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RESEARCH ARTICLE

Engaging Students in Audiovisual Coding Through Interactive MATLAB GUIs

CARLOS CUEVAS, CARLOS CORTÉS, AND NARCISO GARCÍA, (Life Senior Member, IEEE)

Grupo de Tratamiento de Imágenes (GTI), Information Processing and Telecommunications Center (IPTC), and ETSI Telecomunicación, Universidad Politécnica de Madrid (UPM), 28040 Madrid, Spain

Corresponding author: Carlos Cuevas (carlos.cuevas@upm.es)

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ABSTRACT Traditional educational methods in higher education, such as lectures and hands-on exercises, often struggle to fully engage students or address the complexities inherent in audiovisual signal coding. This gap underscores the need for innovative educational tools that not only foster deeper understanding but also enhance student engagement within the university setting. Effective evaluation of these tools requires comprehensive assessment of both learning outcomes and user experience. This study introduces three novel graphical user interface applications designed to strengthen foundational knowledge in audio, image, and video signal coding. These interactive tools, specifically developed for use in university courses, allow students to experiment with various coding techniques, providing hands-on experience that bridges theoretical concepts and practical application. Furthermore, we propose a robust methodology to evaluate the effectiveness of these tools in improving learning outcomes. The tools, developed using MATLAB, were integrated into a computer vision course and assessed through a combination of pre- and post-tests, the System Usability Scale, and the Evaluation Tool for Learning Quality. Results indicate a significant improvement in student knowledge and positive feedback regarding the usability and educational value of the tools. These findings suggest that the interactive nature of the tools not only enhances knowledge retention but also boosts student engagement, offering a valuable complement to traditional educational methods in higher education.

INDEX TERMS Audiovisual coding, graphical tools, interactive learning, MATLAB GUI, student engagement, teaching effectiveness.

I. INTRODUCTION

With the continuous expansion of high-quality multimedia content [1], [2], the demand for professionals skilled in audiovisual signal coding has never been greater. This growing need emphasizes the importance of effective educational approaches to equip students with the necessary knowledge and expertise in this field [3], [4], [5]. However, traditional methods such as lectures and hands-on exercises often fail to fully engage students or adequately address the complexity of the subject matter [6]. To bridge this gap, interactive graphical tools have been introduced, offering a visually engaging and hands-on learning experience [7]. These tools allow students to experiment with different concepts and techniques, fostering a deeper understanding of the underlying principles [8], [9].

A. CONTRIBUTION

In this paper, we present three publicly available graphical user interface (GUI) tools for audiovisual coding, along with a validation of their effectiveness on learning performance.

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These tools have been designed to impart a comprehensive understanding of audio, image, and video signal coding. Each tool offers a range of interactive features tailored to specific coding tasks:

- Audio coding tool: Allows exploration and manipulation of audio data with various coding schemes, including uniform and non-uniform quantization techniques.
- Image coding tool: Focuses on the Discrete Cosine Transform (DCT) for image compression, enabling experimentation with different parameters.
- Video coding tool: Shows motion estimation and compensation, essential for understanding video compression principles.

These tools, developed using MATLAB, aim to enhance student engagement, comprehension, and retention of complex coding concepts, making them valuable for both newcomers and those seeking deeper technical knowledge.

The primary objective of this study is to assess the effectiveness of these tools in enhancing the learning experience in audiovisual coding education. We investigate their impact on student motivation, knowledge acquisition, and overall learning outcomes. A controlled experiment with students enrolled in a computer vision course evaluated these aspects through pre- and post-tests, the System Usability Scale (SUS) [10], and the Evaluation Tool for Learning Quality (ETLQ) [11].

The proposed tools are publicly accessible,[1] ensuring that educators, students, and researchers can utilize them to deepen their understanding of audiovisual coding principles and enhance their learning experiences.

In addition, to support independent learning, we have developed three tutorial videos, one for each of the GUI tools (audio, image, and video coding), which are accessible on the same website as the tools. These videos provide guided instruction on the functionalities and key concepts of each tool, making the learning experience more accessible, especially for students who may not attend in-person sessions.

B. ORGANIZATION

The remainder of this paper delves into related work on GUIs in education (section II), presents the theoretical framework that supports the development and use of the proposed tools (section III), outlines the implementation of the developed tools in a use case scenario (section IV), details the research methodology (section V), presents the obtained results (section VI), and discusses their significance (section VII). Finally, we conclude by summarizing the key findings and highlighting the impact on audiovisual coding education (section VIII).

II. RELATED WORK

Traditional educational methods, such as lectures, textbooks, and hands-on coding exercises, have long been the mainstay of education. However, these methods can sometimes fall short in providing an engaging and interactive learning experience, particularly for students who struggle with abstract concepts [12] or lack prior programming experience [13], [14].

GUIs play a crucial role in modern education by making complex concepts more accessible and engaging [15]. The use of GUIs in educational tools supports visual learning, interactive experiences, and collaborative work, significantly enhancing the traditional classroom environment [16].

Several reviews and meta-analyses have explored the impact of GUIs in educational settings, providing a comprehensive overview of their effectiveness in enhancing learning outcomes. Here are some key findings from recent studies.

In the study in [17], a GUI aimed at teaching machine learning concepts through interactive tutorials and assessments was described. It highlighted the effectiveness of interactive learning tools in enhancing students' understanding of complex AI concepts.

The review in [18] focused on the use of educational robotics simulators with GUIs, highlighting their benefits in teaching robotics concepts and preparing students for competitions. The study found that GUIs in simulators enhance student engagement and learning efficiency.

The review in [19] focused on the integration of event-driven programming (EDP) into educational curricula, highlighting the benefits of using GUIs to teach EDP concepts. The study found that GUIs facilitate a better understanding of programming concepts and enhance student engagement.

In [20], the use of GUIs in creating and evaluating educational activities with autonomous robots was discussed. It demonstrated that adaptive GUIs can personalize learning experiences and improve student engagement and comprehension.

The systematic review in [21] identified key usability and user experience characteristics for learning support platforms with GUIs. It provided guidelines for designing effective educational interfaces that enhance user satisfaction and learning outcomes.

In summary, GUIs can enhance learning experiences across various disciplines. By incorporating them into educational practices, educators can promote deeper understanding, increase student engagement, and cater to diverse learning needs.

Recently, MATLAB-based GUIs have gained attention in education for their ability to simplify complex concepts and enhance student engagement through interactive learning experiences. Their use spans a wide array of topics, from fundamental physics principles to advanced engineering technologies.

For example, the study in [22] describes a MATLAB-based GUI developed for controlling commonly available undergraduate lab electronic test instruments, such as digital oscilloscopes and waveform generators. This tool not only fosters computational thinking and hands-on skills

[1] http://www.gti.ssr.upm.es/data

but also introduces students to practical applications like biosignal processing, bridging the gap between foundational engineering concepts and real-life scenarios.

Similarly, the study in [23] introduced an educational MATLAB-based GUI tool designed to enhance engineering students' understanding of maximum power point tracking techniques in photovoltaic systems. The evaluation compared student performance and engagement during a semester using the GUI tool with a previous semester where the tool was not used, demonstrating an improvement in learning outcomes and student attitudes toward the subject.

In another instance, the study in [24] introduced a MATLAB-based GUI as an educational tool to facilitate student comprehension of Coulomb's law and Gauss's law by allowing users to manipulate simulation parameters and visualize these concepts. The GUI received positive feedback in survey responses, highlighting student enthusiasm for the engaging, hands-on learning experience provided by the tool.

Additionally, the study in [25] highlights a MATLAB-based GUI developed to teach the complex receiver structure of Galileo E5 signals. The tool demonstrates key baseband signal processing concepts, including signal acquisition, tracking, and navigation data extraction, offering students a practical approach to mastering advanced satellite communication technologies.

Several educational tools have been developed to enhance student understanding in the fields of image and video processing. For instance, the Digital Image Processing Teaching Auxiliary System in [26] utilizes a MATLAB-based GUI to facilitate the comprehension of complex image processing concepts through interactive simulations. This tool has proven to be effective in making abstract ideas more tangible for students. Similarly, the Short Project-Based Learning with MATLAB Applications [27] approach leverages short projects to teach image and video processing, fostering skill development through hands-on experience.

These tools, while valuable in their respective domains, focus primarily on general image and video processing techniques rather than on the specific domain of audiovisual signal compression. To the best of our knowledge, our set of tools is the first to provide an integrated learning environment specifically aimed at teaching the compression of audio, image, and video signals. This makes our approach unique in its ability to address a crucial aspect of audiovisual signal processing that is often underrepresented in educational tools.

The three MATLAB GUI tools presented in this study contribute to the growing body of work on interactive and visually engaging tools for audiovisual signal coding education. By providing a user-friendly and interactive environment for exploring and understanding these fundamental concepts, these tools aim to enhance student engagement, comprehension, and overall learning outcomes. The tools can be integrated into various educational settings, including traditional classrooms, online courses, and individual learning environments.

III. PEDAGOGICAL FOUNDATIONS

The development of the proposed GUI tools is grounded in several key educational theories that emphasize active, experiential, and contextual learning. These pedagogical foundations provide a strong rationale for the use of interactive tools to enhance student engagement and understanding of complex audiovisual compression concepts.

- Constructivism: Constructivist learning theory emphasizes the active role of learners in constructing their own understanding through interaction with their environment [28]. In the context of this study, the GUI tools enable students to experiment with real audiovisual signals, manipulate parameters, and visualize the effects of different compression techniques. This hands-on approach aligns with constructivist principles, where knowledge is built through experience rather than passive reception [29]. By allowing students to directly engage with the material, the tools foster deeper understanding and retention of the underlying concepts.
- Experiential Learning: Kolb's experiential learning theory suggests that knowledge is created through the transformation of experience [30]. The cycle of experiential learning—concrete experience, reflective observation, abstract conceptualization, and active experimentation, is fully supported by the interactive nature of the GUI tools. Students are able to experiment with different audiovisual coding techniques and immediately observe the results, facilitating a reflection process and a deeper conceptualization of the theoretical principles behind signal compression.
- Situated Cognition: Situated cognition theory asserts that knowledge is best acquired when embedded in meaningful and realistic contexts [31]. The GUI tools provide students with a contextualized learning environment that mirrors real-world applications of audiovisual compression. By immersing students in tasks that resemble professional practice, the tools bridge the gap between abstract theoretical knowledge and its practical application, making learning more relevant and engaging.

IV. USE CASE DESCRIPTION

The three GUIs developed aim to provide a hands-on learning experience for students to explore and solidify their understanding of core principles in audiovisual compression. At the beginning of the activity, the instructors provide a brief demonstration of the functionalities of the tools. Then, students engage in hands-on exploration with the GUIs, experimenting with different parameters and analyzing the results to understand how various coding techniques impact compression efficiency and signal fidelity.

A. EXPLORING AUDIO CODING BASICS

Students delve into the fundamentals of audio coding using the audio coding tool, depicted in Fig. 1. They conduct a series of analyses on two short audio files with diverse

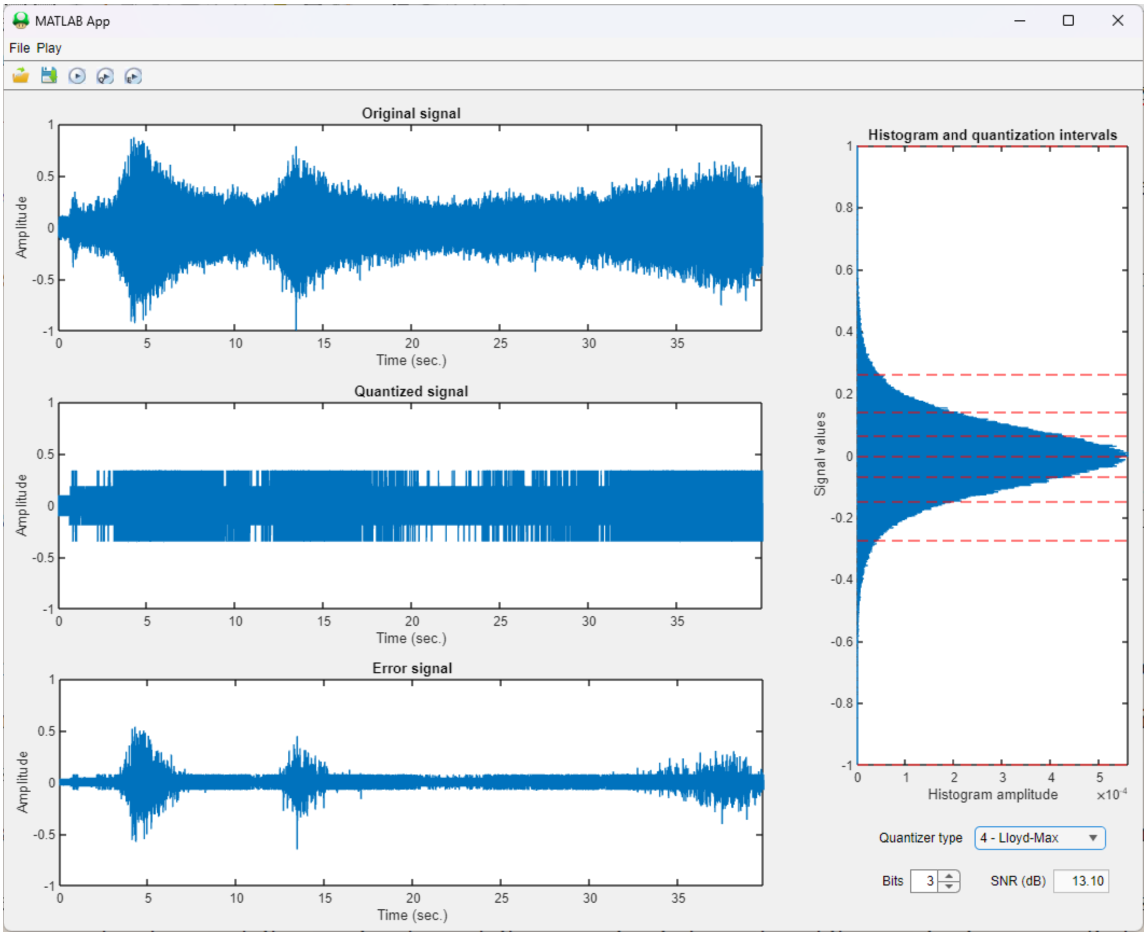

FIGURE 1. GUI of the audio coding tool.

frequency content to gain a comprehensive understanding of audio coding techniques.

- Analyzing original audio characteristics: Students actively listen to the original audio file to get a firsthand impression of its sound quality and identify any notable characteristics. They also examine the visual representation of the audio waveform to understand the temporal variations in sound amplitude and identify the presence of high- and low-frequency components. They further analyze the histogram of the audio signal's amplitude values.
- Applying quantization schemes: Students experiment with different quantization schemes (uniform, non-uniform, and Lloyd-Max). For each scheme, they vary the number of bits used for quantization and analyze the resulting coded audio. Students calculate and compare the Signal-to-Noise Ratio (SNR) values obtained for each quantization scheme and number of bits combination. They further explore the relationship between SNR values and histograms of the original signal. This helps them understand how quantization affects the distribution of sound intensities and introduces distortion. Finally, students listen to the coded audio samples to subjectively assess the perceived quality of the reconstructed sound.

B. EXPLORING IMAGE CODING BASICS

Students delve into the fundamentals of image coding using the image coding tool, illustrated in Fig. 2. They conduct a series of analyses on four images with diverse characteristics (different frequency content and luminance ranges) to gain a comprehensive understanding of image coding techniques.

- Original image analysis: Students visually examine the distribution of high- and low-frequency components within the original image, its histogram of luminance values, and its entropy. This analysis helps them understand the inherent characteristics of the image and their impact on compression efficiency.
- Image domain coding: Students experiment with two quantization schemes (uniform and Lloyd-Max). For each scheme, they vary the number of bits used for quantization and analyze the resulting coded image. The analysis should focus on the Root Mean Square Error (RMSE), the entropy of the coded image, and the areas of the coded image where quantization introduces significant distortion.

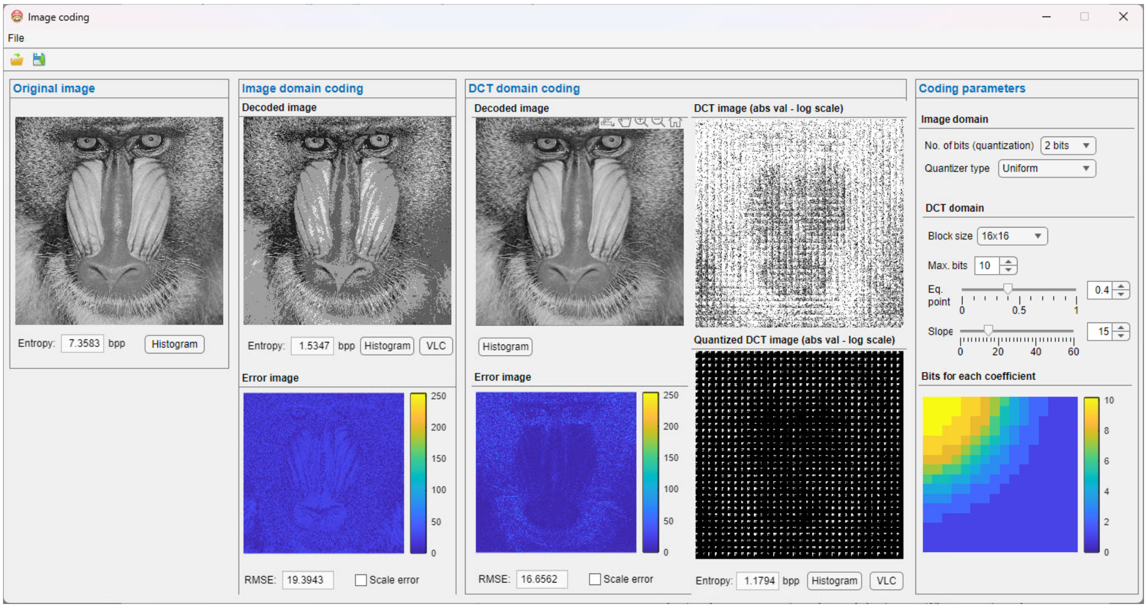

FIGURE 2. GUI of the image coding tool.

- Transformed domain coding: Students investigate the impact of block size on the Discrete Cosine Transform (DCT) domain coding. By selecting different block sizes, they analyze the resulting coded image and pay attention to the RMSE, the entropy of the coded image, and the quantized DCT coded image. To ensure a fair comparison between image and DCT domain coding, students should adjust the parameters of a bi-dimensional sigmoid function[2] (shown in the lower right corner of Fig. 2) to achieve a target entropy level equivalent to that obtained in image domain coding experiments.

C. EXPLORING VIDEO CODING BASICS

Students delve into the fundamentals of video coding using the video coding tool, illustrated in Fig. 3. They conduct a series of analyses on one short video file to gain a comprehensive understanding of video coding techniques, particularly focusing on the concept of motion prediction.

- Visualizing the video sequence: Students begin by watching the video sequence to get a general sense of the motion patterns and content present. This helps them understand the challenges and opportunities for motion prediction in video compression. Students also analyze the histogram and the entropy of the video frames that will be encoded next.
- Exploring motion prediction techniques: Students investigate three different motion prediction approaches (predicting from a previous frame of the same shot, predicting from a non-consecutive frame of the same shot, and predicting from a frame of a different shot). For each of these cases, students analyze the prediction results using different motion estimation methods offered by the tool (e.g., exhaustive search, logarithmic search, hierarchical search), along with varying block sizes and search areas.

[2]Monotonically decreasing function that allocates a greater number of bits the closer the coefficient is to the upper left corner of the DCT block.

V. RESEARCH METHODOLOGY

The use case described in section IV provided a context to evaluate the effectiveness of the proposed graphical tools in terms of student motivation and knowledge acquisition related to audiovisual compression basics. This evaluation employed a unidirectional pre-test, post-test experimental design. Participants completed a pre-test to assess their initial knowledge level, interacted with the graphical tools during the activity and then completed a post-test to measure their knowledge gain. Additionally, the usability of the tool and student engagement were evaluated through the SUS and ETLQ questionnaires, respectively. Informed consent was obtained from the students before participating in the study.

The following sections delve deeper into the research methodology, providing details about context and sample population (section V-A), research procedure (section V-B), methods and instruments used to collect data on the learning effectiveness of the tools (section V-C), and statistical analysis on the obtained data (section V-D).

A. CONTEXT AND SAMPLE

This research was conducted within the framework of the Audiovisual Communications undergraduate course taught at the School of Telecommunication Engineering of the Universidad Politécnica de Madrid (UPM). This mandatory course is part of the Audiovisual Systems minor within the

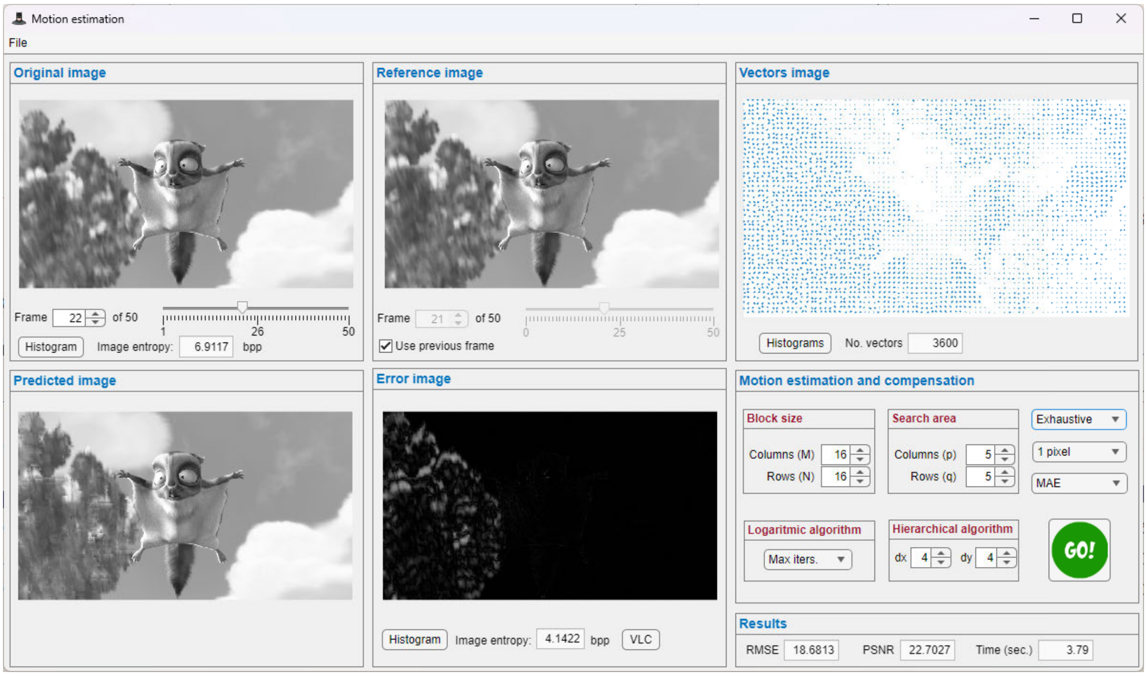

FIGURE 3. GUI of the video coding tool.

fourth year (Senior year) of the Bachelor of Engineering in Telecommunication program. The course workload is equivalent to six European Credit Transfer System (ECTS) credits, which typically translates to approximately 150-180 hours of student effort.

The Audiovisual Communications course focuses on applied training in the design, development, integration, and management of systems for implementing audiovisual services. Students gain a fundamental understanding of these services and develop a structured approach to identify and address challenges related to multimedia services. This course also lays the groundwork for integrating their knowledge with future coursework.

To facilitate student comprehension of the subject matter, the first unit delves into the fundamental concepts of audiovisual signals and their coding. The graphical tools used in this research were introduced to students at the conclusion of the first unit. This timing ensured that students had a solid foundation in audiovisual coding principles before actively using the tools for exploration and experimentation.

A total of 13 students participated in the study. The sample population consisted of 10 males and 3 females, with a median age of 21.

B. PROCEDURE

This research employed a unidirectional pre-test, post-test experimental design with a single intervention session lasting approximately 120 minutes. Two instructors facilitated the session: the course professor and a support instructor. The procedure consisted of the following steps, also illustrated in Fig. 4:

- Pre-test: The session commenced with a pre-test designed to assess students' prior knowledge of the fundamental concepts related to audiovisual compression covered in the first unit of the Audiovisual Communications course. This pre-test served as a baseline measure of student understanding before encountering the tools and ensured a fair evaluation of the intervention's impact on knowledge acquisition.
- Tool introduction and instructions: The instructor delivered a comprehensive introduction to the three graphical tools. This introduction included detailed instructions about the activity structure, functionalities of each tool, and effective strategies for utilizing them.
- Tool-based activity: The core of the intervention session was a hands-on activity lasting approximately 80 minutes. During this time, students actively engaged with the three graphical tools, following the set of tasks outlined in the use case description (section IV). This hands-on exploration allowed students to experiment with different parameters, analyze results, and solidify their understanding of core principles through practical application.
- Post-test and questionnaire: The session concluded with two final assessments. First, a post-test was administered to evaluate the effectiveness of the intervention in enhancing students' knowledge acquisition of audiovisual compression concepts compared to their baseline understanding measured in the pre-test. Second, the SUS and ETQL questionnaires were distributed to gather student feedback regarding their perceptions of the usefulness of the tools, their ease of use, and

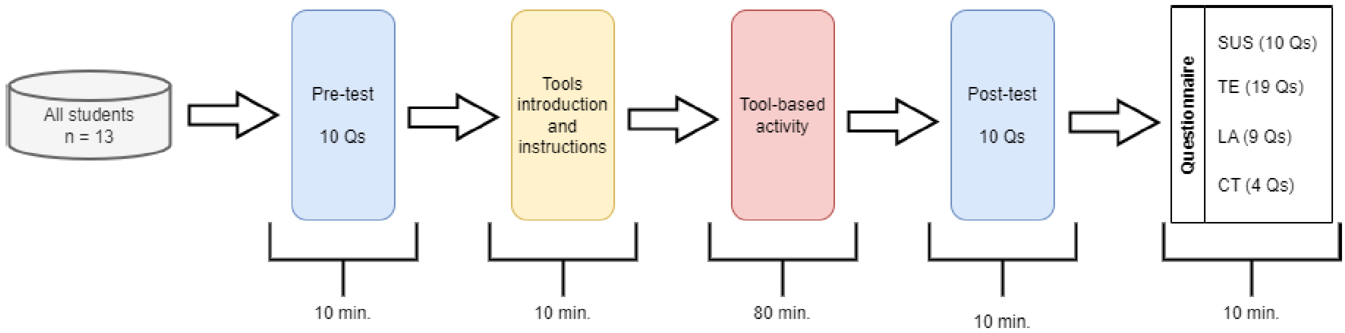

FIGURE 4. Procedure steps involved in the evaluation, along with the time taken for each step.

their overall learning experience with the graphical tools.

C. METHODS AND INSTRUMENTS

All student information was collected electronically through the Moodle platform, the learning management system used to support the Audiovisual Communications course.

To assess student learning outcomes, the study employed objective pre-test and post-test assessments administered electronically through Moodle. These multiple-choice tests, consisting of 10 identical questions for all students in both pre-test and post-test versions, were designed to evaluate students' understanding of the key audiovisual coding concepts covered during the intervention session with the graphical tools. To prevent students from memorizing answers and artificially inflating post-test scores, no feedback was provided after completing the pre-test. This ensured that the post-test accurately reflected the knowledge students gained from actively engaging with the tools and the intervention session.

In addition to the pre-test and post-test, a student perception questionnaire was also administered electronically through Moodle to gather feedback on the tools and the overall learning experience. This questionnaire used a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) to capture student responses across various aspects of the intervention. The specific questionnaire items (presented and analyzed in section VI) are categorized as follows:

- SUS: Ten questions to evaluate the usability of the tools.
- ETLQ (TE factor): Ninehteen questions to evaluate the teaching-learning environment.
- ETLQ (LA factor): Nine questions to evaluate the student approach to learning.
- ETLQ (CT factor): Four questions to evaluate higher-order thinking skills.

D. DATA ANALYSIS

The data collected from the pre-tests, post-tests, and student perception questionnaires underwent analysis using various statistical methods to evaluate the effectiveness of the graphical tools in enhancing student learning and fostering positive learning experiences.

Descriptive statistics, including mean (M) and standard deviation (SD), were computed for both the pre-test and post-test scores to summarize student performance on the knowledge acquisition assessments. The Shapiro-Wilk test [32] was used to assess the normality of the data distribution for the pre-test / post-test scores. Since the data were determined not to be normally distributed, non-parametric statistical methods were utilized for further analysis. To explore the learning effectiveness of the tools, a Wilcoxon signed-rank test [33] for paired samples was conducted on the pre-test and post-test scores. This test aimed to ascertain whether there existed a statistically significant difference between the scores students achieved on the pre-test (baseline knowledge) and the post-test (knowledge after using the tools).

Regarding the questionnaires, to assess participants' learning experience during the lab sessions, a shortened and validated version of the ETLQ [34], [35] was used. Furthermore, to evaluate the usability of the GUI video coding tool, the SUS [36] was used. The same descriptive statistics previously mentioned were also calculated for the questionnaire responses on the Likert scale (1-5) to comprehend student perceptions across various aspects of the intervention.

VI. RESULTS

A. USER EXPERIENCE

The SUS was utilized to evaluate the usability of the GUI tools developed. This well-established tool employs a questionnaire of ten items, where participants rate their agreement with each statement on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) (see Table 1). The survey includes both positive and negative statements to capture a comprehensive user perspective (e.g., see the first two items in Table 1). Following the recommended scoring approach [37], negative statements were reverse-scored before calculating the total score. The individual question scores were then ranged from 0 to 4 and multiplied by 2.5, resulting in a final range of 0 to 10 for each question.

The overall SUS score for the video coding tool was 70.21 (with a standard deviation of 6.94). The literature suggests that a SUS score above 68 indicates good usability [36]. Based on this benchmark, the score obtained indicates that

TABLE 1. SUS questionnaire results.

Item	M (SD)
I think that I would like to use this system frequently	3.58 (0.79)
I found the system unnecessarily complex	2.08 (0.90)
I thought the system was easy to use	4.25 (0.75)
I think that I would need the support of a technical person to be able to use this system	2.50 (1.09)
I found the various functions in this system were well integrated	3.75 (0.75)
I thought there was too much inconsistency in this system	1.92 (1.16)
I would imagine that most people would learn to use this system very quickly	4.00 (0.85)
I found the system very cumbersome to use	2.00 (0.74)
I felt very confident using the system	3.50 (0.80)
I needed to learn a lot of things before I could get going with this system	2.50 (0.67)

TABLE 2. Descriptive statistics and p-value for the pre-test and post-test.

Pre-test $[M\ (SD)]$	4.25 (1.60)
Post-test $[M\ (SD)]$	5.75 (1.71)
Learning performance $[M\ (SD)]$	1.50 (1.45)
p-value	< 0.05

the proposed tool has good usability, making it user-friendly and easy for students to navigate and interact with during the intervention session.

B. ACQUISITION OF KNOWLEDGE

Table 2 summarizes the pre-test and post-test scores achieved by students, along with the learning performance. Learning performance is calculated as the difference between post-test and pre-test scores.

As shown in the table, students achieved an average score of 4.25 on the pre-test, indicating their baseline knowledge of the video coding concepts before interacting with the graphical tools. Following the intervention session, the average score increased to 5.75, demonstrating a gain in knowledge acquisition. The average learning performance was 1.50 points (with a standard deviation of 1.45).

While the data distribution of the pre-test/post-test scores did not satisfy the assumptions of normality, a non-parametric Wilcoxon signed-rank test was employed as a suitable alternative statistical method. This test revealed a statistically significant improvement in student knowledge scores ($p < 0.05$). In simpler terms, the results indicate that the difference between pre-test and post-test scores is unlikely to have occurred by chance. These findings suggest that the intervention session utilizing the graphical tools facilitated student learning and improved their understanding of the audiovisual coding concepts covered in the first unit of the Audiovisual Communications course.

C. LEARNING QUALITY

This section presents the results of the evaluation of learning quality, focusing on student perceptions of the teaching environment and their own approaches to learning. To assess the effectiveness of educational practices, researchers often

TABLE 3. TE questionnaire results.

Item	M (SD)
This programme encouraged me to relate what I learned to issues in the wider world	3.75 (0.75)
I could see the relevance of most of what we were taught in this programme	3.92 (0.90)
I enjoyed being involved in this programme	4.17 (0.72)
Staff helped us to see how you are supposed to think and reach conclusions in this subject	4.08 (0.90)
The teaching in this programme helped me to think about the evidence underpinning different views	3.75 (0.62)
This programme has given me a sense of what goes on 'behind the scenes' in this subject area	3.25 (1.22)
Staff tried to share their enthusiasm about the subject with us	3.75 (1.14)
What we were taught seemed to match what we were supposed to learn	4.08 (0.79)
Staff were patient in explaining things which seemed difficult to grasp	3.92 (0.90)
The feedback given on my work helped me to improve my ways of learning and studying	3.83 (1.11)
The feedback given on my set work helped to clarify things I hadn't fully understood	3.50 (1.00)
The set work helped me to make connections to my existing knowledge or experience	3.75 (1.06)
I found I could generally work comfortably with other students in this programme	3.92 (0.51)
Students supported each other and tried to give help when it was needed	3.83 (0.83)
Talking with other students helped me to develop my understanding	3.83 (0.72)
It was clear to me what was expected in the work assessed for this programme	3.33 (0.98)
I could see how the set work fitted in with what we were supposed to learn	3.67 (1.23)
It was clear to me what I was supposed to learn in this course unit	3.67 (1.07)
I regularly received feedback from teachers on my set work	3.25 (0.87)

TABLE 4. LA questionnaire results.

Item	M (SD)
On the whole, I've been quite systematic and organized in my studying	3.83 (0.83)
I've generally put a lot of effort into my studying	4.08 (0.67)
I've organized my study time carefully to make the best use of it	3.58 (1.08)
I've looked carefully at the evidence before reaching my own conclusion about what I'm studying	3.75 (0.87)
Ideas I've come across in my academic reading often set me off on long chains of thought	3.33 (0.65)
When I've been communicating ideas, I've thought over how well I've got my points across	3.67 (0.89)
If I've not understood things well enough when studying, I've tried a different approach	3.58 (0.79)
I've often had trouble in making sense of the things I have to remember	2.50 (1.00)
Much of what I've learned seems no more than lots of unrelated bits and pieces in my mind	2.58 (1.31)

TABLE 5. CT questionnaire results.

Item	M (SD)
I have learnt to analyze and organize information	4.00 (0.74)
I have learnt to evaluate issues critically	3.58 (0.79)
I have learnt to apply theoretical knowledge to practice	3.83 (1.03)
I have learnt to develop new ideas	3.58 (0.67)

utilize instruments that gauge student experiences. One such well-established tool is the ETLQ [11]. This questionnaire explores two key areas believed to influence learning quality:

students' perceptions of the teaching environment and their approaches to learning.

For this study, we used a modified version of the ETLQ specifically targeted towards higher education settings [34]. This modified version offers the benefit of a validated Spanish translation [35], making it particularly suitable for our student research population. The version of the ETLQ used in this study is divided into three core areas:

- TE: This area captures student perceptions of the learning environment created by the intervention session, including aspects such as clarity of instruction, organization of activities, and opportunities for interaction. As shown in Table 3, the average scores obtained on a 5-point Likert scale ranged from 3.25 ($SD = 1.22$) to 4.17 ($SD = 0.72$), indicating a moderate to high level of agreement with statements about the teaching and learning experience. Overall, the findings from the TE area suggest that the intervention session utilizing the graphical tools created a positive and supportive learning environment that facilitated student understanding and fostered collaboration.
- LA: This area explores students' self-reported approaches to learning, such as their motivation to engage with the course material. As reported in Table 4, the average scores on a 5-point Likert scale ranged from 3.33 ($SD = 0.65$) to 4.08 ($SD = 0.67$).[3] The adjusted scores indicate a moderate to high level of agreement with the statements, highlighting that although some students faced challenges in making sense of their learning materials, the overall approach to learning is positive.
- CT: This area assesses students' perceptions of opportunities to develop critical thinking skills during the learning experience. As demonstrated in Table 5, the average scores on a 5-point Likert scale ranged from 3.58 ($SD = 0.67$) to 4.00 ($SD = 0.74$), indicating a generally positive perception of their learning experience in relation to critical thinking. These results suggest a potential positive influence of the intervention session on students' perceptions of their critical thinking development, particularly regarding information analysis and application of knowledge.

VII. DISCUSSION

This study explored the impact of an intervention using GUIs on student learning in an Audiovisual Communications course. The findings provide promising evidence across user experience, knowledge acquisition, and learning quality.

The SUS scores ($M = 70.21$) indicate good usability of the graphical tools, aligning with positive perceptions of the learning environment reflected in the TE section of the ETLQ. Students found the tools user-friendly and easy to interact with, fostering a supportive learning atmosphere. The ease of use and perceived usefulness of the tools likely contributed to creating a positive environment that facilitated understanding.

The statistically significant improvement in student knowledge scores (pre-test: $M = 4.25$, post-test: $M = 5.75$) suggests the intervention facilitated learning. This implies the visual and interactive nature of the graphical tools likely enhanced knowledge retention and understanding.

Insights from the ETLQ results are valuable:

- TE scores ($M = 3.25$ to 4.17) indicate a generally positive perception of the learning environment. The intervention fostered clarity of instruction, well-organized activities, and interaction opportunities.
- LA scores ($M = 3.33$ to 4.08, with adjusted scores of 3.50 and 3.42 for the last two items) indicate a moderate to high level of agreement. While students generally felt organized and put considerable effort into their studies, some faced challenges with their learning materials. Incorporating strategies to promote critical thinking and knowledge integration could enhance the intervention.
- CT scores ($M = 3.58$ to 4.00) suggest a positive perception of critical thinking skill development, particularly in information analysis and applying knowledge. This aligns with knowledge acquisition findings, indicating the tools encouraged students to analyze and utilize information effectively.

Limitations of this study include:

- A relatively small sample size, limiting result generalizability.
- The pre-test/post-test design cannot definitively establish causal relationships.

Future research could:

- Increase sample size diversity for more generalizable findings.
- Utilize a control group design to establish stronger causal inferences.
- Incorporate additional measures like direct observations and performance assessments for a comprehensive understanding.
- Explore long-term effects of the intervention on learning outcomes and critical thinking.

VIII. CONCLUSION

This study contributes to the expanding research on the efficacy of graphical tools in enhancing learning experiences. Specifically, it investigates the use of three innovative GUIs, developed using MATLAB, to bolster foundational knowledge in audio, image, and video coding. These tools are freely accessible for further exploration by interested individuals.

The positive outcomes of this study highlight the potential of well-designed graphical tools to enhance teaching and learning practices. These tools can increase student engagement and improve comprehension, particularly in specialized areas like audiovisual coding. The three tools developed

[3] Note that the last two items in LA correspond to negative statements and their associated values should be inverted to 3.50 and 3.42, respectively.

in this study demonstrate how interactive applications can help educators create effective and supportive learning environments tailored to complex technical content.

The tools proved user-friendly and conducive to a positive learning atmosphere. Students reported favorable perceptions regarding the ease of use and utility of the tools, indicating they effectively facilitated interaction and comprehension.

Students showed substantial improvements in understanding and applying audiovisual coding concepts. The notable improvement in knowledge scores implies that the intervention successfully conveyed the coding principles covered in the course. The visual and interactive nature of the tools likely bolstered knowledge retention and understanding.

Results from the ETLQ positively reflect the impact of the graphical tools on student learning. Students perceived a supportive learning environment with clear instruction, organized activities, and interactive opportunities. Additionally, the tools fostered the development of critical thinking skills related to information analysis and knowledge application.

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CARLOS CUEVAS received the Ingeniero de Telecomunicación degree and the Doctor Ingeniero de Telecomunicación (Ph.D. Graduation) degree from the Universidad Politécnica de Madrid, Spain, in 2006 and 2011, respectively. He is currently an Associate Professor with Universidad Politécnica de Madrid. His teaching interests include communication systems, audiovisual signal coding, and image/video processing and analysis.

CARLOS CORTÉS received the bachelor's degree in electronic systems engineering from the University of Mlaga (UMA), in 2017, and the master's degree in electronic systems engineering and the Ph.D. degree in signal theory and communications from Universidad Politécnica de Madrid, in 2018 and 2024, respectively. His teaching interest includes the development of learning quality assessment methods.

NARCISO GARCÍA (Life Senior Member, IEEE) received the Ingeniero de Telecomunicación degree and the Doctor Ingeniero de Telecomunicación (Ph.D.) degree in communications from Universidad Politécnica de Madrid, Spain, in 1976 and 1983, respectively. Since 1977, he has been a member of the Faculty of the UPM, where he is currently a Professor of signal theory and communications. He leads the Image Processing Group of the UPM. His current research interests include digital video compression, computer vision, and quality of experience.