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The impact of technology integration in flute pedagogy on student performance levels *

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Abstract

Although technology-assisted accompaniment (TAA) has been addressed in flute pedagogy, existing research has predominantly emphasized students' perceptions and preparatory processes or relied on earlier-generation technologies, resulting in limited empirical evidence on the direct effects of contemporary accompaniment applications on performance outcomes. This study investigates the impact of technology-assisted accompaniment applications on flute students' performance levels using a mixed-methods research design. The quantitative phase employs a counterbalanced design with 10 flute students, comparing their performances with and without accompaniment. The accompaniment phase of the research implementation was conducted utilizing a digital accompaniment platform specifically designed for instrumental instruction and musical practice. Performance evaluations are based on a 13-criteria rubric assessing various musical and technical dimensions. In the qualitative phase, semi-structured interviews provide insight into students' experiences and perceptions of technology-assisted accompaniment. Quantitative analysis demonstrated that performances with accompaniment were significantly superior to those without (d = –1.921), reflecting a substantial enhancement in both technical accuracy and musical expressiveness. The qualitative phase comprised semi-structured interviews designed to elicit participants' perceptions of technology-assisted accompaniment utility, functionality, and limitations. Accordingly, content analysis yielded six overarching themes: (1) contribution to performance and musicality, (2) functionality, (3) challenges, (4) technology-assisted accompaniment applications, (5) comparison with live accompanist, and (6) anxiety. Qualitative findings highlight that technology-assisted accompaniment enhances motivation and practice flexibility while also presenting challenges related to synchronization and interpretative depth. These findings underscore the pedagogical value of technology-assisted

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accompaniment applications in instrumental music education, particularly as a supplementary tool for independent practice and skill development in the absence of live accompaniment. Based on the findings of this study, it is recommended that technology-supported accompaniment applications be integrated into educational practices. It is expected that future studies will investigate not only the impact of these applications on performance levels, but also their effects on interpretive dimensions such as period-specific stylistic expression, vocalization, anxiety reduction, and motivation.

Introduction

Technology continues to evolve and be integrated into various domains, including education, healthcare, and industry, with the primary aim of enhancing efficiency, cost-effectiveness, and operational speed. The human ability to harness technological advancements is a defining characteristic that distinguishes our species from others (Volti & Croissant, 2024). In the field of education, the progressive incorporation of technology has led to transformative shifts in pedagogical approaches, reshaping traditional learning environments (Roy, 2019). The 21st century, often referred to as the Information Age, is characterized by the pivotal role of technology in facilitating access to and utilization of knowledge. Loveland (2012) underscores that technology should not be perceived as an end in itself but rather as a strategic tool to support and enhance educational objectives.

In the field of music education, technology serves as a pivotal instrument in facilitating effective learning outcomes. The integration of emerging digital tools has redefined traditional pedagogical approaches, fostering a more interactive and immersive learning experience. These technological advancements have significantly enhanced student engagement by introducing dynamic and interactive methodologies (Pandita & Kiran, 2023; Yüksel & Mustul, 2015). Empirical studies by Wan and Gregory (2018) and Huang (2022) highlight that digital tools in music education not only support motivational strategies but also contribute to heightened levels of student motivation, attention, confidence, and overall learning satisfaction.

PLATO (Programmed Logic for Automated Teaching Operations), the first comprehensive computer-assisted instruction system, was introduced across various higher education disciplines, including music education (Ajero, 2007; Mohan Kömürcü, 2019; Özgül, 2016). By the late 1960s, computer-based instructional tools such as PLATO and computer-controlled tape recorders had gained widespread adoption in music education (Ajero, 2007). Building upon these advancements, GUIDO, developed in 1974, emerged as one of the pioneering projects in computer-assisted music theory and notation. This system significantly enhanced students' auditory and reading skills by providing structured exercises on intervals, melody, chords, harmony, and rhythm, thereby establishing itself as an effective pedagogical tool for music education (Eddins, 1981; Mohan Kömürcü, 2019).

The advancement of music technology has facilitated the development of extensive sound libraries derived from acoustic instruments and various digital sources. These libraries, collectively referred to as virtual instruments, encompass sound synthesizers, drum modules, and samplers, allowing for greater flexibility in music production and education (Karaöngel & Çifti, 2022). Modern computing capabilities have further enabled the archival, manipulation, and reuse of these virtual instruments, expanding their applications across multiple musical contexts. The term virtual instruments gained prominence following Steinberg's introduction of Virtual Studio Technology (VST), which revolutionized digital music production (Fukui et al., 1993; Getahun et al., 2018; Karaöngel ve Çifti, 2022; Tanev & Božinovski, 2014). Simultaneously, the concept of the synthetic performer emerged in academic discourse (Dannenberg, 1991; Vercoe, 1984), referring to computer-based systems capable of listening, interpreting, performing, and teaching musical structures, effectively simulating the role of

a human musician within an ensemble. Over time, this concept has evolved into a broader framework known as machine musicianship, encompassing advanced computational models for interactive musical creativity and real-time performance adaptation (Alexandraki & Bader, 2014).

Technological advancements have facilitated the integration of computer-based accompaniment systems into instrumental music education. The development of technology-assisted accompaniment (TAA) applications has been driven by multiple factors, primarily addressing the challenges associated with accessing professional accompanists. Expert accompanists are required to demonstrate highly sophisticated technical and musical competencies, including rapid score-reading of complex passages, transposition across various keys, and precise synchronization with performers (Maievska & Kryzhanovska, 2023; Mohan Kömürcü, 2019). However, many music education institutions face a shortage of pianists possessing these specialized skills, and opportunities for collaboration beyond scheduled class hours are often limited (Mohan Kömürcü, 2019). Several studies specifically highlight the scarcity of qualified accompanists in Türkiye, further exacerbating this challenge (Coşkuner, 2016; Güleç & Pirgon, 2021; Hepyücel & Yıldırım, 2017). While hiring external pianists may offer a potential solution, the financial burden associated with this approach poses significant challenges for institutions (Kalkanoğlu Mamaç, 2021).

Global disruptions caused by pandemics, particularly COVID-19, have profoundly impacted music education, necessitating the adoption of computer-based and technology-assisted instructional models as cost-effective solutions to mitigate educational interruptions (Andaryani et al., 2023; Ebbini, 2023; Morin, 2024; O'Leary & Bannerman, 2023). Well-designed digital learning platforms offer students flexible study options tailored to their individual abilities and self-paced learning needs (Özgül, 2016). The rapid development of technology-assisted applications during the pandemic has significantly transformed flute pedagogy (FP) by facilitating location-independent practice opportunities, thereby ensuring continuity in instrumental training despite physical restrictions.

The integration of TAA applications in instrumental education offers distinct pedagogical benefits, particularly in enhancing flexibility and learning efficiency. These applications provide both temporal and spatial adaptability, allowing students to engage in self-directed, repetition-based learning, which has been shown to improve knowledge retention (Kalkanoğlu Mamaç, 2021). In educational settings where access to skilled accompanists is limited, TAA applications serve as an important pedagogical tool, ensuring continuity in the learning process by offering adaptable accompaniment solutions (Tseng, 1996). Furthermore, these technologies contribute to increased student engagement, enhance motivation, and reinforce newly acquired skills in instrumental training, thereby enriching the overall educational experience (Kalkanoğlu Mamaç, 2021).

Research have consistently demonstrated the pedagogical benefits of computer-assisted accompaniment across diverse musical settings, ranging from facilitating instructional objectives to addressing varied pedagogical needs (Dannenberg & Raphael, 2006; Li, 2020; Rao & Lau, 2018). In particular, several studies have investigated the efficacy of TAA in FP, highlighting its role in enhancing student engagement, technical proficiency, and overall learning outcomes (Aytemur & Sönmezöz, 2022; Klee, 1998; Üstün & Ozer, 2020; Tseng, 1996).

This study investigates the direct impact of TAA applications on students' performance levels, with a particular focus on the role of technology in fostering musical performance development. By adopting a distinct methodological approach, this research differentiates itself from prior studies in the field, including those conducted by Aytemur and Sönmezöz (2022), Üstün and Ozer (2020), Tseng (1996), and Klee (1998). While existing research has explored various dimensions of TAA in music education, these studies have primarily concentrated on students' perceptions, practice habits, and preparation strategies rather than direct performance outcomes.

Aytemur and Sönmezöz (2022) examined students' attitudes toward computer-assisted accompaniment tools, reporting significant negative perceptions that suggest a lack of full recognition or utilization of these technologies' educational potential. Tseng (1996) investigated how the computer-controlled Vivace program influenced flute students' practice behaviors, while Klee (1998) explored the role of computer-assisted accompaniment in solo flute repertoire preparation. Although these studies provide valuable insights into the motivational and preparatory aspects of TAA, they do not systematically assess its direct impact on students' performance quality. Both Tseng (1996) and Klee (1998) offer broad frameworks on the potential benefits of computer-assisted accompaniment; however, they lack a comprehensive examination of the specific nature of these benefits and do not incorporate detailed student perspectives. Therefore, although these studies have made foundational contributions to the field, they leave significant gaps in understanding the measurable effects of TAA on performance outcomes when supported by student perspectives. This study aims to address this gap, at least in part.

Research on TAA in FP began in the 1990s. However, the rapid evolution of digital music technologies necessitates a reassessment of their contemporary impact. This study examines the contribution of modern accompaniment applications that utilize recent technological advancements to the performance development of flute students, thereby offering new insights into the role of TAA in FP. Beyond updating current understandings of technology's pedagogical function in FP, this study establishes a comprehensive framework for evaluating the educational efficacy of contemporary digital accompaniment systems. This study differentiates itself from prior research by not only exploring students' subjective experiences but also quantitatively measuring the direct impact of TAA on performance levels using a modern accompaniment tool. Moreover, the integration of performance evaluations with qualitative insights provides a comprehensive understanding of both technical improvement and the psychological dimension of TAA usage, addressing a gap in the existing literature.

In instrumental music education programs, particularly in contexts where access to skilled accompanists is limited, TAA applications serve as essential tools for enabling students to engage with music in its complete form. These applications provide an accessible and cost-effective alternative for concert preparation, competitions, examinations, and daily practice, addressing a critical gap in instrumental training. This study investigates how such applications enhance performance levels in FP, offering a performance-centered perspective that expands upon existing literature. By analyzing student experiences, this research evaluates the evolving role of technology in music education and examines its potential to improve flute performance through the following research questions:

RQ1: Is there a significant difference in performance levels between the accompanied and unaccompanied sections performed by flute students?

Hypotheses for the first research question:

H0: There is no difference in performance levels between the accompanied and unaccompanied sections performed by flute students.

H1: There is a difference in performance levels between the accompanied and unaccompanied sections performed by flute students.

RQ2: What are the participants' views on the use of TAA?

Method

Research model

This study adopted an explanatory sequential mixed methods design, which involves an initial quantitative data collection phase followed by a qualitative data-gathering process to provide deeper insights into the findings (Büyüköztürk et al., 2020). This methodological approach was selected to achieve a comprehensive understanding of TAA in FP by first assessing its impact on performance levels and subsequently exploring students' perceptions and experiences. The quantitative phase involved comparative observations of accompanied and unaccompanied performances to measure the direct effects of TAA applications on flute performance outcomes. These findings were then integrated with qualitative data obtained through semi-structured interviews, enabling a more nuanced and holistic interpretation of the results.

In the quantitative phase of the study, an ex post facto research design was employed, a methodological approach commonly used when the independent variable has already been introduced and cannot be manipulated or randomly assigned (Erkuş, 2021) This design was intentionally preferred over experimental and quasi-experimental approaches because the independent variable was already integrated into the existing instructional setting, making manipulation or random assignment unfeasible. The study aimed to assess the impact of TAA applications on students' performance levels in flute training at the Department of Music Education, Faculty of Education, Bursa Uludag University. The analysis focused on evaluating the contribution of an already existing pedagogical practice through systematic observational methods.

This study employed a single-group within-subjects comparative design, commonly used in correlational research contexts. In this framework, performance scores obtained from the unaccompanied section and the accompanied section of the same musical piece were compared within the same group of participants. This approach allows for the examination of performance differences across naturally occurring instructional conditions while controlling for inter-individual variability. Table 1 shows the structure of the single-group performance comparison design.

Table 1. Structure of the Single-Group Within-Performance Comparative Design

Group	Unaccompanied Performance	Ongoing Instructional Process (with and without TAA)	Accompanied Performance
Group 1	Measurement 1	+	Measurement 2

The qualitative phase used a case study design to explore participants' perspectives on TAA, providing deeper insights into their experiences (Glesne, 1992/2020). A convergent approach was adopted to integrate quantitative and qualitative data, comparing numerical performance findings with qualitative interview data. This method allowed for a comprehensive interpretation, presenting statistical differences first, followed by direct participant quotations to contextualize and expand on the results.

Participants

The study group consisted of 10 homogeneous flute students enrolled in the Department of Music Education, Faculty of Education, Bursa Uludağ University, during the fall semester of the 2023–2024 academic year. The participants were selected based on their similar educational backgrounds and training levels to ensure methodological consistency in performance assessment. Table 2 presents the demographic characteristics of the participants.

Table 2. Demographic information of the participants

Participant Code	Group	Gender	Academic Level	Flute Playing Time (years)
P1	1 A	Male	Postgraduate	12
P2	1 B	Female	Postgraduate	11
P3	2 A	Male	Undergraduate 4th Year	8
P4	2 B	Female	Undergraduate 4th Year	8
P5	3 A	Female	Undergraduate 2nd Year	6
P6	3 B	Female	Postgraduate	10
P7	4 A	Female	Undergraduate 3rd Year	7
P8	4 B	Female	Undergraduate 1st Year	5
P9	5 A	Female	Undergraduate 2nd Year	3
P10	5 B	Female	Undergraduate 3rd Year	3

Participant grouping reflects both formal education level and instructor-assessed performance level based on sustained instructional observation, rather than academic year alone. Although participants were enrolled at different academic levels, the grouping presented in Table 2 was also informed by performance level. The matching of participants across levels (e.g., P5–P6) was based on sustained observation within the regular flute training process, taking into account students' technical proficiency, musical competence, and repertoire demands. This approach reflects common pedagogical practice in performance-based music education, where instructional level may not strictly correspond to formal academic classification.

This study employed a counterbalanced design to minimize potential confounding effects arising from skill development through experience and individual aptitude differences in performance variation measurements. In this framework, each group undergoes all phases of the process in different sequences, thereby ensuring greater control over order effects and enhancing the reliability of the findings (Fraenkel et al., 2012).

Given the varying proficiency levels among students, selecting a single piece or movement for all participants was not feasible. To address this challenge, the 10 participants were categorized into five subgroups based on their skill levels. Pairing was conducted according to years of flute-playing experience and current academic standing, ensuring comparable skill levels between groups. This matching method facilitated the formation of balanced pairs, where each student in Group A was matched with a counterpart in Group B possessing a similar level of proficiency. To maintain consistency and anonymity, participants were coded as P1, P2, etc. Table 3 presents the counterbalanced study design model implemented in this research.

Table 3. Counterbalanced Study Design of the Research

Group A	Unaccompanied Movement	Measurement 1	Accompanied Movement	Measurement 2
Group B	Accompanied Movement	Measurement 2	Unaccompanied Movement	Measurement 1

Data collection tool

The study was approved by the Bursa Uludağ University Social and Humanities Research and Publication Ethics Committee (decision number and date: 18.12.2023/12).

Performance Assessment Rubric for Instrumental Music

In the quantitative phase of the study, a graded instrumental performance assessment rubric was utilized to evaluate video-recorded performances and assess the impact of TAA on students' performance levels. These performances were recorded using a video camera in the regular flute lesson rooms to ensure that students played in a familiar acoustic environment, reducing potential performance anxiety or adaptation issues. The performance assessment rubric used in this study is an institutional instrument that has been routinely employed in flute performance evaluation at the Department of Music Education, Faculty of Education, Bursa Uludag University since 2020. The original

rubric was developed by faculty members of the department for instructional and assessment purposes. To ensure its relevance and methodological rigor, the rubric was revised and refined in alignment with the specific objectives of this study. Following these modifications, its validity and applicability were reviewed through expert consultation with three specialists in FP. The rubric is grounded in performance-based assessment principles widely adopted in instrumental music education and is based on a multidimensional evaluation framework that integrates both technical accuracy and musical dimensions. Within this framework, constructs such as musicality were operationalized through observable performance indicators, including phrasing, dynamic control, articulation, tempo stability, and expressive coherence, allowing for systematic and holistic performance assessment. The updated version of the institutional rubric prepared for the present study was first presented in the first author's graduate thesis. For the purposes of the present study, the rubric was revised, translated into English, and is provided in Appendix to support transparency and replicability.

The revised performance assessment rubric comprises 13 criteria designed to comprehensively evaluate instrumental performance. These criteria encompass various musical and technical aspects, including tone production, tempo stability, rhythmic accuracy, uninterrupted continuity, tempo consistency in technically demanding passages, precise execution of the musical score, articulation accuracy, dynamic control, intonation, adherence to stylistic characteristics of the period, ornamentation execution, musical coherence, and expressive interpretation. A five-point rating scale was developed to assess each criterion's execution level, with scores assigned as follows: 4 points for complete or excellent execution, 3 points for satisfactory or largely successful execution, 2 points for partial execution, 1 point for poor or largely incorrect execution, and 0 points for complete failure to execute. The total possible score ranges from 0 to 52 points. Beyond these performance criteria, observers were also required to record participant codes, piece and movement details, and whether the performance was accompanied or unaccompanied, ensuring accurate documentation and consistency in the assessment process.

Semi-Structured Interview

In the qualitative phase of the study, semi-structured interviews were conducted to explore students' perspectives on the contribution of TAA on their performance levels. The interview questions were designed to elicit detailed insights into students' experiences and perceptions regarding the pedagogical contributions of TAA. To ensure content validity, the interview questions were reviewed by three experts in FP, who evaluated their appropriateness, comprehensiveness, and clarity. Based on expert feedback, the questions were refined and structured, consisting of core questions supplemented by targeted probing questions to facilitate deeper exploration of specific themes.

Based on expert feedback, the finalized interview protocol comprised two main questions and five sub-questions, excluding demographic inquiries, aimed at exploring students' experiences with TAA. These questions were designed to assess students' perspectives on the contribution of TAA on performance level and musical development, evaluate the functionality of digital platforms, and identify any challenges encountered during practice.

Additionally, the interview included comparative questions, prompting students to contrast their experiences with TAA versus studying with a live accompanist. These comparisons specifically addressed the perceived contributions of each approach to performance quality, musical development, and anxiety management during practice sessions.

Data analysis

Quantitative data analysis

For the quantitative data analysis, the scores obtained through the Performance Assessment Rubric for Instrumental Music were digitized and processed using Microsoft Excel. To assess the consistency among expert ratings, inter-rater reliability was measured using Kendall's W coefficient of concordance, a statistical measure commonly employed to evaluate agreement among multiple raters. The results of the Kendall's W analysis indicated a W value of .78 ($p = .01$) for Accompanied Movement and a W value of .75 ($p = .01$) for Unaccompanied Movement, both of which suggest a statistically significant level of agreement among the expert evaluators.

To examine whether there were statistically significant differences in performance levels between accompanied and unaccompanied movements, the assumption of normality was first assessed using the Shapiro–Wilk test. The results indicated that both unaccompanied ($W = 0.945$, $p = .604$) and accompanied ($W = 0.984$, $p = .983$) performance scores were normally distributed. Accordingly, a paired-samples t-test was conducted to compare performance levels between the two conditions. The significance level (α) was set at .05 to determine the threshold for statistical significance.

Qualitative data analysis

Following the quantitative phase, semi-structured interviews were conducted using questions derived from both the quantitative findings and the literature review. The interview data were analyzed using content analysis methodology, a systematic approach for identifying recurring themes and patterns within qualitative data.

To enhance the reliability of the analysis, both researchers independently coded the data, and inter-coder reliability was assessed using Miles and Huberman's (1994) internal consistency formula, yielding a reliability coefficient of 85.56%. This value exceeds the recommended threshold of 70%, indicating a high level of inter-coder agreement (Şimşek & Yıldırım, 2021). Subsequently, the themes, sub-themes, and codes were reviewed and refined to ensure conceptual clarity and alignment with the research objectives. In the findings section, the frequency of code occurrences is provided in parentheses, and direct participant quotations are incorporated to support and contextualize the analysis.

Results

Performance Levels Comparison of the Accompanied and Unaccompanied Sections

To address the first research question, which explored whether there were statistically significant differences in performance levels between accompanied and unaccompanied movements, a paired-samples t-test was conducted. Table 4 presents the results of this analysis, providing insights into the comparative impact of TAA on flute performance outcomes.

Table 4. Results of Paired-Samples t-Test Analysis

Performance	N	M	SD	t	df	p	Cohen's d
Unaccompanied	10	32.13	2.77	-6.07	9	< .001	-1.92
Accompanied	10	37.87	2.04				

Based on the statistical analysis presented in Table 4, the null hypothesis (H_0) was rejected, and the alternative hypothesis (H_1) was accepted, indicating a statistically significant difference in favor of accompanied performance ($p < .001$). The results demonstrated that flute students achieved higher performance levels in accompanied movements ($M = 37.87$, $SD = 2.04$) compared to unaccompanied movements ($M = 32.13$, $SD = 2.77$). Furthermore, the large effect size (Cohen's $d = -1.92$) suggests that accompaniment had a substantial impact on performance quality. These findings indicate that flute students performed significantly better when playing with accompaniment during the research process.

Participants' Views

The second research question explored participants' perspectives on TAA through individual interviews. Content analysis of the interview data revealed six primary themes: (a) contribution to performance and musicality, (b) functionality, (c) challenges, (d) TAA applications, (e) comparison with live accompanist, and (f) anxiety.

During the interviews, participants evaluated the contribution of TAA applications to performance and musicality in terms of both positive and negative aspects. The most frequently mentioned positive codes were contribution to performance (n=7) and contribution to musicality (n=6). Additionally, participants noted that these applications enhanced their dynamics (n=3), emotional expression (n=3), rhythm (n=2), motivation (n=2), coordination (n=2), performance continuity and coherence (n=2), piece mastery (n=1), and enjoyment (n=1). However, a small number of negative perspectives were also expressed regarding the applications' contribution to performance and musicality. These negative aspects were coded as: difficulty in coordination (n=1), synchronization problems (n=1), and lack of contribution to musicality (n=1).

Below are some participant responses regarding the "Positive Views" sub-theme under the "Contribution to Performance and Musicality" theme:

> P2: "When I play individually, I sometimes experience rhythm problems in certain sections. However, this problem doesn't occur with TAA... And when performing with TAA, I pay as much attention as possible to my musicality since I need to coordinate with the accompaniment. This contributes to my performance."

> P8: "Even though you maintain a steady tempo when practicing with a metronome without accompaniment, working with accompaniment brings a different emotional dimension to the piece... When you have an accompaniment that emphasizes where to pay attention while expressing dynamics and tonality, you become more emotionally engaged..."

Regarding the "Negative Views" sub-theme under the "Contribution to Performance and Musicality" theme, one participant noted:

> P3: "With TAA, I need to adapt to it. Therefore, when I make a mistake, I can't perform the piece as a whole. I think this negatively affects my performance... I experience problems with notation and accompaniment synchronization."

Participants were asked to evaluate the functionality of TAA applications. Their assessments were primarily based on their experiences with Tomplay[3], which was used during the research process, and YouTube applications, which they had previously utilized. All participants found TAA applications functional. However, some participants (n = 4) noted that functionality varied depending on the specific application. Additionally, one participant (n = 1) stated that these applications were particularly non-functional in musical expressions requiring rallentando or fermata.

The following excerpts illustrate participants' perspectives on functionality:

> P5: "I don't find it very functional as I used it in a very limited way. To give an example of why I don't find it functional, when it comes to timing, especially with fermatas, I can't determine how long to extend or how brief to keep the notes... Apart from this situation, it's definitely functional."

> P7: "I didn't use YouTube accompaniments until I was very proficient with the piece because they're set at a fixed tempo. When you slow down a YouTube recording, the accompaniment's intonation becomes distorted. Although, with the Tomplay application we used during the research process, the sound quality remains intact when we slow down the recording... I don't find YouTube very functional due to the issue I mentioned, but I find the Tomplay application we used during the research process functional."

[3] Tomplay is a commercially available digital accompaniment application. The authors declare no financial interest, sponsorship, or affiliation with the developer of the software.

The sub-themes related to challenges experienced by students using TAA applications were categorized as general challenges, challenges specific to YouTube applications, and challenges specific to Tomplay applications. Similar to the "Functionality" theme, participants evaluated these challenges primarily through their experiences with YouTube and Tomplay applications. The general challenges reported while using TAA applications included ensemble coordination (n=4), resuming from specific points (n=4), keeping pace (n=3), finding audio amplification equipment (n=2), perceiving entries (n=1), and balance issues (n=1). Additionally, challenges specific to YouTube applications included sound quality deterioration at different tempi (n=5), tempo adjustment issues (n=3), limited availability of accompaniments for certain pieces (n=1), musicality concerns (n=1), and edition differences (n=1). Challenges with the Tomplay application were related to cost (n=2) and musicality (n=1).

The challenges theme is illustrated through these representative quotes:

> P1: "I particularly experience difficulties in perceiving entries while playing the piece, and catching up when I miss certain points... I face challenges with maintaining ensemble coordination and synchronization when using these applications."

> P10: "...when I play the accompaniment through my phone, I can say that the sound is somewhat inadequate."

An important aspect of our inquiry focused on whether TAA applications could serve as a viable alternative to a live accompanist. Analysis of participants' responses formed the "TAA Applications" theme. The overwhelming majority of participants (n=9) expressed that these applications could not fully replace a live accompanist, while one participant viewed them as an adequate substitute.

Below, selected participant views regarding the potential of TAA applications to serve as a substitute for a live accompanist are presented.

> P6: "It's not really comparable. I can achieve better emotional expression and communication when working with a live accompanist."

> P10: "...I experience more anxiety when working with a live accompanist. As someone who deals with this tension, I believe the TAA can effectively substitute."

Following participants' views on whether TAA applications could substitute for a live accompanist, we asked them to compare their experiences with both accompaniment processes in terms of contribution to performance and musicality. Their responses formed the "Comparison with live accompanist" theme. Participants noted several advantages of performing with a live accompanist, including more effective interpretation and musicality (n=8), easier ensemble coordination (n=5), better synchronization (n=4), more enjoyable music-making experience (n=1), seamless communication (n=1), and the ability to focus specifically on problematic sections (n=1). Conversely, they identified advantages of TAA applications, such as their contribution to the preparation process (n=3), the absence of physical endurance constraints that might affect a live accompanist (n=3), ability to focus on accurate performance (n=3), unlimited repetition opportunities (n=1), and support in achieving overall performance coherence (n=1).

Below are representative responses from the "Comparison with live accompanist" theme:

> P4: "...with a live accompanist, you immerse yourself in the music and create an atmosphere where you become unified. With TAA applications, you focus entirely on playing the notes correctly."

> P8: "...during practice, we naturally make mistakes or have points we might overlook. When working with an accompanist, there's a social communication aspect that allows for immediate feedback."

Following their comparisons of performance and musicality, participants were asked to compare anxiety levels when working with TAA versus live accompanists. Six participants reported increased anxiety levels when working with a live accompanist, while four indicated higher anxiety when using TAA applications.

Participants' experiences with anxiety are demonstrated through these representative accounts:

> P3: "I feel more anxious with TAA because if I lose my place, catching up becomes more complicated. TAA also requires high-quality equipment. However, with a live accompanist, we can communicate through eye contact and understand each other."

> P9: "Since TAA is a tool, it can't criticize me. It won't say things like "you made a mistake" or similar comments. Nevertheless, a live accompanist might get tired of repeating the same sections. My mistakes could demoralize them, and their frustration could, in turn, demoralize me. A live accompanist increases my anxiety level, which makes TAA seem more logical."

Discussion

The first research question investigated whether accompanied performances significantly affected flute students' performance levels compared to unaccompanied performances. The t-test results indicated a significant difference in favor of accompanied performances, revealing that students achieved higher performance levels with accompaniment. The Cohen's d value of -1.921 suggests an exceptionally large effect size, indicating that accompanied practice substantially improved students' performance. Several methodological and technological factors may explain this pronounced effect. First, the careful matching of participants based on skill levels and academic standing ensured comparable baseline abilities, minimizing potential confounding variables. Second, unlike previous studies, this research utilized the Tomplay application, which offers flexible tempo adjustments without compromising sound quality—a feature that likely enhanced learning outcomes. Third, the comprehensive assessment rubric allowed for a multidimensional evaluation of performance, capturing improvements across various technical and musical parameters. These methodological refinements, combined with the advanced capabilities of modern accompaniment technology, likely contributed to the substantial effect size observed in this study. It is important to distinguish between the pedagogical significance of the observed effect size and its statistical interpretation. Pedagogically, the large effect size suggests meaningful instructional benefits of TAA; however, statistically, the small sample size necessitates cautious interpretation of this magnitude and limits the generalizability of the findings.

This finding is supported by Kalkanoğlu Mamaç (2021), whose research showed positive student development across multiple performance dimensions, including rhythmic precision, intonation accuracy, and overall coherence, when using TAA applications. In survey results, Kalkanoğlu Mamaç (2021, p. 46) reported that students noted improvements in "sense of unity (100%), correct intonation (84.6%), understanding of music (84.6%), impact of harmonic coherence on dynamics (84.6%), accurate counting (76.9%), tempo fluency (76.9%), enjoyment while playing (76.9%), and motivation (61.5%)." These perspectives conceptually align with the high effect size observed in the present study and help contextualize the pedagogical relevance of the findings, rather than serving as direct statistical validation.

In the literature, studies by Tseng (1996) and Klee (1998) underscore the pedagogical benefits of accompanied practice. Tseng (1996) reported that computer-assisted accompaniment applications support students' intonation and expressive development, while Klee (1998), citing Walker, emphasized the role of accompaniment in fostering an understanding of the overall musical structure. Extending this line of inquiry, more recent research on technology-supported music education across different instructional contexts suggests that digital and intelligent tools can similarly enhance learning outcomes

and student achievement (Ou et al., 2025; Wang, 2025). Although conducted in different instructional contexts, these studies collectively highlight the positive role of technological support in instrumental music education, contributing to musical coherence and technical development.

In contrast, findings by Sheldon et al. (1999) differ from our study, as they reported no significant difference between live and digital accompaniment, likely due to variations in assessment tools and procedures. However, Klee (1998) demonstrated in his doctoral thesis that students using interactive accompaniment recordings achieved higher performance scores, reinforcing the potential benefits of TAA applications. These studies suggest that integrating TAA applications into instrumental education can positively influence performance levels and open new research avenues.

To contextualize the quantitative findings, qualitative perspectives obtained from the participants were also examined. The performance improvements (d = -1.92) observed in the quantitative phase are further elucidated through qualitative findings on enhanced rhythm, intonation, and musical coherence. Additionally, participants' remarks on increased motivation and enjoyment when using TAA offer further insights into the substantial effect size reported in the quantitative results.

The second research question examined participants' perspectives on TAA. Through individual interviews, participants provided comprehensive evaluations of both the applications and their experiences. While the quantitative findings demonstrated a clear positive impact on performance levels, the qualitative phase offered deeper insights into the underlying mechanisms driving this improvement. Participants attributed their enhanced performance scores to key factors such as increased motivation, improved rhythmic accuracy, and greater musical engagement.

Analysis of participant responses revealed a nuanced understanding of TAA's impact on musicality, incorporating both positive and critical perspectives. A systematic review of participant feedback, categorized according to the Performance Assessment Rubric for Instrumental Music, demonstrated alignment with the rubric criteria. In addition to general improvements in performance and musicality, participants highlighted positive effects on dynamics, emotional expression, rhythmic coordination, musical coherence, and pieces mastery. Furthermore, they identified additional benefits beyond the rubric criteria, particularly increased motivation and enjoyment—contextual factors that may explain the high effect size observed in the quantitative analysis. These motivational and affective components likely contribute to the heightened performance levels observed in accompanied settings.

Existing literature supports these motivational findings. Klee (1998) determined that computer-assisted accompaniment significantly boosts motivation in FP. Yüksel and Mustul (2015) similarly found that students considered such applications engaging and valuable for developing musical interpretation, intonation control, and structural coherence. Further support comes from Mohan Kömürcü's (2019) doctoral research, which found that computer-assisted accompaniment motivates students in vocal and accompaniment training, with students expressing enjoyment in this learning approach.

However, participants also indicated challenges in using TAA, including adaptation difficulties, synchronization issues, and perceived limitations in musical expressiveness. Aytemur and Sönmezöz's (2022) study on computer-assisted accompaniment in flute lessons reported similar challenges, with students expressing adaptation difficulties and predominantly negative views toward these applications. Their analysis suggested that these perspectives may stem from established practice habits, such as reliance on traditional practice methods or live accompanist support. Additionally, their methodology, which restricted accompaniment to two tempi, may have further contributed to adaptation difficulties. In contrast, our study utilized Tomplay, which enabled students to adjust tempi as they progressed, thereby mitigating adaptation challenges.

When assessing participants' views on the functionality of TAA, all participants rated these applications as functional, though they noted variability depending on the specific application. For instance, sound quality issues during tempo reductions on YouTube detracted from functionality. Participants also observed that these applications were limited in managing expressive tempo adjustments, such as fermata. Mohan Kömürcü (2019) similarly noted that these applications fall short in conveying expressive elements like ritardando and rallentando. He also highlighted a significant limitation of computer-assisted accompaniment: its inability to provide gestural and facial cues, which affects synchronization and musical expression. Acquilino and Scavone (2022) found that software focused on pitch accuracy lacked support for rhythmic flexibility, aligning with our study's findings.

Students encountered several additional challenges, primarily related to ensemble coordination, synchronization at entry points, balance adjustment, tempo control, and sound quality degradation. Platforms like YouTube posed issues due to sound quality deterioration during tempo changes and limited availability of accompaniments. Tomplay, while preferred for its features, was sometimes viewed negatively due to its cost and repertoire limitations.

Mohan Kömürcü (2019) noted that accompaniment applications cannot substitute for the nuanced communication provided by live accompanists. Similarly, students expressed that technology-assisted applications were less effective than live accompaniment in terms of communication and musical interpretation. Kalkanoğlu Mamaç (2021, p. 54) also identified challenges such as "incomplete perception of the piece, difficulty in understanding the whole piece, feelings of inadequacy, lack of discipline, tempo inconsistencies, lack of enjoyment, lack of musical flow, limited musical richness, lack of emotional expression, and insufficient mastery."

Notably, several students endorsed TAA for its preparation benefits, highlighting improved focus on note accuracy, better understanding of compositions, and repetition flexibility. This aligns with Tseng's (1996) findings using the Vivace application, where students reported positive impacts on performance preparation. In conclusion, while TAA applications provide useful features for preparation, the absence of human interaction and interpretive flexibility associated with a live accompanist led students to perceive these applications as insufficient for holistic performance.

When comparing anxiety levels between TAA and live accompanists, responses were mixed: six students reported increased anxiety with live accompaniment, while four felt the opposite. This aligns with Conklin's (2011) research, which found lower anxiety levels with virtual accompaniment. Although anxiety levels warrant further investigation due to multiple influencing factors, some students noted increased anxiety in front of audiences or with live accompaniment. Both literature and participant responses suggest that the coordination support of live accompaniment may create a less anxiety-inducing environment. Despite the significant performance gains observed quantitatively, variations in participants' anxiety levels across accompaniment methods suggest that performance improvement may occur independently of anxiety levels, highlighting the complex relationship between psychological comfort and technical proficiency.

Conclusion and Recommendations

The integration of quantitative and qualitative findings provides a comprehensive perspective on the impact of TAA on flute pedagogy. Quantitative analysis revealed statistically significant performance enhancements with TAA ($d = -1.921$). Nevertheless, given the relatively small sample size, the magnitude of the observed effect should be interpreted with caution. These results are consistent with prior research (Kalkanoğlu Mamaç, 2021; Klee, 1998; Tseng, 1996). Qualitative insights further elucidated both the advantages (increased motivation, practice flexibility) and limitations (synchronization challenges, constraints on musical expressiveness) associated with TAA. Overall, the findings suggest that TAA may offer a less anxiety-inducing learning environment, whereas live accompaniment remains essential for the development of nuanced musical expression. These findings indicate that TAA applications significantly enhance performance levels relative to unaccompanied

practice and serve as an invaluable resource during preparatory phases, particularly in contexts where live accompanist support is inaccessible.

Based on these findings, several practical and research-oriented recommendations emerge. Music educators are encouraged to incorporate TAA applications into curricula, ensuring the availability of necessary technological resources and optimal practice environments. Educators should actively foster student engagement with these tools, emphasizing their pedagogical advantages in skill acquisition and performance enhancement. For future research, we suggest investigating the efficacy of TAA across diverse musical periods and genres, employing larger sample sizes and extended experimental durations to enhance the generalizability of findings. Additionally, future studies should explore TAA's influence on broader dimensions of musicianship, including period-specific interpretation, anxiety regulation, and intrinsic motivation.

This study contributes to the field of instrumental music education by demonstrating the direct performance-enhancing impact of TAA through quantitative assessment, in contrast to earlier perception-based studies. Additionally, the use of a modern accompaniment platform and a mixed-methods approach integrating performance evaluations and student perceptions provides a comprehensive framework for future research on digital tools in music performance education.

Research Limitations

Our study was subject to several limitations related to the selected application, choice of musical repertoire, and fixed implementation period. The Tomplay application was chosen based on a comprehensive evaluation of its sound quality, repertoire diversity, tempo adjustment capabilities, metronome and tuner integration, recording functions, sheet music printing options, and cost-effectiveness. For the instructional process, Baroque and Classical fast movements were selected according to the following criteria: (1) rhythmic clarity to minimize tempo-related inconsistencies, (2) appropriateness for student proficiency levels, and (3) comparable difficulty in terms of tempo, rhythmic structure, and technical complexity.

Additionally, the ten-week implementation period, with five weeks allocated per movement, may not have adequately accounted for individual variations in practice requirements, which could be influenced by group proficiency levels and piece-specific technical demands. In addition, the relatively small sample size limits the generalizability of the findings, and the large effect size should therefore be interpreted with caution.

Additionally, although the performance assessment rubric was structured and supported by expert review, its application inherently involved a degree of interpretive judgment. As with all performance-based assessments, this interpretive component may have influenced scoring decisions.

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Appendix. Instrumental Performance Assessment Rubric (English Version)

Graded Instrumental Performance Assessment Rubric

Student Code: **Piece / Movement:**

With Accompaniment: ☐ **Without Accompaniment:** ☐ **Evaluator**

Performance Criteria Related to the Interpretation of the Piece	**4**	**3**	**2**	**1**	**0**	**Comments / Score**
1- Tone Production (Flute Tone / Tone Quality)	The student demonstrates a high level of tone quality.	The student demonstrates an adequate level of tone quality.	The student demonstrates a partially adequate tone quality.	The student demonstrates a partially poor tone quality.	The student demonstrates a poor tone quality.	
2- Performance at the Correct Tempo	The piece was performed entirely at the correct tempo.	The piece was performed largely at the correct tempo.	The piece was performed partially at the correct tempo.	The piece was performed largely at an incorrect tempo.	The piece could not be performed at the correct tempo.	
3- Rhythmic Accuracy (Accurate Execution of Rhythmic Patterns)	All rhythms were performed accurately throughout the piece.	Most rhythms were performed accurately.	Rhythms were performed partially accurately.	Most rhythms were performed inaccurately.	Rhythms could not be performed accurately.	
4- Performance Without Hesitation	The piece was performed entirely without hesitation.	The piece was performed largely without hesitation.	The piece was performed with partial hesitation.	The piece was performed with frequent hesitation.	The piece was performed with significant and frequent pauses.	
5- Maintaining a Steady Tempo During Technical Passages	Technical passages were performed at a completely steady tempo.	Technical passages were performed largely at a steady tempo.	Technical passages were performed partially at a steady tempo.	The tempo slowed considerably during technical passages.	Technical passages could not be performed at the intended tempo.	
6- Pitch Accuracy (Correct Notes)	All notes were performed accurately.	Most notes were performed accurately.	Notes were performed partially accurately.	Most notes were performed inaccurately.	Notes could not be performed accurately.	
7- Accuracy of Articulation	All articulations were performed accurately.	Most articulations were performed accurately.	Articulations were performed partially accurately.	Most articulations were performed inaccurately.	Articulations could not be performed accurately.	
8- Performance in Accordance with Dynamic Markings (Nuance)	All dynamic markings were performed accurately.	Most dynamic markings were performed accurately.	Dynamic markings were performed partially accurately.	Most dynamic markings were performed inaccurately.	Dynamic markings could not be performed accurately.	
9- Intonation Accuracy	The piece was performed with completely accurate intonation.	The piece was performed largely with accurate intonation.	The piece was performed with partially accurate intonation.	The piece was performed largely with inaccurate intonation.	Accurate intonation could not be achieved.	
10- Performance in Accordance with Period / Style Characteristics	The piece was performed fully in accordance with period/style characteristics.	The piece was performed largely in accordance with period/style characteristics.	The piece was performed partially in accordance with period/style characteristics.	The piece was performed largely inconsistently with period/style characteristics.	The piece could not be performed in accordance with period/style characteristics.	

11- Execution of Ornaments in Accordance with Period / Style	All ornaments were performed accurately and stylistically appropriately.	Most ornaments were performed accurately and stylistically appropriately.	Ornaments were performed partially accurately.	Most ornaments were performed inaccurately.	Ornaments could not be performed accurately.
12- Musical Coherence and Integrity	The piece was performed with complete musical coherence.	The piece was performed largely with musical coherence.	The piece was performed with partial musical coherence.	The piece was performed largely without musical coherence.	Musical coherence could not be achieved.
13- Expressive and Interpretative Quality	The student fully demonstrated expressive and interpretative quality.	The student largely demonstrated expressive and interpretative quality.	The student partially demonstrated expressive and interpretative quality.	The student demonstrated very limited expressive quality.	The student did not demonstrate expressive or interpretative quality.
Total score					