Activity 3: The Cause of Timbre" was not delivered fluently. In the follow-up interview, Teacher Z indicated the need for better conceptual scaffolding. Therefore, Version 2.2 provided a clear outline linking the three prior topics to the causes of timbre, aiming to support the teacher's explanation. Other observations were marked in red to flag potential difficulties noted in class, while blue annotations indicated added or revised content.

3. Version 2.3. Teacher Z noted that Lesson 2 had fewer interactive activities and recommended adding hands-on tasks related to overtone enhancement and timbre adjustment. As a result, Version 2.3 incorporated new interactive activities at the end of both "Development Activity 2: Human Resonance Spaces" and "Development Activity 3: The Cause of Timbre." Red annotations highlighted areas for further teacher attention—mostly revisions added in the previous version—while earlier red notes had been addressed, demonstrating the teacher's responsiveness to instructional feedback.

4. Version 2.4. After the third implementation, the researcher identified several instructional issues that persisted despite repeated teaching, suggesting design flaws rather than teacher unfamiliarity. These areas were revised accordingly.

In Lesson 1's "Development Activity 2: The Concept of Overtones," the overtone pitches from the trumpet video were initially introduced before defining the terms fundamental frequency, overtone, and overtone series. To improve instructional logic, these definitions were moved earlier in the sequence, with the overtone pitch mapping now placed at the end of the section.

In Lesson 2's "Development Activity 1: Resonance Box Size," a discussion question—"Why can't the double bass play high notes?"—was meant to prompt reflection on the relationship between resonance box size and timbral range. Previously, this question followed a video comparing large and small guitars, but the sequence disrupted the flow. In Version 2.4, the question was posed before the video to create anticipation and guide student observation, thereby aligning better with typical learning processes.

Finally, analysis of student worksheets revealed that some key ideas or answers were presented too implicitly in earlier versions. To address this, new annotations were added to the lesson plan, reminding teachers to highlight important explanations or cues during instruction explicitly. These refinements aim to improve clarity and ensure that all students can more readily connect classroom activities with core scientific concepts.

Summary. The differences across Iteration 2's lesson plan versions were relatively minor, focusing primarily on sequencing and clarification of instructional content. However, these nuanced revisions reflect careful pedagogical consideration and may serve as useful references for future curriculum designers.

5.6.3 Research Design

Several modifications were made to the research design in Iteration 2 to enhance the richness and diversity of the data collected. First, the number of participating choruses increased from one to three, and an additional teacher was interviewed. These changes broadened the scope of data sources and contributed to more comprehensive perspectives, allowing the study to examine the course's adaptability and effectiveness across different group contexts and teaching styles.

In terms of instrumentation, the pre/post questionnaires retained only the Science Learning Interest Scale, while two new tools were introduced: open-ended pre-class questions and the Learning Satisfaction Scale administered after the course. The open-ended questions provided deeper insights into students' prior conceptions, supporting more targeted lesson adjustments, while the satisfaction scale offered immediate feedback on students' perceptions of the lesson's clarity, relevance, and overall quality. Both additions successfully captured valuable data as anticipated, enriching the understanding of how students experienced and responded to the interdisciplinary course.

For field notes and teacher interviews, the lesson plan served as a structural reference for documentation, which significantly improved the precision of instructional observations and informed micro-level revisions to the teaching plan. This systematic alignment between the plan and observation ensured that data collection focused on key moments of teaching and learning, resulting in more actionable feedback for refining content, pacing, and classroom management.

In terms of research participants, instruments, and implementation procedures, three key aspects warrant further discussion: the differences among the participating choruses, reflections on the use of student worksheets, and the intervals between implementations.

1. Differences Among the Three Choruses. While the basic demographic and contextual information of the three choruses has been introduced in the earlier description of research participants, classroom implementation revealed that the actual variation in student characteristics was far greater than initially anticipated. These nuanced differences became evident only through direct observation and teacher interviews during the lessons. Therefore, this section presents these differences as part of the research reflections rather than as background information, highlighting how understanding and responding to students' diverse traits is crucial for the effective adaptation of interdisciplinary instruction in future practice.

Beyond the objective differences in gender composition, group size, and school ranking, the researcher identified distinct student characteristics across the three choruses through classroom observations and post-lesson teacher interviews.

Chorus A, led by Teacher Z, exhibited a relatively quiet classroom atmosphere despite the familiarity between the teacher and students. The researcher speculated that the students were deeply accustomed to the teacher's usual rehearsal style; thus, even when instructional strategies were altered, students responded passively out of habit. In Iteration 1, Teacher Z noted that although these students were diligent and motivated, they tended to be constrained by existing knowledge structures, requiring additional time to adapt to new content or learning approaches. Chorus A students also displayed a noticeable fear of making mistakes when answering questions, often waiting for the "correct answer" from the teacher. This behavior influenced the design of both Iteration 1 and Iteration 2 lesson plans, which intentionally minimized pressure during class discussions. On the other hand, this cautious attitude led students to ask questions when confused, enabling the instructor to clarify in real-time and providing observers with valuable insights into student comprehension.

Chorus B, which frequently collaborates with Chorus A, was also familiar with Teacher Z. The classroom atmosphere was notably more active, with several students responding enthusiastically. Compared to the other groups, Chorus B demonstrated the greatest individual variation: some students were consistently eager to participate, while others appeared disengaged. Teacher L explained in interviews that two such students had special education needs—one later transitioned to home schooling and was actively engaged in stock trading. At the same time, the other, diagnosed with an autism spectrum disorder (Asperger's Syndrome), regularly visited the school counseling office at lunch. Interestingly, Chorus B scored the highest in pre-test measures of ISL, both in terms of mean and median scores, suggesting a stronger baseline engagement with science content.

Chorus C, by contrast, was less familiar with Teacher Z, and Teacher L described the students as less self-directed and more passive in classroom settings. The atmosphere was comparatively subdued. According to Teacher L, students in Chorus C generally exhibited lower cognitive readiness and motivation, often requiring multiple explanations to grasp key concepts and showing little enthusiasm for group-related activities. However, they tended to comply readily with teacher instructions, placing greater demands on teacher experience and classroom management skills.

In summary, despite the geographic proximity of the three choruses and the close collaboration among conductors, there were substantial differences in student profiles and classroom dynamics. Nevertheless, the course was successfully implemented across all three groups, contributing to measurable gains in students' ISL, demonstrating the curriculum's adaptability and broad applicability.

2. Reflection on Student Worksheets. The role of student worksheets shifted notably between Iteration 1 and Iteration 2. Originally used as end-of-class reflection tools, the worksheets in Iteration 2 were integrated directly into classroom instruction as guided notes and in-lesson exercises. Students were thus expected to complete them with as much accuracy as possible.

Upon analyzing the worksheet responses, two recurring issues emerged: incomplete answers and misinterpretation of questions. The former was often linked to a lack of emphasis in video materials or teacher explanations; this prompted the inclusion of teacher reminders about worksheet completion in the final version of the lesson plan. The latter typically stemmed from ambiguous question phrasing or unclear instructions, leading to revisions in item wording and the addition of explanatory notes in the teaching plan to reduce misunderstanding.

3. Implementation Intervals. The three implementations of Iteration 2 occurred within a short timeframe, with only a two-day gap between Iteration 2-2 and Iteration 2-3. This limited the extent of possible adjustments between sessions and left insufficient time to analyze student worksheets and questionnaire data prior to the next round. Consequently, all revisions—except those in Version 2.4—were based solely on field notes and teacher interviews.

Looking ahead, it is advisable to ensure adequate time between each implementation to allow for comprehensive analysis and reflection. Such spacing would better align with the iterative intent of DBR and enable more meaningful refinements based on full data review.

Summary. In sum, the revised research design in Iteration 2 allowed for more robust and nuanced data collection through the inclusion of additional participant groups, expanded instrumentation, and improved documentation methods. The comparative analysis across three choruses highlighted the importance of contextual factors in shaping instructional effectiveness. Meanwhile, the integration of worksheets into real-time instruction and the compressed implementation schedule offered valuable insights into the practical challenges of iterative refinement. Together, these reflections underscore the need for both methodological flexibility and strategic planning in DBR.

5.6.4 Teacher Empowerment

In the reflection on Iteration 1, the researcher identified that choral conductors often lack formal pedagogical training and require additional support. In response, Iteration 2 incorporated several strategies to enhance teacher readiness. Beyond providing a more detailed lesson plan, a model teaching demonstration was conducted prior to the first implementation to help the instructor become familiar with the content and activities. Furthermore, the researcher found that the most effective way for instructors to gain confidence was simply through repeated practice. Not only did teaching this course increase students' scientific interest and improve their vocal technique, but it also appeared to contribute to the teachers' professional development, as detailed below.

1. Teacher Z's Growth Through Teaching. Across the three implementations, the researcher observed noticeable progress in Teacher Z's delivery—from the tentative and disjointed instruction in Iteration 2-1, to the more natural handling of students with special needs in Iteration 2-2, and finally to the adaptive inclusion of extra interactive activities in Iteration 2-3. This progression suggests that the "learning-by-doing" principle applies well to chorus instructors: with a well-structured teaching plan, they can become more confident and effective through repeated implementation. In interviews, Teacher Z frequently attributed classroom challenges to a lack of familiarity with the materials, noting that it was difficult to prepare in advance fully. Therefore, repeated teaching was essential for mastery. For future teachers intending to adopt this course, it is recommended not only to review the teaching materials thoroughly but also to conduct one or two trial runs to ensure optimal delivery.

2. Contributions to Teacher Professional Development. In Iteration 1, Teacher Z extended the learning experience into regular rehearsals by designing vocal exercises related to the oral cavity space. On the other hand, Teacher L observed a shift in Chorus B after completing the course: students became more attuned to rehearsal instructions. They expected greater clarity, which prompted Teacher L to reflect on the precision of his language and even sparked interest in exploring the science of vocal sound further. Recognizing this potential, the researcher integrated more rehearsal-enhancing strategies into the Iteration 2 lesson plan.

Teacher L also noted that the course had a profound impact on his instructional mindset. For example, the use of "positive behavior support"—originally added to the script as a humorous touch—prompted serious reflection. He began questioning whether his usual rehearsal style leaned too heavily on criticism and sarcasm, and upon experimenting with more positive reinforcement, he noticed a clear improvement in the rehearsal atmosphere.

While the course was initially designed to enhance students' ISL, with secondary goals of fostering musical engagement and improving choral attitudes, no significant changes were detected through formal measurement tools. Nevertheless, teacher interviews revealed that the course unexpectedly heightened both student awareness and teacher intentionality. From the researcher's perspective, chorus rehearsals are rich educational settings, and thoughtfully designed curricula tailored for chorus instructors could help transform the rehearsal environment into a more engaging and pedagogically informed space.

Summary. In conclusion, Iteration 2 not only advanced student learning but also empowered teachers through structured support and iterative practice. Teacher Z's progression across implementations exemplified how repeated engagement with a clear instructional framework can foster pedagogical confidence and adaptability. Meanwhile, both teachers reported that the course prompted deeper reflection on instructional language, classroom dynamics, and even personal teaching philosophy. These findings highlight the potential of interdisciplinary curricula not only to enhance student outcomes but also to serve as a catalyst for meaningful teacher professional development, particularly in rehearsal-based educational contexts where formal pedagogy is often underemphasized.

Chapter 6 Discussion

This chapter synthesizes key insights from the design, implementation, and evaluation of an interdisciplinary course that integrates science and music to enhance students' ISL. Guided by three research questions, the discussion is organized into three main sections. The first section (6.1) addresses critical design principles, exploring how the course was structured to align with students' musical needs while incorporating accessible scientific content and interactive pedagogical strategies. The second section (6.2) examines the extent to which the course influenced students' ISL, highlighting shifts in both situational and personal interest as well as qualitative indicators of engagement and reflection. The final section (6.3) turns to practical challenges and opportunities encountered during implementation, focusing on the perspectives of teachers, students, and the researcher. Together, these findings offer a comprehensive understanding of how interdisciplinary curriculum design can meaningfully support science learning in authentic educational settings.

6.1 RQ1: What design principles can be derived from the iterative development of an interdisciplinary course that integrates science and music to stimulate students' ISL?

This section addresses RQ1 by identifying key design principles that emerged through the iterative development and implementation of the interdisciplinary course. Drawing on field observations, student responses, and teacher interviews across both iterations, five major considerations were distilled. These principles reflect the pedagogical shifts and content adjustments made to align the course with the practical realities of choral instruction while enhancing students' ISL. Rather than approaching science as the central focus, the course design emphasized relevance to students' musical experiences, clarity of instruction, and cognitive accessibility (Aikenhead, 2006; Rule, 2006). Each of the following subsections discusses one design consideration, supported by data and reflections from the course development process.

6.1.1 Selecting Topics Based on Students' Choral Needs

In both iterations of the course design, "how to adjust timbre" was chosen as a core instructional focus. This decision was based on three considerations. First, compared to volume and pitch, the mechanisms underlying timbre are more abstract and complex, making them more difficult for students to understand. The researcher observed that this concept is one of the most commonly encountered yet least consciously addressed aspects of vocal technique among chorus students. This observation was supported by responses to the open-ended pre-questionnaire in Iteration 2: most students were unable to articulate specific mechanisms for adjusting timbre. Instead, they tended to rely on imitation or trial-and-error strategies, often using vague terms such as “placement,” reflecting the presence of numerous alternative conceptions. In addition, Teacher Z stated in the post-course interview for Iteration 1 that if the course were to be implemented again, “adjusting timbre” should remain the central topic, as it is both essential for chorus members and relatively accessible through practice.

This design approach also departs from the structure of many previous interdisciplinary courses (Crowther, 2012; Tojeiro-Pérez & Gillanders, 2024), which typically place science concepts at the center and use music as a supplementary tool to stimulate interest or support understanding. In contrast, this study began from the practical needs of chorus instruction—specifically, the improvement of vocal technique—and then incorporated scientific knowledge to support that goal. In doing so, it offers a reversed design logic: one that foregrounds students’ real-world interests rather than abstract scientific content.

Underlying this approach is a broader critique of the dominant view of science in formal education. Science is often framed as objective, authoritative, and intrinsically valuable—a subject linked to high-stakes assessments and academic success (Aikenhead, 2006; Osborne et al., 2003). While this positioning reinforces its importance, it may also contribute to students’ perception of science as distant, rigid, or unengaging. By embedding scientific concepts within a context that students care about, such as improving their singing ability within a chorus, this course seeks to make science more approachable and personally relevant. This design also aligns with the view that learning is more engaging when it connects with students’ lived experiences, personal goals, or areas of interest (Renninger & Hidi, 2011; Ryan & Deci, 2000).

Looking ahead, for future implementations of similar interdisciplinary courses, it may be beneficial to begin by observing actual chorus rehearsals to identify specific vocal challenges faced by students or by discussing instructional observations with on-site chorus teachers. Instructors might initiate lessons based on common choral practices, such as blending, tuning, or resonance, and guide students in uncovering the underlying physical or acoustic mechanisms. By using students' lived singing experiences as the starting point, scientific knowledge can be introduced in ways that feel directly relevant and immediately useful, thereby fostering both conceptual understanding and sustained engagement.

6.1.2 Prioritizing Direct Instruction Over Exploratory Methods

In Iteration 1, the researcher initially incorporated several student-centered pedagogical strategies, such as cooperative learning and guided inquiry, in an effort to increase engagement and stimulate interest. These methods are commonly advocated in the literature as effective for promoting student motivation and learning interest (Blumenfeld et al., 1991; Renninger & Hidi, 2011). However, classroom observations revealed that these methods were not particularly effective in this context. The instructor was unfamiliar with these approaches and lacked the pedagogical training to implement them effectively. As a result, the researcher revised the instructional approach in Iteration 2, shifting primarily to direct instruction. This included teacher-centered explanation of concepts, supplemented by conductor-led demonstrations. Not only did this improve instructional efficiency, but it also aligned more closely with the rehearsal practices typically used by choral conductors, thereby making it more feasible for them to teach the course.

Teacher Z confirmed this alignment during the post-course interview for Iteration 1, noting that conductor training often emphasizes efficiency and time-sensitive rehearsal management. Consequently, most choral conductors are more comfortable with directive and teacher-led instructional formats. That said, because many conductors are also skilled singers, demonstration-based teaching can serve as a complementary strategy that remains within their comfort zone.

On the other hand, evidence from Iteration 2 indicates that this shift to direct instruction did not compromise students' conceptual understanding. Analysis of the pre-class open-ended questions and student worksheets revealed clear gains in students' grasp of the target concepts. For instance, while students initially gave vague or intuitive explanations for how to adjust volume, pitch, and timbre, their worksheets showed substantial improvements: over 80% accurately applied the notion of overtones to explain timbre, and similar gains were observed for questions related to volume and pitch. These results demonstrate that, within a teacher-led framework, students were able to internalize and apply key scientific ideas in meaningful ways.

Looking ahead, if similar courses are to be taught by chorus conductors, it would be advisable to rely primarily on direct instruction and demonstration methods to ensure teaching quality and effectiveness. If student-centered or exploratory teaching approaches are to be introduced, sufficient scaffolding and teacher training should be provided to ensure instructional effectiveness and confidence.

6.1.3 Simplifying Scientific Content Through Observable Phenomena

Although the initial course design already aimed to reduce the density of scientific content, feedback from Iteration 1 revealed that many students—and even instructors—struggled to grasp the concepts fully. In Iteration 2, the scientific rigor was maintained, but much of the abstract theoretical content was removed. Instead, everyday examples were introduced to clarify scientific terms and ideas. Field notes and student worksheets indicated improved participation and understanding, and Teacher Z confirmed in the post-course interview that this adjustment made the content feel more approachable for most students.

From the perspective of science educators, there is often a natural inclination to explain the underlying mechanisms behind observable phenomena (Osborne et al., 2003). Ideally, this would lead students to develop transferable conceptual knowledge. However, given the constraints of class time, students' limited prior knowledge, and the instructors' varying levels of science teaching experience, aiming for depth can backfire. In practice, intriguing or thought-provoking phenomena tend to be more effective in sparking students' interest than complex theoretical explanations (Hidi & Ann Renninger, 2006; Mitchell, 1993). Using relatable, real-world examples helps students connect new information to prior experience, making scientific ideas more deeply internalized and meaningful (Duit & Treagust, 2003; Rule, 2006).

For future interdisciplinary course designs that aim to enhance students' ISL, it is essential to evaluate the difficulty level of the scientific content carefully. If the material is too abstract or cognitively demanding, students may become overwhelmed and disengaged, ultimately reinforcing the perception that science is inaccessible or uninviting.

6.1.4 Integrating Interactive Activities Around Conceptual Instruction

Interactive activities consistently received positive feedback from both students and instructors during Iteration 1. These activities were therefore expanded in Iteration 2, with additional segments added even after the second implementation (Iteration 2-2) to enhance engagement further. Teacher Z noted that students' attention levels significantly improved after engaging in such activities and recommended placing them both before and after theoretical explanations to reinforce key concepts. He also pointed out that, since Iteration 2 relied more heavily on direct instruction, these activities played an essential role in differentiating the course from typical academic classes and maintaining student interest.

In this context, interactive activities included teacher-student exchanges such as Q&A, the use of physical props or demonstration tools, and guided vocal practice. These activities not only encouraged student participation and improved classroom dynamics but also provided multiple modes of representation for abstract concepts. By seeing, hearing, or physically experiencing phenomena, students developed a more intuitive and emotionally resonant understanding of the content (Duit & Treagust, 2003; Rule, 2006). This not only enhanced memory retention but also fostered greater emotional engagement with the subject matter.

Looking ahead, when designing courses aimed at stimulating students' ISL, integrating interactive and experiential components can help create a more dialogic classroom atmosphere. Such activities promote not only cognitive gains but also affective engagement, which is critical for cultivating lasting interest (Renninger & Hidi, 2011; Ryan & Deci, 2000).

6.1.5 Structuring the Course Within a Realistic and Focused Time Frame

The final key design consideration pertains to lesson duration and how it affects both research implementation and instructional effectiveness. During Iteration 1, the course was delivered as a single three-hour workshop. While this extended format allowed for more content, it created practical challenges for both data collection and learning continuity. Many students were unable to attend the entire session due to scheduling conflicts or fatigue, which not only reduced the number of matched pre-/post-questionnaires but also resulted in some students missing key activities and explanations. This partial participation weakened both the research data quality and the instructional coherence for those students. To address this, Iteration 2 adopted a condensed two-period format (approximately 90 to 100 minutes) that aligned more realistically with the scheduling of club activities in Taiwanese high schools. This adjustment enabled more students to participate in the entire lesson without leaving midway, ensuring that each student could complete the full sequence of learning activities while also providing more complete data for research purposes.

In addition to supporting full participation, the shorter lesson format also enhanced students' sustained attention and active engagement throughout the session. Field notes and teacher interviews during Iteration 1 revealed that student focus dropped significantly in the latter half of the three-hour workshop, limiting learning effectiveness. Research on classroom dynamics supports this finding, suggesting that lesson length and pacing can significantly influence students' attention and engagement (Blatchford et al., 2003). In contrast, the more focused 90–100-minute lesson in Iteration 2 helped maintain high levels of student concentration until the end, with no noticeable decline in participation. This demonstrates that designing lessons within a realistic time frame not only maximizes cognitive engagement but also reinforces the completeness and coherence of the learning experience.

Looking ahead, this course structure could serve as a useful model for implementing similar interdisciplinary content in informal settings or extracurricular contexts. A workshop lasting approximately 90 to 100 minutes appears optimal for maintaining student concentration while fitting within real-world scheduling constraints. If this course were to be adapted for formal classroom settings, such as general science or music classes, the difference in time allocation and pacing would need to be addressed, particularly the continuity and connection between lessons spread across separate days.

Summary

Together, these five design principles illustrate how the course evolved to suit better the needs of both learners and instructors within a chorus-based setting. By foregrounding students' practical concerns, simplifying content without sacrificing rigor, and adopting familiar instructional formats, the course became more engaging, accessible, and teachable. These design considerations were not predetermined but emerged through iterative refinement and close attention to the realities of classroom implementation. They demonstrate how interdisciplinary instruction, when grounded in learners' authentic experiences, can meaningfully integrate scientific understanding into arts-based education. These insights may inform the development of future courses that aim to foster science interest in non-traditional learning environments.

6.2 RQ2: To what extent does participation in the course influence students' ISL?

To address the second research question, this section explores the extent to which students' ISL was influenced by participation in the interdisciplinary course. As one of the central indicators of instructional impact, ISL was assessed through a five-subscale framework that distinguishes between two types of interest: personal interest—reflecting internalized, long-term engagement—and situational interest—reflecting context-specific motivation driven by immediate affective and cognitive responses (Hidi & Ann Renninger, 2006; Mitchell, 1993). By analyzing patterns of change across the five subscales, we examine how the course design, implementation context, and student characteristics shaped both the short-term and potential long-term interest outcomes. The following subsections present a layered analysis, beginning with overall trends in Iteration 2, followed by a comparison between Iteration 1 and 2, a cross-group analysis of the three choruses, and a dimension-specific reflection on the implications for future design.

6.2.1 Overall Impact of the Course on Students' ISL

In all three implementations of Iteration 2, the pre- and post-test results of the Science Learning Interest Scale indicate that the course consistently promoted students' interest in science across different educational settings. The scale comprises five subscales, with the first two—latent interest and actualized interest—representing personal interest, which reflects students' long-term motivation and internalized desire to learn science. The remaining three subscales—triggered situational interest, maintained situational interest-feeling, and maintained situational interest-value—are categorized as situational interest, capturing students' affective and value-based engagement during classroom activities. In Iteration 2, each of the three choruses showed statistically significant gains in at least two subscales, indicating a generally positive influence of the course on student interest.

The design of Iteration 2 was guided by several key principles: drawing from students' familiar singing experiences, simplifying scientific language, emphasizing directly applicable knowledge related to vocal performance, and incorporating sensory-based, feedback-rich learning activities. These strategies not only enhanced classroom engagement but also allowed students to perceive clearer links between scientific content and musical practice, which in turn increased their attentiveness and sense of relevance. As Hidi and Ann Renninger (2006) argue, interest development depends not only on the inherent appeal of the content but also on opportunities for meaningful cognitive processing and personal connection.

Taken together, the findings suggest that an interdisciplinary course that integrates acoustics with music, when grounded in students' real-life experiences and delivered through accessible, engaging instruction, holds strong potential to foster situational interest and motivate deeper learning. Through carefully designed teaching language and activity structures, students were not only able to enjoy the learning process but also began to build a conceptual bridge between their lived experiences and underlying scientific principles, laying the groundwork for longer-term interest and motivation.

6.2.2 Changes in Outcomes from Iteration 1 to Iteration 2

Within the framework of DBR, this course underwent multiple rounds of revision, and the results indicate that these refinements contributed meaningfully to the improvement of students' ISL. In Chorus A, for example, only one subscale—triggered situational interest—showed a statistically significant increase during Iteration 1, suggesting that while the course initially captured attention, it was less successful in fostering emotional involvement, value recognition, or action-oriented engagement. In contrast, during Iteration 2, four out of the five subscales showed significant gains, including all three dimensions of situational interest and latent personal interest. Only actualized interest remained non-significant, indicating substantial overall improvement in both breadth and depth of engagement.

This shift may be closely related to several key modifications made in the course design. First, Iteration 2 included more real-life examples that resonated with students' everyday experiences, such as connecting sound principles to vocal performance, instrumental sound production, or even analogies from food and visual art. These examples helped students perceive scientific content as more relevant and accessible. Second, the course emphasized interactive activities that featured immediate feedback and embodied experiences, such as producing overtones by swinging a whirly tube or demonstrating wave motion with a jump rope. These activities not only enhanced student participation but also increased the sense of novelty and emotional engagement within the learning environment.

Such strategies are especially important for triggering and sustaining interest. As Mitchell (1993) argues, situational interest is often sparked by novelty, challenge, and the inherent appeal of the activity itself. Similarly, Palmer (2009) emphasizes that students are more likely to engage when they can physically interact with materials and construct meaning through firsthand experiences.

These results suggest that when course design thoughtfully incorporates students' familiar contexts and interactive elements, it not only captures initial attention but also encourages cognitive engagement and value formation, thereby supporting the development of personal interest. The transformation from Iteration 1 to Iteration 2 not only demonstrates the course's adaptability but also highlights the substantial impact that instructional design details can have on student ISL.

6.2.3 Differences Among the Three Choruses and Possible Contributing Factors

Although the course produced positive effects on students' science learning interest across all three schools, the degree and pattern of impact varied noticeably among the groups. These differences suggest that the effectiveness of implementation may be influenced by contextual factors such as school environment, teacher-student dynamics, and learner characteristics.

Chorus A demonstrated the most comprehensive improvement, with four out of five subscales showing statistically significant increases. This result may be attributed to several factors. First, the students had a strong rapport with the instructor, creating a comfortable and interactive learning atmosphere. Second, some students had participated in Iteration 1 and thus possessed prior exposure to the course content, which may have enabled deeper understanding in Iteration 2. Additionally, Chorus A is an all-girls school, and the students appeared especially responsive to examples related to everyday experience. When lessons connected vocal resonance or sound perception to familiar situations, students often showed strong emotional engagement and value recognition. This finding aligns with Krapp's (2002) observation that when physics instruction is closely linked to students' real-life contexts, interest levels rise significantly, particularly among female students, who tend to respond more sensitively to such learning environments and display higher levels of interest.

Chorus B showed significant gains in both "Maintained Situational Interest-Value" and "Triggered Situational Interest," with the former being the most prominent. This suggests that students not only found the course engaging but also recognized its value, especially in applying scientific knowledge to improve vocal performance, a connection they may not have previously considered. This is consistent with theoretical models suggesting that the development of interest involves not only affective engagement but also a growing appreciation of the content's personal or instrumental value (Hidi & Ann Renninger, 2006; Schiefele, 1991). It is also notable that Chorus B had the highest mean and median ISL scores in the pre-course survey, which may have introduced a ceiling effect, limiting the room for further measurable growth despite active participation and positive classroom dynamics.

Chorus C showed a statistically significant improvement only in the "Actualized Interest" subscale, making it the only group to exhibit growth in this dimension. This suggests that some students not only became interested in the science of sound but also began to recognize its practical implications and develop a desire for further application or exploration. Chorus C students were generally characterized as passive yet well-behaved. However, classroom interaction was less active compared to the other two groups; the shift in perception regarding the usefulness of science seemed to occur subtly over time. This kind of internal cognitive shift may not be immediately observable through behavior, but it is reflected in the interest scale data, indicating a quiet but meaningful change (Renninger & Hidi, 2011).

Taken together, while there were commonalities across all three groups, their differing response patterns underscore the importance of contextual factors in interdisciplinary instruction. Teacher style, student background, classroom culture, and prior exposure all appear to shape the effectiveness of interest development. These findings highlight the need for adaptable, flexible curriculum design to ensure relevance and scalability across diverse educational settings.

6.2.4 Analysis of Interest Dimensions and Future Directions for Course Optimization

Analysis of the five subscales of the Science Learning Interest Scale revealed that the course had the most consistent impact on situational interest, particularly in the dimensions of maintained situational interest-feeling and maintained situational interest-value. This suggests that students found the lessons enjoyable and meaningful, with many recognizing the personal relevance of the course content. These outcomes can be attributed to the course’s emphasis on concrete demonstrations, sensory-rich activities, and real-life contexts, which helped students engage more readily with the material and derive positive emotions and value from the learning experience (Mitchell, 1993; Schiefele, 1991).

In contrast, changes in personal interest, which include latent interest and actualized interest, were less consistent across groups but still showed important highlights. Chorus A demonstrated a significant gain in latent interest, indicating that students developed a deeper curiosity about science as a potential area of further exploration. Chorus C showed a significant improvement in actualized interest, suggesting that some students moved beyond interest and began to consider applying or extending what they had learned. These results indicate that when the course content is meaningfully contextualized and personally relevant, there is potential for supporting the development of personal interest as well.

According to Renninger and Hidi (2011), personal interest emerges through repeated exposure, cognitive challenge, and opportunities for autonomous meaning-making. In this study, although the course successfully fostered participation and emotional resonance, its structure and time frame may not have been sufficient to support long-term motivation or self-initiated learning fully. To strengthen the development of personal interest, future iterations of the course may consider the following design enhancements:

First, incorporate more opportunities for student autonomy and extended tasks, such as open-ended questions, observational assignments, or group-based research projects that allow learners to explore beyond the classroom. Second, reinforce connections to students' self-concept, for instance, by encouraging reflection on their own vocal experiences and helping them translate scientific ideas into personalized singing strategies. Third, provide opportunities for longer-term engagement and follow-up, enabling students to revisit and deepen their understanding of key concepts across different learning stages and gradually internalize interest as a sustained motivational force.

In summary, the course demonstrated clear success in triggering and maintaining situational interest, particularly through its engaging teaching contexts and activity design. To further promote the development of personal interest, future course designs should attend more explicitly to mechanisms that foster long-term investment, thereby supporting students in moving from "finding it interesting" to "wanting to learn more."

Summary

In summary, the interdisciplinary course demonstrated a meaningful and multi-layered impact on students' ISL. The findings show that situational interest—especially affective engagement and perceived value—was consistently enhanced across diverse learning environments, while certain groups also exhibited growth in personal interest. Iteration 2 yielded broader and deeper improvements than Iteration 1, suggesting that design refinements, such as contextualizing scientific concepts through familiar experiences and increasing interactive activities, played a key role in strengthening student motivation. Variation across the three choruses further highlights how contextual factors, including teacher-student familiarity, gender composition, and baseline interest levels, may shape the course's effectiveness. Finally, a closer look at the subscales revealed that while triggering and maintaining situational interest were robust outcomes, transforming that interest into sustained, self-directed engagement remains a challenge—one that future designs should explicitly address. Collectively, these findings affirm the course's potential to promote science interest through music-based, context-rich instruction, while also pointing to clear directions for deepening long-term motivation.

6.3 RQ3: What challenges and opportunities arise when implementing such a course in authentic educational settings?

Implementing an interdisciplinary course that combines science and choral education in real-world contexts presents both significant challenges and meaningful opportunities. These challenges are not limited to one group of stakeholders but emerge across all levels of course involvement, from the teachers responsible for delivering the lessons to the students receiving them and the researchers facilitating the process. Accordingly, this section examines the implementation of the course from three perspectives—teacher, student, and designer—by identifying the obstacles encountered, strategies for overcoming them, and the unique growth opportunities that emerged from practice-based engagement. This multi-perspective analysis provides a more comprehensive understanding of what it takes to translate an interdisciplinary curriculum into authentic educational settings.

6.3.1 Challenges and Opportunities about the Teacher

A major challenge in implementing this course lies in the limited pedagogical and scientific knowledge among chorus conductors in Taiwan. Many conductors do not have formal training in education, and some are not even specialized in choral conducting, but rather in voice or piano performance. As a result, they often lack key components of teacher professional knowledge—namely, pedagogical knowledge (PK) and pedagogical content knowledge (PCK)—and possess primarily content knowledge (CK). This imbalance makes it difficult for instructors to address student learning difficulties effectively, which can, over time, impact both the musical quality of the ensemble and the sustainability of the chorus program (Shulman, 1986). A central goal of this course is to enable general chorus conductors, regardless of their background in science, to implement the curriculum. However, without adequate preparation, these instructors may struggle to understand the materials or respond confidently to student questions.

To address this, both short-term and long-term strategies were adopted. In the short term, course content and instructional strategies were tailored to the capabilities of the specific teacher involved in each implementation, ensuring instructional quality. For long-term dissemination, it is recommended that future iterations build on teaching approaches and content structures already familiar to chorus conductors, gradually introducing more diverse methods and deeper scientific content. This should be accompanied by teacher training and clear instructional materials to provide the necessary scaffolding and support.

Although some conductors initially expressed discomfort or uncertainty about teaching the course, the implementation process revealed meaningful opportunities for professional development. Teacher L explicitly noted during the interview that the course supported the growth of chorus conductors' instructional expertise, prompting them to reflect on their teaching language and rehearsal strategies. Teacher Z, after completing the course, independently incorporated teaching activities into his regular rehearsals, applying what he had learned. These examples suggest that the course not only supports students' development in science learning and vocal technique but also contributes to teachers' pedagogical growth. As choruses are inherently educational spaces, implementing such a course can enhance both student learning and teaching effectiveness, ultimately leading to more productive and pedagogically informed rehearsals (Borko, 2004; Clarke & Hollingsworth, 2002).

6.3.2 Challenges and Opportunities about the Student

Students in the chorus came from diverse grade levels and academic tracks, resulting in varied levels of prior knowledge. As Teacher Z noted during Iteration 2-1, although simplifying the course content helped most students follow the lessons, it led to confusion among students with stronger science backgrounds, who found the material overly simplistic. This highlights the difficulty of designing a curriculum that fully aligns with all students' entry-level competencies. In addition, some students had special educational needs—for example, Chorus B included several students requiring individualized support, posing challenges for classroom management and instructional responsiveness.

To accommodate student diversity, the curriculum should aim for a level of difficulty accessible to the majority while maintaining room for extension. Differentiated instruction may be used to offer tasks of varying difficulty, or heterogeneous grouping can allow higher-achieving students to support their peers. Differentiated instruction emphasizes modifying content, process, and product based on student readiness, interest, and learning profile (Tomlinson, 2001), while heterogeneous cooperative learning groups have been shown to support mutual understanding and motivation through peer interaction (Johnson & Johnson, 1999). The former requires teachers to possess sufficient content knowledge to anticipate and address students' advanced questions, while the latter depends on teachers' classroom management skills and appropriate pedagogical training. These demands point to the need for strong pedagogical content knowledge (PCK) in addition to general teaching competence (Shulman, 1986). For students with special needs, it is recommended that instructors unfamiliar with a particular chorus consult with the regular conductor beforehand to understand students' characteristics better and prepare appropriate instructional strategies.

From classroom observations and student worksheets, it was found that although the level of classroom enthusiasm varied, most students were able to follow the lessons and demonstrated consistent engagement through their in-class performance and worksheet responses. Furthermore, post-course learning satisfaction surveys revealed significant gains across all three choruses in terms of both satisfaction and perceived learning outcomes. These findings indicate that the course effectively addressed students' needs in terms of both atmosphere and content, yielding visible and practical learning benefits. Since students are the central stakeholders in any educational intervention, their high receptivity and satisfaction underscore the course's strong potential for broader implementation.

6.3.3 Challenges and Opportunities about the Designer

DBR is characterized by iterative implementation, ongoing revision, and the use of multiple data sources to gain a deeper understanding of instructional phenomena (Design-Based Research Collective, 2003). These features, while essential, pose significant challenges in terms of time and workload. In this study, the entire research process—from the initial course design to the final interview—spanned over a year. Course implementation had to be scheduled around students' academic calendars and school events, including music competitions, exams, and vacation periods. In addition, the researcher devoted substantial time to discussing lesson plans and revisions with the collaborating teacher. The volume of data collected, particularly during Iteration 2 (which included three rounds of implementation), was approximately three times greater than that of Iteration 1, resulting in a substantial workload for data management and analysis.

Having a long-term and cooperative teaching partner is crucial in DBR. Such partnerships not only enable consistent data collection but also ensure ongoing course refinement through reflective teaching (Barab & Squire, 2004). Although Teacher Z lacked a background in science and had limited pedagogical training, he was highly committed to the educational philosophy of the course. After each lesson, he was willing to reflect on what worked and what did not, and implement adjustments in subsequent sessions. This iterative process significantly improved both instructional quality and research validity. Given the large volume of diverse data, the researcher had to make selective decisions—analyzing every piece in fine detail was impractical. For this reason, the study focused on key insights that emerged across multiple data sources. Interview transcripts, for instance, were not analyzed verbatim; instead, notes from the interviews were synthesized and cross-referenced with other sources such as worksheets and field observations to enhance coherence and consistency.

Throughout the DBR process, the designer could gain a deeper appreciation of classroom realities. Many instructional theories or pedagogical models that seem effective in theory may not be easily applicable to specific contexts like choral instruction. For example, while student-centered methods were initially adopted to increase engagement, they were less effective when the teacher was unfamiliar with them. Furthermore, designing a science-integrated course from the perspective of choral instruction differs significantly from traditional science lesson planning. By grounding the course in students' lived experiences and learning needs, the researcher was able to shift away from a discipline-centric approach and instead focus on how scientific knowledge could be used to support student growth. Ultimately, this represents a learner-centered design process that bridges theory and practice in meaningful ways (diSessa & Cobb, 2004).

Summary

In sum, the implementation of this interdisciplinary course revealed that authentic educational settings are shaped by a complex interplay of teacher expertise, student diversity, and design logistics. A teacher with limited pedagogical and scientific backgrounds presented notable challenges, yet the course might offer opportunities for their professional development through practice and reflection. Similarly, the diversity and varying readiness levels among students required instructional flexibility, but their overall engagement and satisfaction affirmed the course's effectiveness and adaptability. From the designer's standpoint, the design-based approach was both labor-intensive and insightful, offering a rare opportunity to reconcile theoretical design with on-the-ground realities. These findings suggest that while authentic implementation demands significant effort and adaptability from all parties involved, it also creates rich conditions for mutual growth, deeper understanding, and sustainable educational innovation.

Chapter 7 Conclusion

7.1 Summary of the Study

This study aimed to design and implement an interdisciplinary course that integrates science and music, using a high school chorus as the primary learning context. The goal was to explore how such a course could enhance students' ISL. Adopting a DBR methodology, the study went through two major iterations of course design and implementation. A mixed-methods approach was used to collect and analyze data, including questionnaires, student worksheets, field observations, and teacher interviews. Participants included students from three high school choruses and one instructor.

In the second iteration, results from the Science Learning Interest Scale indicated significant improvements, particularly in the three dimensions of situational interest. This suggests that the course effectively stimulated students' interest in acoustics-related scientific concepts. Analyses of pre-course questions and student worksheets revealed clear gains in students' understanding and application of concepts such as overtones, resonance, and timbre. Field notes and teacher interviews further indicated that the course not only enhanced student motivation but also contributed to the professional development of the instructor.

The findings suggest that interdisciplinary instruction of science and music is both feasible and impactful in authentic educational settings. This study offers concrete insights for future course development and teacher training in similar contexts. With these outcomes in mind, the next section outlines the key contributions this study makes to educational research and practice.

7.2 Contributions of the Study

The contributions of this study can be discussed across three major dimensions: curriculum design, student learning outcomes, and professional growth for teachers and researchers.

First, by employing a DBR approach, this study developed an interdisciplinary course that integrates acoustics and choral singing within a high school chorus setting. It offers a concrete and practical model for educators and researchers interested in designing integrated courses that combine science and music. By documenting the full trajectory of course development and refinement, the study fills a gap in the literature where music education is often underrepresented in interdisciplinary curriculum research.

Second, the course effectively enhanced students' ISL, especially in all three dimensions of situational interest. This suggests that the curriculum not only connects well with students' prior singing experiences but also successfully uses simplified scientific language and hands-on activities to make abstract concepts more accessible. It serves as a replicable and adaptable model for motivating science learning through familiar artistic contexts.

Lastly, the implementation of the course yielded positive impacts on teachers, students, and the researcher. The instructor became more confident and skillful in teaching scientific content, students demonstrated deeper and more varied forms of understanding, and the researcher gained valuable insights into the alignment between instructional theory and practice. Together, these outcomes suggest that the course has long-term developmental potential and meaningful educational value. Despite these contributions, certain methodological and contextual limitations remain, which are discussed in the following section.

7.3 Limitations of the Study

Although this study presents an innovative interdisciplinary curriculum and implements it across three chorus contexts, several limitations should be acknowledged regarding the design and execution of the research.

First, the number of participants was relatively small, including both the collaborating teacher and the student groups. While the curriculum was deliberately designed to be accessible for most chorus conductors and feedback was gathered from an observing teacher, the actual teaching was carried out by only one instructor. This means that the findings cannot fully capture how different teachers might implement the course or what challenges they might encounter. In addition, although three separate chorus groups were recruited, each ensemble had only about 15 to 25 members, resulting in a total of just 37 valid student questionnaires for Iteration 2. This limited sample size weakens the explanatory power of the quantitative findings regarding the course's impact on students' interest in science learning.

Second, the duration of instruction was relatively short. To ensure sufficient sample size and to enable students to participate in the entire course without interruption, the lesson was condensed into a 100-minute workshop format. However, fostering sustained interest—especially the development of enduring personal interest—typically requires extended exposure and repeated reinforcement. While short-term gains in situational interest were observed, the limited timeframe means it is unclear whether this situational interest can stimulate long-term personal interest and deeper engagement in science learning.

Third, the scope of observation was somewhat limited. Although the study utilized multiple sources of qualitative and quantitative data, the focus remained primarily on pre- and post-implementation measures within the course itself. Moreover, the science learning dimension emphasized in this curriculum mainly targeted improving scientific knowledge and understanding the nature of science, rather than addressing broader aspects such as increased time invested in science-related activities outside class or measurable improvements in science achievement. As such, additional indicators that could demonstrate changes in students' sustained learning behaviors and academic performance were not collected, which constrains the ability to draw comprehensive conclusions about the broader impact of the curriculum.

Taken together, these limitations suggest that the findings should be interpreted with caution and highlight areas where future research can build upon and extend the insights gained from this study. Building on these reflections, the final section proposes directions for future inquiry that can extend and deepen the work initiated by this study.

7.4 Suggestions for Future Research

Building on the limitations identified above, several directions are recommended for future research to strengthen the robustness and applicability of interdisciplinary instruction that integrates science and music.

First, future studies should aim to increase the overall sample size by involving more teachers and student groups. Recruiting additional chorus conductors to implement the curriculum and provide feedback would help examine how diverse teaching styles and classroom contexts influence the effectiveness and adaptability of the course. Expanding the number of participating choruses would also enhance the validity and reliability of the findings.

Second, future research should consider extending the duration of instruction to provide more sustained exposure and reinforcement. While each individual session could remain within a manageable time frame (e.g., 90 to 100 minutes), distributing the lessons across multiple weeks would offer students repeated opportunities to engage with scientific concepts. This extended timeframe could better support the development of enduring personal interest in science learning beyond the initial situational interest observed.

Third, future work should broaden the scope of observation and data collection to capture the longer-term impact of the curriculum on students' science learning behaviors and outcomes. This could include follow-up studies that track changes in students' academic performance in science subjects, monitor how much time they devote to science-related activities outside of class, or explore whether participation in the course influences their future study and career choices. Such longitudinal data would provide more comprehensive evidence of the curriculum's potential to foster sustained interest and engagement in science.

By addressing these areas, future research can build on the insights gained from this study and contribute to the continued refinement and scaling of interdisciplinary science-music instruction in diverse educational contexts.

References

Aikenhead, G. S. (2006). *Science Education for Everyday Life: Evidence-Based Practice*. Teachers College Press.

Ainley, M., Hidi, S., & Berndorff, D. (2002). Interest, learning, and the psychological processes that mediate their relationship. *Journal of Educational Psychology*, *94*(3), 545-561. https://doi.org/10.1037/0022-0663.94.3.545

Akker, v. d. J. J. H., Gravemeijer, K. P. E., McKenney, S., & Nieveen, N. M. (2006). *Educational design research* [Book editing]. Routledge Taylor & Francis Group.

Barab, S., & Squire, K. (2004). Design-Based Research: Putting a Stake in the Ground. *Journal of the Learning Sciences*, *13*(1), 1-14. https://doi.org/10.1207/s15327809jls1301_1

Beane, J. A. (1997). *Curriculum integration: Designing the core of democratic education*. Teachers College Press.

Bequette, J. W., & Bequette, M. B. (2012). A Place for Art and Design Education in the STEM Conversation. *Art Education*, *65*(2), 40-47. https://doi.org/10.1080/00043125.2012.11519167

Blatchford, P., Bassett, P., Goldstein, H., & Martin, C. (2003). Are Class Size Differences Related to Pupils' Educational Progress and Classroom Processes? Findings from the Institute of Education Class Size Study of Children Aged 5-7 Years. *British Educational Research Journal*, *29*(5), 709-730. https://doi.org/10.1080/0141192032000133668

Blumenfeld, P. C., Elliot, S., W., M. R., S., K. J., Mark, G., & and Palincsar, A. (1991). Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. *Educational Psychologist*, *26*(3-4), 369-398. https://doi.org/10.1080/00461520.1991.9653139

Borko, H. (2004). Professional Development and Teacher Learning: Mapping the Terrain. *Educational Researcher*, *33*(8), 3-15. https://doi.org/10.3102/0013189x033008003

Braund, M., & Reiss, M. (2006). Towards a more authentic science curriculum: The contribution of out-of-school learning. *International Journal of Science Education*, *28*(12), 1373-1388. https://doi.org/10.1080/09500690500498419

Brown, A. L. (1992). Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings. *Journal of the Learning Sciences*, *2*(2), 141-178. https://doi.org/10.1207/s15327809jls0202_2

Chang, H. Y., Liu, C. C., Wen, C. T., Chang, M. H., Fan Chiang, S. H., & Hwang, F. K. (2023). The effect of the cyclic curricular design of modelling-based instruction with virtual labs. *International Journal of Science Education*. https://doi.org/10.1080/09500693.2023.2219365

Cheng, H.-L. (2004). *The Effects of the Thematic Approach Integrating Curriculum on Music Learning Attitude and Achievement by Junior High School Students [主題式統整課程對國中學生音樂學習態度與成效之研究]* (Master's Thesis, National Taiwan Normal University). National Digital Library of Theses and Dissertations in Taiwan. https://hdl.handle.net/11296/4e7a3b

Cheng, J.-C., Hung, J.-F., & Huang, T.-C. (2013). *Promoting Junior High Students' Situational Interests With Multiple Teaching Strategies in Informal Nanometer-Related Curricula* [採用多元教學策略的非制式奈米課程對國中生情境興趣之促進]. *Journal of Educational Practice and Research*, *26*(2), 1-28. https://www.airitilibrary.com/Article/Detail?DocID=19935633-201312-201401200027-201401200027-1-28

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education*, *18*(8), 947-967. https://doi.org/10.1016/S0742-051X(02)00053-7

Cobb, P., Confrey, J., Disessa, A., Lehrer, R., & Schauble, L. (2003). Design Experiments in Educational Research [Article]. *Educational Researcher*, *32*(1), 9-13. https://doi.org/10.3102/0013189X032001009

Collins, A. (1992). Toward a Design Science of Education. New Directions in Educational Technology, Berlin, Heidelberg.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design Research: Theoretical and

Methodological Issues. *Journal of the Learning Sciences*, *13*(1), 15-42. https://doi.org/10.1207/s15327809jls1301_2

Crowther, G. (2012). Using science songs to enhance learning: An interdisciplinary approach. *CBE Life Sciences Education*, *11*(1), 26-30. https://doi.org/10.1187/cbe.11-08-0068

Cunningham, C. M., Lachapelle, C. P., Brennan, R. T., Kelly, G. J., Tunis, C. S. A., & Gentry, C. A. (2020). The impact of engineering curriculum design principles on elementary students' engineering and science learning. *Journal of Research in Science Teaching*, *57*(3), 423-453. https://doi.org/10.1002/tea.21601

Dean, S. (2024). Phenomenon Walks. *Science and Children*, *61*(5), 20-24. https://doi.org/10.1080/00368148.2024.2384123

Design-Based Research Collective. (2003). Design-Based Research: An Emerging Paradigm for Educational Inquiry. *Educational Researcher*, *32*(1), 5-8. https://doi.org/10.3102/0013189x032001005

Dewey, J. (1913). *Interest and Effort in Education*. Houghton Mifflin Company. https://doi.org/10.1037/14633-000

diSessa, A. A., & Cobb, P. (2004). Ontological Innovation and the Role of Theory in Design. *Journal of the Learning Sciences*, *13*. https://doi.org/10.1207/s15327809jls1301_4

Drake, S. M., & Burns, R. C. (2004). *Meeting standards through integrated curriculum*. ASCD.

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*, *25*(6), 671-688. https://doi.org/10.1080/09500690305016

Edelson, D. C. (2002). Design Research: What We Learn when We Engage in Design. *Journal of the Learning Sciences*, *11*(1), 105-121. https://doi.org/10.1207/S15327809JLS1101_4

George, D., & Mallery, P. (2010). *SPSS for Windows Step by Step: A Simple Guide and Reference 18.0 Update*. Prentice Hall Press.

Habig, B., & Gupta, P. (2021). Authentic STEM research, practices of science, and interest development in an informal science education program. *International Journal of STEM Education*, *8*(1), Article 57. https://doi.org/10.1186/s40594-021-00314-y

Halim, L., Abdullah, S. I. S. S., & Meerah, T. S. M. (2014). Students' Perceptions of Their Science Teachers' Pedagogical Content Knowledge. *Journal of Science Education and Technology*, *23*(2), 227-237. https://doi.org/10.1007/s10956-013-9484-2

Harackiewicz, J., Barron, K., Tauer, J., & Elliot, A. (2002). Predicting Success in College: A Longitudinal Study of Achievement Goals and Ability Measures as Predictors of Interest and Performance From Freshman Year Through Graduation. *Journal of Educational Psychology*, *94*, 562-575. https://doi.org/10.1037/0022-0663.94.3.562

Hidi, S. (1990). Interest and Its Contribution as a Mental Resource for Learning. *Review of Educational Research*, *60*(4), 549-571. https://doi.org/10.3102/00346543060004549

Hidi, S., & Ann Renninger, K. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111-127. https://doi.org/10.1207/s15326985ep4102_4

Hidi, S., & Harackiewicz, J. (2000). Motivating the Academically Unmotivated: A Critical Issue for the 21st Century. *Review of Educational Research - REV EDUC RES*, *70*, 151-179. https://doi.org/10.3102/00346543070002151

Häussler, P. (1987). Measuring students' interest in physics - design and results of a cross-sectional study in the Federal Republic of Germany. *International Journal of Science Education*, *9*(1), 79-92. https://doi.org/10.1080/0950069870090109

Häussler, P., & Hoffmann, L. (2000). A curricular frame for physics education: Development, comparison with students' interests, and impact on students' achievement and self-concept. *Science Education*, *84*(6), 689-705. https://doi.org/c534d8

Hsu, Y.-S., Chuang, F.-T., & Lin, T.-C. (2012). Exploring the Framework and Implementation of the Design Research Method in Science Education. *Journal of Research in Education Sciences*, *57*(1), 1-27. https://www.airitilibrary.com/Article/Detail/2073753X-201203-201306030020-

201306030020-1-27

Huang, K.-C. (2023). *A Study on the Learning Attitude and Satisfaction of Digital Audio Workstation APP into the Music Creation: Taking an Elementary School in a Rural Area as an Example [編曲軟體 APP 融入音樂創作之學習態度與滿意度探討之研究—以偏鄉某國小為例]* (Master's thesis, Kao Yuan University). National Digital Library of Theses and Dissertations in Taiwan. https://hdl.handle.net/11296/r56na6

Hulleman, C. S., & Harackiewicz, J. M. (2009). Promoting interest and performance in high school science classes. *Science*, *326*(5958), 1410-1412. https://doi.org/10.1126/science.1177067

Hultén, M. (2013). Boundary objects and curriculum change: the case of integrated versus subject-based teaching. *Journal of Curriculum Studies*, *45*(6), 790-813. https://doi.org/10.1080/00220272.2013.812245

Ivanitskaya, L., Clark, D., Montgomery, G., & Primeau, R. (2002). Interdisciplinary learning: Process and outcomes. *Innovative Higher Education*, *27*(2), 95-111. https://doi.org/10.1023/A:1021105309984

Jacobson, M. J., Markauskaite, L., Portolese, A., Kapur, M., Lai, P. K., & Roberts, G. (2017). Designs for learning about climate change as a complex system. *Learning and Instruction*, *52*, 1-14. https://doi.org/10.1016/j.learninstruc.2017.03.007

Johnson, D. W., & Johnson, R. T. (1999). *Learning together and alone: Cooperative, competitive, and individualistic learning*. Allyn & Bacon.

Kennedy, T., & Fields, D. (2023). Augmenting Upper and Early-Learning STEM Lessons Through Phenomenon-Based Learning Projects. *Journal of Higher Education Theory and Practice*, *23*. https://doi.org/10.33423/jhetp.v23i18.6630

Korsun, I. (2017). The use of interdisciplinary approach for the formation of learners' situational interest in physics. *Asia-Pacific Forum on Science Learning and Teaching*, *18*(2), Article 5. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85065505227&partnerID=40&md5=3c7ea9c27e9f839e3ee70646bea3c70e

Krapp, A. (1999). Interest, motivation and learning: An educational-psychological perspective. *European Journal of Psychology of Education*, *14*(1), 23-40. https://doi.org/10.1007/BF03173109

Krapp, A. (2002). Structural and dynamic aspects of interest development: theoretical considerations from an ontogenetic perspective. *Learning and Instruction*, *12*(4), 383-409. https://doi.org/10.1016/S0959-4752(01)00011-1

Krapp, A., Hidi, S., & Renninger, K. (1992). Interest, learning, and development. In K. A. H. Renninger, S.; Krapp, A. (Ed.), *The role of interest in learning and development* (pp. 3-25). Lawrence Erlbaum Associates.

Krapp, A., & Prenzel, M. (2011). Research on Interest in Science: Theories, methods, and findings. *International Journal of Science Education*, *33*(1), 27-50. https://doi.org/10.1080/09500693.2010.518645

Kurniawan, D., Astalini, A., & Sari, D. (2019). An evaluation analysis of students' attitude towards physics learning at senior high school. *Jurnal Penelitian dan Evaluasi Pendidikan*, *23*, 26-35. https://doi.org/10.21831/pep.v23i1.20821

Lai, C. (2011). *A Survey Study of Music Interest in Learning and Self-determination Needs of the National Taoyuan Senior High School Students [國立桃園高中學生音樂學習興趣與自我決定需求之調查研究]* (Master's thesis, National Taiwan Normal University). National Digital Library of Theses and Dissertations in Taiwan. https://hdl.handle.net/11296/j47vjw

Lee, O., & Brophy, J. (1996). Motivational patterns observed in Sixth-Grade science classrooms. *Journal of Research in Science Teaching*, *33*(3), 303-318. https://doi.org/b8sgt5

Lee, W., Lee, M. J., & Bong, M. (2014). Testing interest and self-efficacy as predictors of academic self-regulation and achievement. *Contemporary Educational Psychology*, *39*(2), 86-99. https://doi.org/10.1016/j.cedpsych.2014.02.002

Linnenbrink-Garcia, L., Durik, A., Conley, A., Barron, K., Tauer, J., Karabenick, S., & Harackiewicz, J. (2010). Measuring Situational Interest in Academic Domains. *Educational and Psychological Measurement - EDUC PSYCHOL MEAS*, *70*, 647-671. https://doi.org/10.1177/0013164409355699

Lo, T.-Y. (2016). *The Effects of Problem-Based Learning (PBL) Scientific Activities on Junior High School Students' Science Learning Interest and Problem-Solving Ability [PBL 科學活動對國中生自然科學學習興趣與問題解決能力的影響]* (Master's thesis, National Changhua University of Education). National Digital Library of Theses and Dissertations in Taiwan. https://hdl.handle.net/11296/q4c2sd

Lonka, K. (2018). *Phenomenal learning from Finland*. Edita Publishing.

McComas, W. F., & Wang, H. A. (1998). Blended Science: The Rewards and Challenges of Integrating the Science Disciplines for Instruction. *School Science and Mathematics*, *98*(6), 340-348. https://doi.org/10.1111/j.1949-8594.1998.tb17430.x

McKenney, S., & Reeves, T. C. (2013). Systematic Review of Design-Based Research Progress: Is a Little Knowledge a Dangerous Thing? *Educational Researcher*, *42*(2), 97-100. https://doi.org/10.3102/0013189x12463781

Michelsen, C., & Sriraman, B. (2009). Does interdisciplinary instruction raise students' interest in mathematics and the subjects of the natural sciences? *ZDM - International Journal on Mathematics Education*, *41*(1-2), 231-244. https://doi.org/10.1007/s11858-008-0161-5

Mitchell, M. (1993). Situational Interest: Its Multifaceted Structure in the Secondary School Mathematics Classroom. *Journal of Educational Psychology*, *85*(3), 424-436. https://doi.org/10.1037/0022-0663.85.3.424

Obrenović, Ž. (2011). Design-based research: what we learn when we engage in design of interactive systems. *interactions*, *18*(5), 56–59. https://doi.org/10.1145/2008176.2008189

OECD. (2016). *PISA 2015 Results (Volume I)*. https://doi.org/10.1787/9789264266490-en

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049-1079. https://doi.org/10.1080/0950069032000032199

Palmer, D. H. (2009). Student interest generated during an inquiry skills lesson. *Journal of*

Research in Science Teaching, *46*(2), 147-165. https://doi.org/10.1002/tea.20263

Penuel, W. R., Kate, H., Buck, B. Z., Nicole, V., & Rivet, A. (2024). Designing Standards-Aligned Instructional Materials That Connect to Students' Interests and Community Priorities. *The Science Teacher*, *91*(5), 62-70. https://doi.org/10.1080/00368555.2024.2390547

Renninger, K. A., Ewen, L., & Lasher, A. K. (2002). Individual interest as context in expository text and mathematical word problems. *Learning and Instruction*, *12*(4), 467-490. https://doi.org/10.1016/S0959-4752(01)00012-3

Renninger, K. A., & Hidi, S. (2011). Revisiting the Conceptualization, Measurement, and Generation of Interest. *Educational Psychologist*, *46*(3), 168-184. https://doi.org/10.1080/00461520.2011.587723

Rotgans, J. I., & Schmidt, H. G. (2011). Situational interest and academic achievement in the active-learning classroom. *Learning and Instruction*, *21*(1), 58-67. https://doi.org/10.1016/j.learninstruc.2009.11.001

Rule, A. (2006). Editorial: The Components of Authentic Learning. *Journal of Authentic Learning*, *3*.

Ryan, R., & Deci, E. (2000). Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being. *The American psychologist*, *55*, 68-78. https://doi.org/10.1037/0003-066X.55.1.68

Sahlberg, P. (2021). *Finnish Lessons 3.0: What Can the World Learn from Educational Change in Finland?* Teachers College Press, Columbia University. https://books.google.com.tw/books?id=t3wUEAAAQBAJ

Schiefele, U. (1991). Interest, Learning, and Motivation. *Educational Psychologist*, *26*(3-4), 299-323. https://doi.org/10.1080/00461520.1991.9653136

Schraw, G., Flowerday, T., & Lehman, S. (2001). Increasing Situational Interest in the Classroom. *Educational Psychology Review*, *13*(3), 211-224. https://doi.org/10.1023/A:1016619705184

Schraw, G., & Lehman, S. (2001). Situational interest: A review of the literature and directions for future research. *Educational Psychology Review*, *13*(1), 23-52, Article 292264. https://doi.org/10.1023/A:1009004801455

Shulman, L. S. (1986). Those Who Understand: Knowledge Growth in Teaching. *Educational Researcher*, *15*(2), 4-14. https://doi.org/10.3102/0013189x015002004

Tan, E., Barton, A. C., Kang, H., & O'Neill, T. B. (2013). Desiring a career in STEM-related fields: How middle school girls articulate and negotiate identities-in-practice in science. *Journal of Research in Science Teaching*, *50*(10), 1143-1179. https://doi.org/10.1002/tea.21123

Teresa, J., & Fields, D. L. (2023). Augmenting Upper and Early-Learning STEM Lessons Through Phenomenon-Based Learning Projects. *Journal of Higher Education Theory and Practice*, *23*(18), 171-183. https://doi.org/10.33423/jhetp.v23i18.6630

Tojeiro-Pérez, L., & Gillanders, C. (2024). (Re)connecting Music and Ecology. *Science & Education*. https://doi.org/10.1007/s11191-024-00601-4

Tomlinson, C. A. (2001). *How to differentiate instruction in mixed-ability classrooms* (2nd ed.). ASCD.

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5-23. https://doi.org/10.1007/BF02504682

Woithe, J., Müller, A., Schmeling, S., & Kuhn, J. (2022). Motivational outcomes of the science outreach lab S'Cool LAB at CERN: A multilevel analysis. *Journal of Research in Science Teaching*, *59*(6), 930-968. https://doi.org/https://doi.org/10.1002/tea.21748

Woolnough, B. E. (2000). Authentic science in schools?—an evidence-based rationale. *Physics Education*, *35*(4), 293-300. https://doi.org/10.1088/0031-9120/35/4/14

Zimmerman, H. T., Weible, J. L., Wright, E. A., Vanderhoof, C., & Jablonski, N. G. (2022). Using youths' personal DNA data in science camps: Fostering genetics learning and socio-emotional attitudes toward science with design-based research. *Science*

Education, *106*(4), 767-796. https://doi.org/10.1002/sce.21709

Appendix A: Teaching Plan

Instructional Design of the Teaching Plan in Iteration 1

教學活動設計	
教學活動內容及實施方式	**時間**
第一節：人聲的本質	50 分
引起動機： 1. 教師播放 Video 1-1，請學生仔細聽根音以外的聲音。 2. 教師詢問學生「聽到了什麼？」 預期學生回答： ● Amazing Grace ● 泛音 ● 唱歌 3. 教師詢問學生「怎麼做到的？」 預期學生回答： ● 一次唱兩顆音 ● 調整泛音 ● 有人幫忙唱 4. 教師收束活動，揭示四節課課程設計與最後所要回答的核心問題：理解泛音後如何幫助我們唱歌？	10 分
發展活動： 1. 複習聲波的性質與聲音三要素，教師採隨機點名詢問學生確認先備知識。 2. 將焦點轉移至人聲上，教師以選擇題的方式詢問學生「人聲的發聲原理是什麼？」與「人聲的調音原理是什麼？」，採全班投票並以異質分組討論的方式請學生互相交流想法，經過一輪後再次全班投票，此次請不同觀點的學生各自分享想法，教師協助重述但不作評斷。 3. 教師播放 Video 1-2 與 Video 1-3，再進行全班投票確認學生有概念改變。 4. 教師講解人聲性質。	30 分
總結活動： 1. 教師詢問學生「(管)風琴和人體器官的英文都是 Organ，兩者之間有何關聯呢？」與「為什麼熬夜或剛起床的時候聲音都可以特別低呢？」，請學生將想法寫在學習單上。 2. 回收學習單，教師預告下次課程將請學生發表想法。	10 分

第二節：泛音的原理	50 分
引起動機： 1. 教師發回學生學習單。 2. 教師詢問學生「哪種長度的雞蛋放進盒子搖晃的時候不會破？」並強調不只一個答案，引導學生仔細思考。 3. 學生分享上次課程最後的提問，教師總結「(管）風琴的發聲原理跟人聲一樣都是由氣流驅動」與「因為人聲的調音原理和弦樂器一樣，且鬆掉的弦聲音比較低，可以推論放鬆狀態的聲帶可以唱出比較低的音」。	10 分
發展活動： 1. 教師將引起動機的雞蛋搖晃情境連結至弦的振動上，請學生思考兩端固定時能產生哪些不同的振動方式。 2. 教師使用跳繩讓學生實際製造波，從慢到快嘗試能順利甩動的頻率。 3. 教師講解駐波的概念，並導出最慢頻率的整數倍皆是駐波的結論。 4. 教師再次使用跳繩讓學生實際製造波，先找到基頻再倍數增加頻率試驗結論。 5. 教師定義基音、泛音與諧音的概念。	30 分
總結活動： 1. 教師展示不同的波形，詢問學生「這些波形分別對應到基音、泛音、非諧音中的哪一個呢？」，採隨機點名並追問想法和支持證據。 2. 教師詢問學生「現實中的弦會怎麼振動呢？」並提供不同選項，請學生將想法寫在學習單上。 3. 回收學習單，教師預告下次課程將請學生發表想法。	10 分
第三節：音色的成因	50 分
引起動機： 1. 教師發回學生學習單。 2. 教師播放不同樂器的音檔（鋼琴、長笛、薩克斯風），詢問學生「這些聲音分別是什麼樂器發出的呢？」 3. 教師詢問學生「明明頻率都一樣，為何相同音高卻有不同音色呢？」請學生先保留想法。 4. 上次課程最後的提問採全班投票並以異質分組討論的方式請學生互相交流想法，經過一輪後再次全班投票，此次請不同觀點的學生各自分享想法，教師協助重述但不作評斷。	15 分

發展活動： 1. 教師以揀選橘子的機器比喻，說明撥弦時產生雜音，經由駐波的選擇才留下諧音，所以弦上會產生所有諧音。 2. 教師連結甩動跳繩的經驗，說明頻率較高的泛音較不易發出，因此音量（聲波強度）會減弱，所以主要頻率為基音。 3. 教師詢問學生「明明頻率都一樣，為何相同音高卻有不同音色呢？」 預期學生回答： ● 波形不一樣（教師追問為何波形不一樣） 4. 教師綜合兩點結論，以線上波動模擬器模擬兩諧音疊加時的狀態，再使用線上方程式繪圖軟體疊加數個波。 5. 教師說明波形不同是因為泛音組成比例不同，並以先前問題的樂器波形圖作範例。	25 分
總結活動： 1. 教師提供不同樂器的波形資料，詢問學生「高頻泛音組成比例多跟少在音色上的差異是什麼？」，請學生將想法寫在學習單上。 2. 回收學習單。	10 分
第四節：共鳴的選擇	50 分
引起動機： 1. 教師發回學生學習單。 2. 教師總結學生上次課程最後提問的回覆：高頻泛音組成比例多的話音色會較清亮尖銳，反之則溫潤暗沉。 3. 教師詢問學生「我們可以改變自己聲音的音色嗎？」 預期學生回答： ● 可以（教師追問怎麼改變） 4. 教師詢問學生「天生聲帶的長度、厚薄、形狀很難改變，我們可以做什麼來改變音色？」	5 分
發展活動： 1. 教師以烏克麗麗和吉他為例，點出共鳴箱會影響音色。 2. 教師講解共鳴的原理，不同大小會加強不同頻率區段的音量。 3. 教師展示人體發聲器官剖面圖，指出人聲從聲帶出發會經過許多共鳴腔。 4. 教師再次播放 Video 1，請學生解釋泛音唱法的原理，以逆向思考鼓勵學生闡述更多或提出不同觀點。	25 分

總結活動： 1. 教師詢問學生「理解泛音後如何幫助我們唱歌？」，請學生將想法寫在學習單上，而後採隨機點名與大家分享。 2. 回收學習單，教師點出更多與泛音有關的聲音現象，如：純率與平均律的差異、和聲的平衡等等，鼓勵學生繼續研究。	20 分

Instructional Design of the Teaching Plan in Iteration 2 (Version 2.4)

教學活動設計	
教學活動內容及實施方式	**時間**
第一節：人聲與泛音	50 分
引起動機：合唱路上的挑戰 1. 教師簡介課程設計理念：合唱教學中經常使用經驗法則（多嘗試來學習），但不一定適用於所有學生，今天的課程提供另外一個角度來看待唱歌這件事，也就是從現象出發，介紹理論並與實務結合，希望可以讓學生在學習唱歌上更有方向（p. 3） 2. 教師介紹課程設計者與授課教師（p. 4） 3. 教師提醒學生準備筆，發下學習單（p. 5） 4. 教師以「在合唱的路上，我們常遇到許多問題...」為起頭，帶出許多常見的合唱相關問題（p. 6） 5. 教師解釋今日時間有限，以三個聲音相關的基本問題作為今日主軸（p. 7） 6. 教師點出這些問題過於負面（p. 8） 7. 教師將三個問題修正成較為正向積極的語句（p. 9） 8. 教師揭示這節課的主題是「人聲與泛音」，下一節課則是「共鳴與音色」（p. 10），藉由理解跟聲音有關的科學知識幫助唱歌（p. 11）	10 分
發展活動 1：人聲的機制 1. 正式進入第一節課（p. 12），教師播放「小號的發聲原理」（01:58-07:09），並提醒學生從影片中獲取資訊完成學習單（p. 13） 註：為鋪陳後續提問，應避免事先點出小號發聲原理與人聲之關係 2. 教師先示範再請學生嘗試用嘴唇吹出聲音，可拿出小號吹嘴演示（p. 14） 3. 教師提出問題：為什麼要知道小號的發聲原理？但不做延伸（p. 15）	30 分

4. 教師播放「聲帶如何運作」(p. 16) 5. 教師公布學習單前兩題答案，以表格比對小號與人聲的發聲原理、調音方式以及調音原理（p. 17） 註：可詢問學生學習單上的內容 6. 教師重現先前問題：為什麼要知道小號的發聲原理？（p. 18)，並回答：因為小號跟人聲的發聲原理類似，皆為氣流通過使樂器振動發出聲音，利用可見的樂器讓大家理解不容易看見的聲帶（p. 19） 7. 教師基於類似發聲原理，進一步以表格比對小號與人聲調整音量與穩定音準的方法，總結想唱大聲需要通過更多的氣流，以及想唱低音需要放鬆聲帶（p. 20） 註：可以搭配示範教學 註：可以加入常見錯誤示範，例如：擠喉嚨唱大聲 發展活動 2：泛音的概念 8. 教師點出剛剛在比較小號與人聲時出現的一些名詞，包括：泛音、泛音列以及基音，但不做解釋（p. 21） 9. 教師介紹基音、泛音與泛音列的簡單概念（p. 22） 註：為鋪陳後續提問，應避免事先提到泛音的比例 10. 為求讓學生理解抽象概念，教師先以拉麵湯頭比喻聲音，則湯底為基音，調味品為泛音（p. 23） 11. 教師再以琇拉的點畫為例，以呈現的顏色比喻聲音，則基底為基音，點綴為泛音，強調不是調色不一樣，是點的組成不同（p. 24） 12. 教師以圖示整理拉麵、點畫與聲音的類比（p. 25） 13. 教師公布影片中泛音列的音高，並播放聲音對照（p. 26） 註：首調唱名可以替換成其他學生能理解的表示方法 14. 教師以鋼琴鍵盤圖讓學生標上泛音的位置，輔以音程或數半音的方式解析算法，搭配音檔顯示泛音列，並補充額外兩個泛音為之後活動鋪墊（p. 27） 發展活動 3：泛音的限制 15. 教師拿出魔音管，開始甩動發出聲音（p. 28） 註：開始甩動前可以讓學生猜猜看如何發出聲音 16. 教師點出魔音管可以甩出的音高固定（p. 29） 17. 教師進一步點出發出的聲音對應到泛音列（p. 30） 18. 教師提出問題：為什麼基音對應的泛音是固定的？回顧前面決定基音後，泛音列也跟著決定了（p. 31）	

19. 教師拿出跳繩模擬聲帶，解釋其同為兩端固定，邀請一位同學上台手持跳繩的另一端，開始甩動跳繩使其出現一至數個迴旋，強調並非所有甩動頻率皆可以產生迴旋（p. 32） 註：可由教師示範或請同學嘗試 註：途中可故意展示頻率不對時無法甩出任何迴旋 20. 教師連結跳繩迴旋數與基音泛音的狀況（p. 33） 21. 教師比較跳繩與聲帶的兩端狀況、產生基音以及產生泛音的方式，藉此說明基音與泛音的關係。 22. 教師重現先前問題：為什麼基音對應的泛音是固定的？（p. 35），並回答：因為產生泛音有條件限制，進一步解釋如同甩動跳繩，並非所有甩動頻率都可以產生迴旋（p. 36）	
總結活動：人聲、樂器、泛音列 1. 教師鼓勵學生中場休息前思考以下問題（p. 37） 2. 教師詢問：人發出聲音的方式跟誰比較像？簡單解釋三種樂器的發聲原理並邀請學生舉手表達，最後公布答案（p. 38） 3. 教師詢問：人調整音高的方式跟誰比較像？簡單解釋三種樂器的調音原理並邀請學生舉手表達，最後公布答案，說明從前面的影片中可以看到聲帶在拉緊或放鬆的過程中長度也會變化，所以這兩個都算符合，不過從高音拉緊伸長、低音放鬆縮短的比較可知鬆緊的變化比較明顯（p. 39） 註：可以強調，樂器類比只是為了讓學生容易理解聲帶的某部分運作機制，實際上各種樂器的機制都不同 4. 教師請學生在學習單的空白鋼琴譜面上列出 D2 的前七個泛音，搭配音程或數半音的方式公布答案後播放聲音，再補充兩個泛音，為之後的課程做鋪墊（p. 40） 5. 中場休息十分鐘（p. 41）	10 分
第二節：共鳴與音色	50 分
引起動機：神奇的泛音歌唱 1. 教師播放「泛音唱法」，提示學生忽略基音，仔細聽較高的泛音組成旋律（p. 42） 註：為鋪陳後續提問，應避免直接點出聽泛音 2. 教師詢問學生「旋律是由哪些音組成的？」 預期學生回答：	10 分

甲、Do, Re, Mi, Sol, 降 Si 乙、A5, C6, D6, E6, #F6, A6 丙、D3 的泛音列 丁、剛剛學習單的內容 教師公布答案，強調是 D3 的泛音列並播放聲音對照（p. 43） 3. 教師詢問：如何操控泛音？解釋剛剛影片中的人唱的是基音，聽的人卻可以聽到不同泛音，那他是用什麼方法控制發出什麼泛音的？ 預期學生回答： 甲、口腔 乙、表情 丙、感覺（p. 44） 4. 教師暫不公布答案，點出可以使用科學尋找答案（p. 45） 5. 教師揭示這節課的主題是「共鳴與音色」，延續上一節課的泛音來探討音色的成因以及如何調整音色（p. 46）	
發展活動 1：大小共鳴箱 1. 教師介紹共鳴箱，包括： 甲、有共鳴箱的樂器：提琴、吉他、琵琶、…… 乙、共鳴箱的主要功用：放大音量 丙、共鳴箱大小的影響：後續說明（p. 47） 2. 教師提出問題：為什麼低音提琴不能拉高音？解釋只要用較短的弦長，應該就可以拉出高音才對，這樣樂團就只要放幾把低音提琴，不用小提琴了（p. 48） 註：若學生表示音色不同，教師可以追問如何不同以及為何會不同，進而帶出下張投影片內容教師播放「吉他大小差異」，提醒學生仔細聽大小不同的共鳴箱聽起來有什麼不同（p. 49） 4. 教師以表格比較大吉他與小吉他的共鳴箱大小，並討論兩者在突出音高（聽起來比較明顯的是高音還是低音）與音色上的差異（p. 50） 註：可以詢問學生或教師自答 5. 教師總結共鳴箱大小會決定增強的音域（p. 51） 註：可以加入女聲的例子，Soprano 唱不到低音（小提琴拉不出低音），Alto 高音不容易好聽（低音提琴拉高音）	30 分

6. 教師重現先前問題：為什麼低音提琴不能拉高音？（p. 52），並回答：因為無法被共鳴箱增強，所以不好聽，進一步解釋大共鳴箱對應到低音音域，相對高音就會比較小聲且沒有共鳴（p. 53） 發展活動 2：人體的共鳴箱 7. 教師將焦點引導至人聲，提問：人聲的共鳴箱在哪裡？引發學生好奇（p. 54） 8. 教師展示人體發聲器官剖面圖，指出人聲從聲帶出發會經過許多共鳴腔，包含聲道與口腔（p. 55） 9. 教師重現先前問題：如何操控泛音？（p. 56），並回答：藉由改變共鳴腔大小，增強不同泛音，進一步提出低音嘴巴空間大，高音嘴巴空間小（p. 57） 10. 教師再次播放「泛音唱法」，請學生仔細觀看影片中的人如何控制泛音，並解釋實際上是內口腔在變化，所以可能無法反映在嘴型上（p. 58） 11. 教師帶領學生嘗試發出泛音，藉由不同的口腔大小與舌頭位置變化強化不同泛音。 發展活動 3：音色的成因 12. 教師回顧先前比對大吉他與小吉他時提到音色，帶出唱歌的人都希望自己聲音能夠好聽（p. 59） 13. 教師播放並說明大家可以分辨同樣音高長笛、小號、鋼琴的聲音，解釋可能因為三個樂器類型差異很大（p. 60） 14. 教師播放並說明大家可以分辨同樣音高直笛、單簧管、雙簧管的聲音，解釋即便發聲原理類似仍然分的出來（p. 61） 15. 教師舉例即便唱同樣的音高，大家仍然可以分辨兩位老師的聲音（p. 62） 註：可以舉例語音助理分辨主人的聲音 16. 教師自問：音高相同，為什麼音色會不同？（p. 63） 17. 教師自問：人有指紋來分辨不同的人，即便是雙胞胎指紋也不一樣，難道聲音也有聲紋？（p. 64） 18. 教師自答：還真的有，而且我們剛剛已經學過了（p. 65） 19. 教師簡單複習人聲、泛音與共鳴三個主題： 人聲—小號和人聲的發聲與調音原理 泛音━我們聽到的聲音都是由基音和一系列泛音組成	

共鳴─共鳴箱大小會決定增強的音域（p. 66） 20. 教師點出聲紋就藏在聲音中的泛音裡（p. 67） 21. 教師展示長笛與小號的泛音組成比例，指出雖然音高相同，不同樂器的泛音組成比例卻不同，且高頻泛音比例越高，音色越尖銳（p. 68） 註：可以補充「聲音是音波，對人耳來說沒有音色，只有不同頻率的強度有多少而已」 22. 教師小結音色與泛音有關，繼續討論影響泛音組成比例的因素為何（p. 69） 23. 教師點出泛音組成比例與發聲原理（或者說是樂器的本性）以及共鳴箱有關（p. 70-71） 24. 教師說明影響音色的關鍵以及細節，包括：樂器的本性、共鳴箱大小、泛音組成比例（p. 72） 發展活動 4：改變音色的關鍵 25. 教師自問：身而為人，我們要如何改變音色？（p. 73） 26. 教師解釋我們無法很難自己樂器的本性，只能從共鳴箱著手（p. 74-75） 註：提到樂器的本性時，可以舉例說人在長大變聲、生病或手術之後才會從根本上改變聲帶 27. 教師重現人體共鳴腔圖，指出我們可以透過調整共鳴腔來改變音色（p. 76） 註：可以現場示範或帶領學生一起嘗試。	
總結活動：音樂與科學 1. 課程進入尾聲（p. 77），教師回顧課程目標：理解聲音相關科學知識來幫助唱歌（p. 78） 2. 教師邀請學生回顧四個主題，包括：人聲、泛音、共鳴、音色，並適時補充內容（p. 79） 註：鼓勵學生提出一句話或一個重點即可，教師利用學生回答多作延伸，主要是增加課程互動性，若時間不足可教師自答 3. 教師回顧課堂一開始的提問，邀請學生回答（p. 80） 註：若時間不足可教師自答 4. 教師總結課程理念，引發學生思考（p. 81） 5. 教師引述法國音樂學家 Jules Combarieu 之名言，並解釋音樂不僅僅是情感的展現，更是一門運用聲音的藝術，故今天的課程對於音樂來說也十分重要（p. 82）	10 分

Appendix B: Pre-/Post-Questionnaires

Pre-Questionnaire in Iteration 1

科學學習興趣量表

1 此部份為調查科學學習興趣，「科學」指的是自然科學，如：物理、化學、生物、地球科學等等。

2 潛在興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
我享受自然科學主題。					
我喜歡自然科學。					
我喜歡從事自然科學的活動。					
學習自然科學對我而言是令人興奮的。					

3 現實興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
對我來說自然科學是有用的。					
自然科學在日常生活中對我來說是有幫助的。					
對我來說能運用或理解自然科學是重要的。					
科學性的思考是我擁有的特質。					

4 促發性情境興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
以前的自然課老師上課是有趣的。					
以前的自然課老師能引起我上課的注意力。					
以前的自然課是好玩的。					
以前的自然課生動有趣能吸引我的注意力。					

5 維持性情境興趣—感覺面向

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
我在以前的自然課所學習到的事物對我是有吸引力的。					
自然科學課程所學習的事物我是感到興奮的。					
我喜歡我在以前的自然課所學會的事物。					
我在以前的自然課所做的事物是有趣的。					

6 維持性情境興趣—價值面向

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
以前的自然課學習到的事物，可幫助我對其他事物了解。					
我在以前的自然課學習到的事物，對我是重要的。					
我在以前的自然課學習到的事物，我可以運用於生活中。					
我在以前的自然課學習到的事物，對我是有價值的。					

音樂學習興趣量表

7 此部份為調查音樂學習興趣，「音樂」指的是學校音樂課程，不含美術、表演藝術或合唱社團課。

8 潛在興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 如果有選擇修課的機會或權力，音樂課會是我優先選擇的科目。					
· 在音樂課中，我向來喜歡學習新的內容。					
· 跟其他科目比起來，我比較喜歡音樂課。					
· 我覺得學習音樂經常使我感到快樂。					
· 長久以來，我對音樂課通常都感到興趣。					

*9 現實興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 為了解決音樂學習上的問題，我會多花一些時間閱讀音樂教科書內容之外的資料。					
· 當我學習音樂感到困惑時，我較喜歡自己去尋找答案，而非請老師給我答案。					
· 學習音樂這門課時，我會主動探索較難的內容。					
· 選擇課外讀物時，我喜歡閱讀和音樂有關的書籍或雜誌。					
· 上過音樂課後，我會主動聆聽與音樂課有關的樂曲。					

*10 文本興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 當音樂教科書各單元的內容較能連貫時，我會較有學習的動力。					
· 當音樂教科書的內容吸引我時，我會比較想翻閱音樂教科書。					
· 當音樂教科書的內容編排由淺入深時，我會對它產生較高的興趣。					
· 當音樂教科書的內容項目多元且視覺效果生動時，我會將教科書多翻閱幾次。					
· 當音樂教科書的內容呈現情境圖片時，我會較喜歡學習它的內容。					

*11 任務興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意

- 我會設定音樂課學期成績的目標，讓自己更有學習動力。
- 由於我對音樂的興趣，所以我會在音樂課前翻閱或預習上課的內容。
- 音樂課的內容若與我的日常生活相關，我會更投入其中。
- 音樂作業若與我的生活經驗相關，我會更樂於學習。
- 我會主動將音樂課習得的內容與生活連結，讓學習音樂的過程更為有趣。

*12 知識興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
當音樂教科書的內容與我以前學過的知識有關時，我會更投入學習。					
當音樂課的主題是我熟悉的內容時，我會較有興趣學習。					
當音樂教科書內容與我的生活經驗有關時，我會更想要瞭解教科書內容。					
當音樂教科書內容是我熟悉的主題時，我會閱讀相關的課外讀物，以便深入瞭解。					
當音樂教科書內容有部分概念是我學過的，我會較有興趣閱讀。					

合唱學習態度量表

13 此部份為調查合唱學習態度，「合唱」指的是合唱社團課，包含合唱社團相關的排練、加練、課程、活動等等。

*14 學習動機

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
合唱課可以提供我想學的知識與技能。					
合唱是重要的科目。					
上合唱課會覺得有壓力。					
我喜歡上合唱課，因為很有趣。					
合唱課的內容很豐富。					
合唱課與我的日常生活無關。					

- 我想學習更多有關合唱的知識與技能。
- 上合唱課是令人期待的。

15 學習態度

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
我會主動蒐集合唱課外的相關資料。					
我希望得到好的合唱成績。					
我會主動向老師提出自己有興趣的問題。					
我喜歡和同學討論合唱相關問題。					
上合唱課時會發呆或做其他事情。					
我會完成老師所指定的作業。					
我對學習合唱沒有信心。					

16 學習情況

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
上合唱課時師生互動良好。					
合唱老師清楚地講解課程內容。					
我能適應合唱老師上課方式。					
合唱課時間大部分是由老師講述。					
上合唱課可以有分工合作的經驗。					
上合唱課時，同學常無精打采。					

17 學習認知

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
我對藝術與人文課程有更深的了解。					
合唱課程內容可以提高我對合唱的學習興趣。					
合唱課可以提升創造力與問題解決力。					

- 合唱課可以增加好奇心與想像力。
- 合唱課不可以獲得成就感。
- 合唱課有肢體表達的機會。
- 合唱課可以強化對情感的表達。
- 合唱課不可以獲得其他科目或領域間的知識。
- 合唱課可以提升自信心。
- 合唱課可以認識周遭環境的文化特質。
- 合唱課可以感受創作的喜樂與滿足。

基本資料問卷

18 此部份為調查基本資料，相關資訊僅作統計分析使用，毋須填入任何可以辨識出你身分的內容。

*19 請給自己一個不會被辨識出來的代號，之後將於課程結束時的問卷填入相同代號。

必選 輸入設定

*20 請問你的性別是？

必選 其他 選項組 選項顯示方式 隨機排序

a 女

b 男

其他

*21 請問你目前的年齡是幾歲？

必選 數字區間

*22 請問你目前就讀幾年級？

必選 其他 選項組 選項顯示方式 隨機排序

a 高中一年級

b 高中二年級

c 高中三年級

◉ 其他

23 請問你目前就讀或欲就讀的類組是？

必選 其他 選項組 選項顯示方式 隨機排序

a 第一類組（社會組）

b 第二類組（理工組）

c 第三類組（理工生物組）

d 未定

◉ 其他

24 請問這是你加入這個合唱團後的第幾個學期？

必選 其他 選項組 選項顯示方式 隨機排序

a 第一個（這學期剛加入）

b 第二個

c 第三個

d 第四個

e 第五個

f 第六個

◉ 其他

25 請問你的參加合唱團的經歷大約有幾年？

必選 選項組 選項顯示方式 隨機排序

a 0~1年

b 1~2年

c 2~3年

d 3~4年

e 4~5年

f 5~6年

g 6~7年

h 7~8年

i 8~9年

j 9~10年

k 10年以上

Post-Questionnaire in Iteration 1

科學學習興趣量表

1 此部份為調查科學學習興趣，「科學」指的是自然科學，如：物理、化學、生物、地球科學等等。

*2 潛在興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 我享受自然科學主題。					
· 我喜歡自然科學。					
· 我喜歡從事自然科學的活動。					
· 學習自然科學對我而言是令人興奮的。					

*3 現實興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 對我來說自然科學是有用的。					
· 自然科學在日常生活中對我來說是有幫助的。					
· 對我來說能運用或理解自然科學是重要的。					
· 科學性的思考是我擁有的特質。					

*4 促發性情境興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 這次課程老師上課是有趣的。					
· 這次課程老師能引起我上課的注意力。					
· 這次課程是好玩的。					
· 這次課程生動有趣能吸引我的注意力。					

5 維持性情境興趣─感覺面向

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 我在這次課程所學習到的事物對我是有吸引力的。					
· 我在這次課程所學習的事物我是感到興奮的。					
· 我喜歡我在這次課程所學會的事物。					
· 我在這次課程所做的事物是有趣的。					

6 維持性情境興趣─價值面向

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 這次課程學習到的事物，可幫助我對其他事物了解。					
· 我在這次課程學習到的事物，對我是重要的。					
· 我在這次課程學習到的事物，我可以運用於生活中。					
· 我在這次課程學習到的事物，對我是有價值的。					

音樂學習興趣量表

7 此部份為調查音樂學習興趣，「音樂」指的是學校音樂課程，不含美術、表演藝術或合唱社團課。

8 潛在興趣

★ 必選 | 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 如果有選擇修課的機會或權力，音樂課會是我優先選擇的科目。					
· 在音樂課中，我向來喜歡學習新的內容。					
· 跟其他科目比起來，我比較喜歡音樂課。					
· 我覺得學習音樂經常使我感到快樂。					
· 長久以來，我對音樂課通常都感到興趣。					

*9 現實興趣

★ 必選 | 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 為了解決音樂學習上的問題，我會多花一些時間閱讀音樂教科書內容之外的資料。					
· 當我學習音樂感到困惑時，我較喜歡自己去尋找答案，而非請老師給我答案。					
· 學習音樂這門課時，我會主動探索較難的內容。					
· 選擇課外讀物時，我喜歡閱讀和音樂有關的書籍或雜誌。					
· 上過音樂課後，我會主動聆聽與音樂課有關的樂曲。					

*10 文本興趣

★ 必選 | 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 當音樂教科書各單元的內容較能連貫時，我會較有學習的動力。					
· 當音樂教科書的內容吸引我時，我會比較想翻閱音樂教科書。					
· 當音樂教科書的內容編排由淺入深時，我會對它產生較高的興趣。					
· 當音樂教科書的內容項目多元且視覺效果生動時，我會將教科書多翻閱幾次。					
· 當音樂教科書的內容呈現情境圖片時，我會較喜歡學習它的內容。					

*11 任務興趣

★ 必選 | 矩陣選項

	非常不同意	不同意	普通	同意	非常同意

- 我會設定音樂課學期成績的目標，讓自己更有學習動力。
- 由於我對音樂的興趣，所以我會在音樂課前翻閱或預習上課的內容。
- 音樂課的內容若與我的日常生活相關，我會更投入其中。
- 音樂作業若與我的生活經驗相關，我會更樂於學習。
- 我會主動將音樂課習得的內容與生活連結，讓學習音樂的過程更為有趣。

*12 知識興趣

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
當音樂教科書的內容與我以前學過的知識有關時，我會更投入學習。					
當音樂課的主題是我熟悉的內容時，我會較有興趣學習。					
當音樂教科書內容與我的生活經驗有關時，我會更想要瞭解教科書內容。					
當音樂教科書內容是我熟悉的主題時，我會閱讀相關的課外讀物，以便深入瞭解。					
當音樂教科書內容有部分概念是我學過的，我會較有興趣閱讀。					

合唱學習態度量表

13 此部份為調查合唱學習態度，「合唱」指的是合唱社團課，包含合唱社團相關的排練、加練、課程、活動等等。

*14 學習動機

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
合唱課可以提供我想學的知識與技能。					
合唱是重要的科目。					
上合唱課會覺得有壓力。					
我喜歡上合唱課，因為很有趣。					
合唱課的內容很豐富。					
合唱課與我的日常生活無關。					

· 我想學習更多有關合唱的知識與技能。

· 上合唱課是令人期待的。

15 學習態度

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 我會主動蒐集合唱課外的相關資料。					
· 我希望得到好的合唱成績。					
· 我會主動向老師提出自己有興趣的問題。					
· 我喜歡和同學討論合唱相關問題。					
· 上合唱課時會發呆或做其他事情。					
· 我會完成老師所指定的作業。					
· 我對學習合唱沒有信心。					

16 學習情況

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 上合唱課時師生互動良好。					
· 合唱老師清楚地講解課程內容。					
· 我能適應合唱老師上課方式。					
· 合唱課時間大部分是由老師講述。					
· 上合唱課可以有分工合作的經驗。					
· 上合唱課時，同學常無精打采。					

17 學習認知

必選 矩陣選項

	非常不同意	不同意	普通	同意	非常同意
· 我對藝術與人文課程有更深的了解。					
· 合唱課程內容可以提高我對合唱的學習興趣。					
· 合唱課可以提升創造力與問題解決力。					

- 合唱課可以增加好奇心與想像力。
- 合唱課不可以獲得成就感。
- 合唱課有肢體表達的機會。
- 合唱課可以強化對情感的表達。
- 合唱課不可以獲得其他科目或領域間的知識。
- 合唱課可以提升自信心。
- 合唱課可以認識周遭環境的文化特質。
- 合唱課可以感受創作的喜樂與滿足。

基本資料問卷

18 此部份為調查基本資料，相關資訊僅作統計分析使用，毋須填入任何可以辨識出你身分的內容。

*19 請填上與課前問卷相同的代號，若忘記或不確定請舉手，我會過去協助你。

必選 輸入設定

Pre-Questionnaire in Iteration 2

謝長達碩士論文研究調查課前問卷

親愛的同學好：

感謝你的協助，本問卷為一份學術問卷，旨在調查參與「泛泛知音」這門課程的學生在「科學學習興趣」以及「課前能力分析」的狀況，以作為評估這們跨領域課程成效的依據。敬請惠予填答，你的協助對本研究有很大的貢獻。

本問卷採匿名方式填寫且不會對外公開，資料僅使用於學術研究之統計分析，不影響個人成績或學習權益，敬請安心填寫。請留意：這不是考試，答案也沒有對錯之分，依照個人實際想法完成每一項填答即可。在過程中，若你感到不舒服想要暫停或退出研究，我們會完全尊重你的意願，且不會影響後續課程參與或合唱學習的權益，而先前已蒐集的資料將不納入分析。完成課程前後兩份問卷的同學，可以獲得「50元全家禮物卡」乙張。

在填答問卷的過程中有任何不清楚或需要解釋的部分請舉手，我會立即過去提供諮詢。謝謝你的用心填答與協助。

祝大家健康快樂、學業進步！

國立臺灣師範大學 科學教育研究所

指導教授：劉湘瑤 博士

研究生：謝長達 敬啟

聯絡信箱：61145014s@gapps.ntnu.edu.tw

* 表示必填問題

科學學習興趣量表

此部份為調查科學學習興趣，「科學」指的是自然科學，如：物理、化學、生物、地球科學等等。

潛在興趣

1。 我享受自然科學主題。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

2。 我喜歡自然科學。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

3。 我喜歡從事自然科學的活動。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

4。 學習自然科學對我而言是令人興奮的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

現實興趣

5。 對我來說自然科學是有用的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

6。 自然科學在日常生活中對我來說是有幫助的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

7。 對我來說能運用或理解自然科學是重要的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

8。 科學性的思考是我擁有的特質。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

促發性情境興趣

9。 以前的自然課老師上課，是有趣的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

10。 以前的自然課老師上課，能吸引我的注意力。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

11。 以前的自然課是好玩的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

12。 以前的自然課生動有趣，能引發我的注意力。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

維持性情境興趣—感覺面向

13。 以前的自然課學習的事物，對我是有吸引力的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

14。 以前自然課學習的事物，我是感到興奮的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

15。 以前自然課學習的事物，是我喜歡的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

16。 以前的自然課學習的事物，是有趣的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

維持性情境興趣—價值面向

17。 以前的自然課學習的事物，可幫助我對其他事物的了解。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

18。 以前的自然課學習的事物，對我是重要的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

19。 以前的自然課學習的事物，我可以運用於生活中。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

20。 以前的自然課學習的事物，對我是有價值的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

課前能力分析

請以自身經驗進行回答。

21。 你是如何調整音量的？ *

22。 你是如何調整音準的？ *

23。 你是如何調整音色的？ *

基本資料問卷

此部份為調查基本資料，相關資訊僅作統計分析使用，毋須填入任何可以辨識出你身分的內容。

24。 請給自己一個不會被辨識出來的代號，之後將於課程結束時的問卷填入相同代號。 *

25。 請問你的性別是？ *

單選。

- 1-女
- 2-男
- 其他：

26。 請問你目前的年齡是幾歲？ * Dropdown

單選。

- 15
- 16
- 17
- 18
- 19

27。 請問你目前就讀幾年級？ * Dropdown

單選。

- 1-高中一年級
- 2-高中二年級
- 3-高中三年級

28。 請問你目前就讀或欲就讀的類組是？ *

單選。

- 1-第一類組（社會組）
- 2-第二類組（理工組）
- 3-第三類組（理工生物組）
- 0-未定
- 其他：

29。 請問這是你加入這個合唱團後的第幾個學期？ * Dropdown

單選。

- 1-第一個（這學期剛加入）
- 2-第二個
- 3-第三個
- 4-第四個
- 5-第五個
- 6-第六個

30。 請問你參加合唱團的經歷大約有幾年？ * Dropdown

單選。

- 1-不到一年
- 2-一至二年
- 3-二至三年
- 4-三至四年
- 5-四至五年
- 6-五至六年
- 7-六至七年
- 8-七至八年
- 9-八至九年
- 0-九年以上

問卷結束

課前問卷到此結束，謝謝你的用心填答，請記住所填寫的代號，課程結束後的問卷還會使用到喔！

Post-Questionnaire in Iteration 2

謝長達碩士論文研究調查課後問卷

親愛的同學好：

感謝你的協助，本問卷為一份學術問卷，旨在調查參與「泛泛知音」這門課程的學生在「科學學習興趣」以及「課後課程回饋」的狀況，以作為評估這們跨領域課程成效的依據。敬請惠予填答，你的協助對本研究有很大的貢獻。

本問卷採匿名方式填寫且不會對外公開，資料僅使用於學術研究之統計分析，不影響個人成績或學習權益，敬請安心填寫。請留意：這不是考試，答案也沒有對錯之分，依照個人實際想法完成每一項填答即可。在過程中，若你感到不舒服想要暫停或退出研究，我們會完全尊重你的意願，且不會影響後續課程參與或合唱學習的權益，而先前已蒐集的資料將不納入分析。完成課程前後兩份問卷的同學，可以獲得「50元全家禮物卡」乙張。

在填答問卷的過程中有任何不清楚或需要解釋的部分請舉手，我會立即過去提供諮詢。謝謝你的用心填答與協助。

祝大家健康快樂、學業進步！

國立臺灣師範大學 科學教育研究所

指導教授：劉湘瑤 博士

研究生：謝長達 敬啟

聯絡信箱：61145014s@gapps.ntnu.edu.tw

* 表示必填問題

科學學習興趣量表

此部份為調查科學學習興趣，「科學」指的是自然科學，如：物理、化學、生物、地球科學等等。

潛在興趣

1。 我享受自然科學主題。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

2。 我喜歡自然科學。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

3。 我喜歡從事自然科學的活動。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

4。 學習自然科學對我而言是令人興奮的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

現實興趣

5。 對我來說自然科學是有用的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

6。 自然科學在日常生活中對我來說是有幫助的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

7。 對我來說能運用或理解自然科學是重要的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

8。 科學性的思考是我擁有的特質。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

促發性情境興趣

9。 這次課程老師上課，是有趣的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

10。 這次課程老師上課，能吸引我的注意力。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

11。 這次課程經常是好玩的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

12。 這次課程生動有趣，能引發我的注意力。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

維持性情境興趣—感覺面向

13。 這次課程學習的事物，對我是有吸引力的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

14。 這次課程學習的事物，我是感到興奮的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

15。 這次課程學習的事物，是我喜歡的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

16。 這次課程學習的事物，是有趣的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

維持性情境興趣—價值面向

17。 這次課程學習的事物，可幫助我對其他事物的了解。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

18。 這次課程學習的事物，對我是重要的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

19。 這次課程學習的事物，我可以運用於生活中。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

20。 這次課程學習的事物，對我是有價值的。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

科學知識融入學習滿意度量表

本量表目的在了解你對於科學知識融入合唱的學習滿意度，請依照你在課程中所產生的感受與學習結果回答。

課程滿意度

21。 我對於在合唱團融入科學知識學習唱歌，很滿意。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

22。 我對於運用科學知識學習唱歌，學習上很滿意。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

23。 我對於運用科學知識學習唱歌，可以提升我對合唱的興趣。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

24。 我希望每學期合唱團至少有兩節課程融入科學知識。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

學習成果

25。 我覺得運用科學知識學習唱歌，理解自己的聲音讓我很有成就感。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

26。 我覺得運用科學知識學習唱歌，可以讓我在合唱團更專心。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

27。 我覺得運用科學知識學習唱歌，可以讓我學習輕鬆沒有壓力。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

28。 我覺得運用科學知識學習唱歌，可以提升學習合唱的自主性。 *

單選。

	1	2	3	4	5	
非常	◯	◯	◯	◯	◯	非常同意

29。 其他回饋

喜歡這門課程的什麼地方？或是有什麼地方可以再調整的？

課前問卷對應

30。 請填上與課前問卷相同的代號，若忘記或不確定請舉手，我會過去協助你。 *

問卷結束

課後問卷到此結束，謝謝你的用心填答，你的協助對這份研究有很大的幫助！
請記得領取「50元全家禮物卡」乙張，祝你課業合唱都順利～

Appendix C: Student Worksheets

Student Worksheets in Iteration 1

「泛泛知音」學習單

設計：謝長達

聲部 年級 姓名

此學習單將作為課程學習紀錄與記錄個人想法使用，內容將與同儕分享且會被設計與授課老師檢閱，請認真書寫內容。此學習單將於每次課程結束時收回，下次上課時發放，並在全數課程結束時掃描建檔後發回，作為此次課程之學習歷程檔案。

第一節：人聲的本質

1. （管）風琴和人體器官的英文都是 Organ，兩者之間有什麼關聯？

2. 為什麼熬夜或剛起床的時候聲音都可以特別低？

3. 本堂課程回饋：針對這節課覺得什麼很有趣？哪邊可以調整？迸出了那些新想法？

第二節：駐波的原理

1. 現實中的弦會如何振動？

2. 本堂課程回饋：針對這節課覺得什麼很有趣？哪邊可以調整？迸出了那些新想法？

第三節：音色的成因

1. 音色跟泛音組成比例有什麼關係？

2. 為什麼泛音組成比例會不同？

3. 本堂課程回饋：針對這節課覺得什麼很有趣？哪邊可以調整？迸出了那些新想法？

第四節：共鳴的選擇

1. 他是怎麼做到的？

2. 理解泛音後如何幫助我們唱歌？

3. 本堂課程回饋：針對這節課覺得什麼很有趣？哪邊可以調整？迸出了那些新想法？

課程總回饋：針對整體課程架構編排的想法或啟發，上完四節課後有什麼想分享的話？

Student Worksheets in Iteration 2

「泛泛知音」學習單

設計：謝長達

聲部　　　　　　　　年級　　　　　　　　姓名

此學習單將作為課程學習紀錄與記錄個人想法使用，內容會被設計與授課老師檢閱，請認真書寫內容。此學習單將於課程結束時收回，並在掃描建檔後發回，作為此次課程之學習歷程檔案。

I 小號的發聲原理

1. 小號如何發出聲音？

2. 小號如何調整音高？

3. 泛音列裡面包含哪些音高？（可以用首調唱名或音名表示）

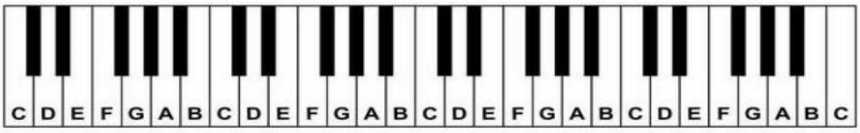
II 人聲

1. 人聲要如何調整音量？

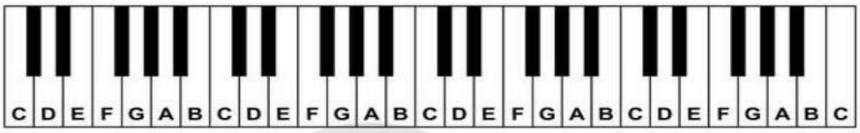
2. 人聲要如何穩定音準？

III 泛音

1. 請將小號泛音列上的音表示在鍵盤上



2. 請列出 D3 的前七個泛音



IV 共鳴

1. 大小吉他在音量上有什麼不同？

2. 大小吉他在音色上有什麼不同？

V 音色

人聲要如何改變音色？

課程總回饋：針對整體課程架構編排的想法或啟發，或有什麼想分享的話？