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How can educational videos with annotations help students in online learning environments?

Riad Bourbia[a,b], Samia Drissi[c], Yacine Lafifi[b,1], Sevinc Gulsecen[d]

[a]*Computer Science Department, University of Souk-Ahras – Souk-Ahras (Algeria)*

[b]*LabStic laboratory, 8 May 1945 University of Guelma – Guelma (Algeria)*

[c]*LiM Laboratory, Faculty of Science and Technology, University of Souk-Ahras – Souk-Ahras (Algeria)*

[d]*Informatics Department, University of Istanbul, Istanbul (Turkey)*

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Abstract

In recent years, many new technologies have been used to enhance the learning outcomes of learners in online learning. Video annotation is one of these new technologies which is an innovative way to make learning more interactive and engaging. It can accommodate different learning styles by turning passive video-watching into an active learning experience. This research aims to evaluate the effectiveness of an e-Learning platform incorporating a Video Annotated Technique. Learners can pinpoint challenging parts of educational videos and then receive personalised explanations from their teachers. The primary purpose of these annotations is to clarify and provide thorough explanations of complex topics, ultimately improving understanding and making preparation for final examination tests easier. This paper presents a new personalization approach by managing the learners' annotations. Furthermore, it offers a video annotation tool incorporated into an e-Learning environment. This tool was tested on a sample of students, and the experimental results demonstrated a significant positive impact on learners' performance.

KEYWORDS: Online Learning Environments, Video-Based Learning, Video Annotation, Assisting Learners, Learning Personalization.

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1. Introduction

Traditional teaching methods, often instructor-centered and based on linear content, no longer meet the needs of today's learners, who are seeking more interactive and immersive learning experiences (Stigler et al., 2015; Bower, 2017). The rise of online learning has amplified this need, creating a demand for pedagogical approaches that not only convey information but also actively and meaningfully engage students (Laurillard, 2013).

The adoption of video in education, commonly referred to as video-based learning (VBL), represents a significant advancement in modern pedagogy. This approach leverages both visual and auditory channels to facilitate knowledge acquisition and retention, thereby offering a more immersive and engaging learning experience (Chui et al., 2016; Brame, 2016; Lam et al., 2021a; Lange & Costley, 2020; Baber et al., 2022; Arora, 2023; Navarrete et al., 2025). The rapid transition to online learning, particularly during the COVID-19 pandemic, has further emphasized the importance of video-based learning (Dong, Cao, & Li, 2020; Lam et al., 2021a; Ahn et al., 2025).

Digital video platforms such as YouTube and Vimeo are profoundly reshaping contemporary society, attracting billions of users and becoming increasingly integrated into educational practices. According to Statista (2023), 93% of internet users consume online video content, with 26% specifically engaging with educational videos. In this context, a substantial proportion of topics covered in high school science curricula is now available on YouTube, often in

[1] corresponding author - email: laf_yac@yahoo.fr

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multiple formats reflecting diverse pedagogical approaches (Alder et al., 2025).

This expansion is further illustrated by the rise of large-scale online learning platforms such as Coursera, which provide courses and recorded lectures from numerous universities worldwide. By the end of 2025, Coursera had reached approximately 197 million registered learners (Coursera, 2026), highlighting the growing demand for flexible and accessible learning solutions.

Educational videos offer considerable pedagogical potential. They enhance the quality of demonstrations, support students in preparing for practical and laboratory activities, and foster motivation as well as sustained engagement in learning (Voronkin, 2019). More broadly, the integration of recorded video lectures constitutes a central driver of online learning, as it increases flexibility while improving the affordability and accessibility of education for diverse audiences (Ahn et al., 2025).

The growing need for dynamic pedagogical approaches, combined with technological advances, has led to the development of Video Annotation Tools (VAT). These tools are increasingly recognized as essential for enhancing online learning by addressing several challenges identified in recent research. One major issue concerns maintaining learner engagement and attention, particularly in the context of lengthy videos, which may negatively affect learning effectiveness (Hughes et al., 2019; Tseng, 2021). This challenge is especially pronounced in environments where interaction with educational content remains largely passive (Guo, Kim, & Rubin, 2014; Hui & Campbell, 2018; Dong et al., 2020; Vandenberg & Magnuson, 2021). Video Annotation Tools transform this dynamic by promoting active learner participation and enabling direct interaction with content at key moments, thereby enhancing knowledge retention (Fiorella & Mayer, 2016; Love et al., 2014; Lam et al., 2021b; Von Wachter et al., 2023).

Empirical studies further support the effectiveness of these tools. For instance, Cassano et al. (2024) examine the impact of a video annotation tool on student engagement during the autonomous learning phase within a flipped classroom model. Their findings indicate a significant improvement in student engagement, particularly in the emotional dimensions, while transforming a traditionally passive activity into an active learning experience.

Moreover, video annotations play a critical role in managing cognitive load, a key factor in effective learning. According to Sweller, Ayres, and Kalyuga (2011), learning is optimized when cognitive load is appropriately regulated. By segmenting information and directing learners' attention to essential elements, video annotations help reduce cognitive overload and promote deeper understanding and more effective knowledge assimilation.

In addition, video annotations support collaborative learning by enabling learners to insert notes, questions, and comments directly within video content. This functionality fosters deeper understanding and critical reflection (Mirriahi et al., 2018; West, 2020; Von Wachter et al., 2023), while also enhancing communication and practical skills (Pérez-Torregrosa et al., 2017; Susantini et al., 2019; Chui et al., 2021; Kim Chau Leung et al., 2021). This interactive approach not only increases motivation but also contributes to the development of an active and engaged learning community (Kay & Kletskin, 2012).

Recent empirical evidence further reinforces these findings. For example, a qualitative study conducted by Rasenberg et al. (2025) on medical students using a Video Feedback System (VFS) during clinical internships shows that learners use annotations in a structured manner for self-assessment and feedback.

In this context, the present study introduces SANED_anot+, a research-oriented video annotation system designed to enhance learner support within an online learning environment through the SANED platform (Bourbia et al., 2024). SANED_anot+ is specifically developed to support learners facing difficulties by enabling them to identify and annotate complex segments of educational videos. In response, instructors enrich these segments with detailed explanations, thereby providing targeted support. These personalized annotations are subsequently shared with all learners, promoting collaborative learning and facilitating targeted assistance and collective knowledge construction.

To effectively address this issue, we must consider several essential research inquiries that require thoughtful and comprehensive responses. So, two main questions might be addressed:

- What is the impact of the video annotation system on the performance of low-scoring learners during pre-test assessment?
- How does the video annotation system affect learners' performance with high pre-test scores?

The document is organised as follows: Section 2 reviews how video annotation can assist learners with difficulties in e-Learning.

The proposed approach is described in Section 3. Section 4 introduces the development tool, while Section 5 presents an experiment conducted in a higher education institution, presenting significant findings and initiating a discussion. Finally, the general conclusion, the work limitations, and the future work are highlighted in Section 6.

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2. Literature Review for video annotation as a way to support e-Learning

As defined by Higuera and colleagues (2014), video annotations refer to valuable data explicitly associated with the spatiotemporal segments of the video. Annotation Video Tools allow additional insightful commentary without modifying the video (Khurana and Chandak, 2013; Chatti, 2016).

According to Yousef's research team (2015), annotations have been found to enhance communication, promote in-depth analysis of video content, and provide valuable feedback.

In the following, we explore a variety of video annotation tools and summarise their applicability and limitations while emphasising the critical distinctions with the proposed video annotation tool. A set of academic, commercial, and open-access tools was selected to ensure a comprehensive approach. Innovative and advanced teaching approaches foster Educational research tools in stimulating learning environments. Commercial solutions offer reliability and ease of use, crucial for large-scale implementation and quick user adoption. In the end, open-access tools provide extended access to quality educational resources, usually free or cheap.

Seven video annotation systems were selected for this analysis due to their potential to help learners and innovative features. These include VideoAnt https://ant.umn.edu/ (Hosack, 2010; Van Drom, 2018), a free web application for video annotation developed by the University of Minnesota, EdPuzzle https://edpuzzle.com/ (EdPuzzle, Rahayu, 2022), a free platform for educational video lessons, CourseMapper https://www.uni-due.de/soco/research/projects/coursemapper.php (Chatti et al., 2016) a collaborative video annotation and analytics platform, GoReact https://get.goreact.com/ (Hager et al., 2020) a video feedback software, TRAVIS GO https://app.travis-go.org/ (Klug, 2021) a web application for simple and collaborative video annotation, ViDeX (Fong et al., 2018) a video player for personalising educational videos, and FEVA (Shrestha, 2023) an event video annotation tool.

All these tools offer various ways to annotate videos, from direct interaction with the content to more organised and collaborative approaches. They enable users, whether teachers or students, to interact with video content more successfully.

A deeper analysis of these video annotation tools reveals that each offers distinct features that suit specific educational environments. With EdPuzzle, teachers can design interactive lessons by embedding questions and comments within videos, increasing

Table 1 - Comparison of Basic Technical Features of selected VATs.

Basic technical features		VideoAnt	EdPuzzle	CourseMapper	GoReact	Travis GO	ViDeX	FEVA
License	Open Source							√
	Proprietary	√	√	√	√	√	√	
	Commercial				√			
	Open Access	√	√			√		√
	Maintained	√	√	√	√		√	√
	Outdated							
Platform	Web	√	√	√	√	√	√	√
	Native							
Annotation Approach	Manual	√	√	√	√	√	√	√
	Automatic							
Context of use	Educative	√	√	√	√	√	√	
	Research							√
Annotation Type	Note	√	√	√	√	√	√	
	Question	√	√	√	√			
	External Resource	√	√	√	√			
Input Type	Textual	√	√	√	√	√	√	
	Audio		√		√			√
	Image				√			
	Video				√			√
Annotation Rating	Teachers			√				
	Peers	√		√				

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student engagement and understanding of the content. CourseMapper innovates by integrating annotations into a mind-map view, providing a better structure for the course material, and offering visual analysis tools to help learners identify the most viewed and annotated parts of videos. Travis GO, on the other hand, focuses primarily on the teaching and analysis of audiovisual media, offering features relevant to video annotation in an educational context. As a versatile tool, Go React facilitates in-depth video analysis and collaborative feedback through synchronised annotations.

FEVA distinguishes itself with its distinctive design, facilitating rapid and precise video annotation through an intuitive interface and streamlined settings. In contrast, ViDeX is positioned as a video player designed specifically for video-based learning, encouraging active viewing, the sharing of annotations between students and teachers, and the identification of consensus annotations based on the 'wisdom of crowds', which refers to the idea that the collective intelligence of a group can often be more accurate and reliable than that of an individual.

In addition, the literature review has enabled us to draw up a list of advanced features of VATs that aim to support learning and help learners. The chosen systems were examined in detail, with particular attention paid to the advanced features (Table 6). These criteria include video annotation capability, collaboration and user interaction facilitation, integration with other educational designs such as LMSs, and compatibility with various content formats. The analysis also assesses usability, accessibility, personalising the learning experience, and providing targeted help.

Finally, the criteria consider support for teacher feedback, assessment of the usefulness of annotations, and sharing and discussion functions, all are essential for a practical and interactive e-Learning environment. Table 6 provides a detailed comparative summary between our developed tool, SANED_Anot+, and the various systems selected for this study.

The study intends to assess the efficacy of video annotation tools in assisting learners with learning disabilities in online platforms. The research reveals several aspects to be taken into account. We found that annotations, mainly initiated by teachers, aim to clarify the course content. However, they are often applied uniformly without considering cognitive variations and students' preferences in terms of learning styles. This one-size-fits-all approach does not effectively address the specific needs of learners with difficulties, which poses a significant problem regarding comprehension.

Moreover, there is an evident lack of adaptation and personalisation of video annotations in response to the requests of students facing challenges. While specific solutions offer responses to inquiries, they fail to rectify the issue by providing tailored video annotations that cater to the particular requirements of these students. Ultimately, assessing video annotations based on indicators like "like" or "dislike" buttons is entirely subjective. This evaluation method does not effectively utilise feedback to improve the tools for students with difficulties.

A novel approach for providing learners with video annotation is being considered to overcome the shortcomings of the previously described works. The main objectives of this approach and the associated tool are presented in the following section.

3. The proposed video annotation module

The research presented in this article is an extension of that shown in the SANED project (Bourbia et al., 2024), which aims to provide support for learners engaged in online learning. SANED is an e-Learning platform that uses the traces left by learners to detect those who have difficulties and provides them with immediate and personalised assistance.

The system additionally assists teachers in structuring learning contents hierarchically, implementing prerequisites, and tailoring teaching resources to match the learner's cognitive level and preferred learning style. SANED dynamically maintains and refines the learner's cognitive profile to adapt resources to their current state as they progress through the learning process.

SANED consists of three distinct subsystems, along with a newly added module, SANED_Anot+, specifically dedicated to the annotation process (see Figure 1). The first subsystem focuses on learning, offering teachers and learners essential tools for effectively managing learning contents and assessment resources.

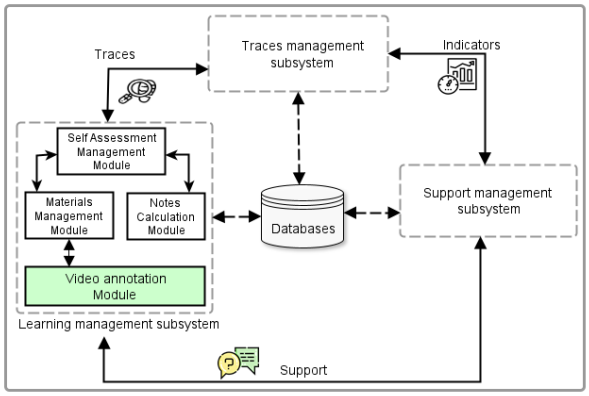


Figure 1- Overview of the General Architecture of SANED and the SANED_Anot+ Module.

The second subsystem collects information regarding the different activities and traces of the learners.

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Subsequently, it furnishes the third subsystem with the essential data required to identify learners encountering difficulties and suggest appropriate forms of assistance.

The integration of SANED_Anot+ is designed to significantly enhance the learning experience by fostering dynamic and personalized interactions between teachers and learners with educational video content. This video annotation module fulfills several key objectives:

- Personalization of Learning: Provide learners with personalized educational support by allowing the addition of comments, questions, and supplementary explanations directly on the videos, tailored to their specific needs and queries.
- Enhancement of Engagement: Encourage active participation from learners by involving them in the analysis of video content, which strengthens their engagement and understanding of the subject matter.
- Facilitation of Real-Time Assistance: Enable teachers to address learners' questions accurately and specifically through annotations synchronized with particular moments in the videos.
- Optimization of Communication and Feedback: Improve communication between teachers and learners through ongoing dialogue based on annotations, facilitating immediate and constructive feedback.

3.1 Functionalities of the Video Annotation Module

The main functionalities of the video annotation module are summarized below.

- Learner-Teacher Interaction: Learners can highlight sections of the video they find complex and submit questions or comments, to which teachers can respond directly through additional annotations.
- Synchronized Annotations: Teachers can add annotations at specific moments in the videos to clarify concepts, provide further explanations, or pose questions designed to stimulate learners' thinking.
- Collaborative Assessments: Learners can evaluate the annotations, thereby contributing to a collaborative learning environment where educational content is continually enhanced by user feedback.

3.2 The Integration Process into the SANED System

All components of the video annotation module are integrated coherently within a structured framework, aimed at ensuring the overall effectiveness of the system.

The internal structure of the annotation module can be depicted as follows:

- Centralized Management Module: The video annotation module is incorporated into SANED's learning management subsystem, enabling centralized management of annotations and facilitating access to resources for both teachers and learners.
- Unified User Interface: The annotation interface is designed to seamlessly integrate with the rest of the SANED learning environment, ensuring a smooth transition between the various functionalities offered by the system.
- Data Security: The database plays a crucial role within the SANED system by centralizing and securing all data collected from the various subsystems. Specifically, it stores all video annotations and interactions between learners and teachers. By consolidating this information in a central location, the database not only ensures the integrity and consistency of the data but also facilitates access for all system users.

4. Presentation of SANED_Anot+ tool

This tool offers learners an easy-to-use interface for watching educational videos and allows them to interact with their teacher for help when they face difficulties understanding certain parts of the video content. When making a request (4), students pinpoint the moments in the video (3) where they require assistance. All the posted comments are displayed chronologically in the annotation feed (2). This function allows users to easily follow the conversation and see the progression of observations over time. Additionally, the chronological order helps maintain the context and relevance of each comment within the feed.

After learners make their requests, the teacher can offer feedback and support to help them understand the complex parts of the video content. He can add different annotation types, such as text, graphics, or a link to an external resource, to enrich the learning experience (Figure 3). Personalised feedback from the teacher demonstrates a real commitment to learners, offering genuine assistance under challenging situations. This approach improves learner motivation by providing reassurance and support on e-Learning platforms without making them feel alone, isolated, or unsupported.

In addition, with this user-friendly User Interface, Learners can evaluate the annotation by assigning a rating using a star rating system, or they can provide feedback through comments if they believe it has been helpful to them. All these features ensure that learners have an efficient and engaging learning process. It is important to note that SANED_Anot+ is currently a

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prototype developed and deployed within the context of this study and is not yet publicly accessible.

5. Experiment: results and discussion

An experiment was conducted at the Computer Science Department of Guelma University in Algeria. The experiment evaluates the effectiveness of a tool called SANED_Anot+ (Supporting Online Learning through Annotated Educational Videos).

The experiment aims to determine how the video annotation system affects students with low pre-test and high pre-test scorers. To achieve these goals, it is essential to establish the appropriate metrics, collect relevant data, and perform statistical analysis to assess the critical relationships and differences between crucial groups or variables. The results of this experiment provide a direct answer to the research questions posed in the introduction section.

5.1 Participants

The experiment involved the participation of sixty-nine (69) third-year undergraduate students. These students were enrolled in "the Introduction to Cryptography and Computer Security" course and had access to the video course content.

5.2 Methodology

The course is organized into several instructional units, each delivered through recorded video lectures. Each video focuses on a specific concept or topic, thereby ensuring a progressive and structured coverage of the entire curriculum. This organization promotes a clear segmentation of the content, facilitating its assimilation by learners. Furthermore, this format supports flexible and individualized learning, allowing students to access the materials at their own pace, review the sequences as often as needed, and pay particular attention to the concepts they perceive as most challenging.

The experimental procedure consists of a sequence of steps followed by the participants. Initially, students are asked to watch the course videos to build a foundational understanding of the subject. A preliminary test is then administered to assess their initial level of comprehension. Learners who encounter difficulties are invited to submit their questions.

Subsequently, students are given access to enriched video content, including teacher-provided annotations that address their specific needs. These annotations aim to clarify complex concepts and provide targeted support. The experiment concludes with a final test designed to evaluate learners' progress and overall understanding. In addition, a post-experiment survey

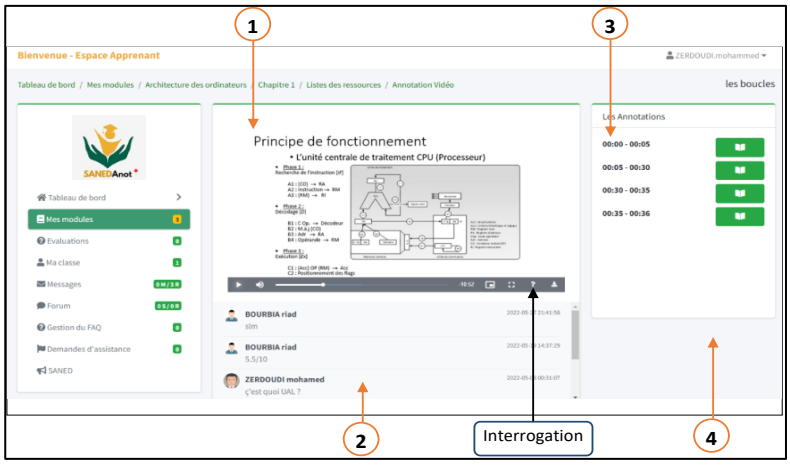


Figure 2 - A screenshot of SANED_Anot+ for a learner.

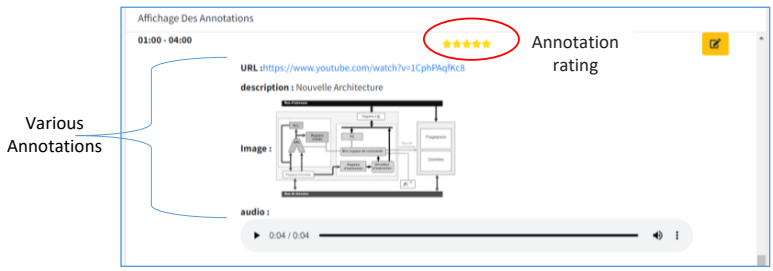


Figure 3 - Used annotation types.

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is conducted to collect participants' perceptions and feedback regarding their learning experience. The questionnaire gathers learners' opinions on the impact of the video annotation system on their exam preparation. However, the results of this survey are not included in the present study and will be addressed in future work. Finally, the developed system is accessible to students through a simple enrollment process via any web browser.

5.3. Results and discussion

This part aims to demonstrate the effectiveness of our underlying system by evaluating its performance in improving the cognitive profiles of the learners.

This section will evaluate how the system influences students with learning difficulties. We present the results derived from a practical evaluation of our system using the following research hypotheses:

- **Null hypothesis H^10**: using the video annotation system does not affect the performance of learners with low pre-test scores.
- **Alternative hypothesis H^11:** using the video annotation system improves learners' performance with low pre-test scores.

To evaluate these hypotheses, a pre-test was administered to all learners, after which students who obtained scores below the average were selected (Table 2).

Table 2 - Number of participants involved in the experiment.

Number of students who took part in the pre-test	Number of students who passed the pre-test	Number of students who failed the pre-test
69	26	43

The learners who did not pass the pre-test (n = 43) subsequently used the SANED_Anot+ platform to address their learning difficulties and better prepare for the final assessment. A paired-samples Student's t-test was conducted to compare pre-test and post-test scores for learners with low initial performance. This test is appropriate for assessing differences between two related measurements obtained from the same participants. All statistical analyses were performed using SPSS (Statistical Package for the Social Sciences).

Prior to the analysis, the assumption of normality was assessed on the difference scores using the Shapiro–Wilk test. The results indicated no significant deviation from normality, supporting the use of the paired t-test. As shown in Table 3, the mean score from the pre-test (M = 2.8140, SD = 0.95757) to the post-test (M = 5.2791, SD = 2.06243). The mean difference between the two conditions was 2.46512 (SD = 2.23978), with a 95% confidence interval ranging from 1.77581 to 3.15442. The paired t-test indicated that this difference was statistically significant, $t(42) = 7.217$, $p < 0.001$, at the 0.05 significance level ($\alpha = 0.05$), suggesting that learners' performance improved following the intervention.

Table 3 - Paired T-test results for low-scoring learners in the pre-test.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Post-test Scores	5,2791	43	2,06243	,31452
	Pre-test Scores	2,8140	43	,95757	,14603

Paired Samples Test

		Paired Differences			
					95% Confidence Interval of the Difference
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	Post-test Scores - Pre-test Scores	2,46512	2,23978	,34156	1,77581

Paired Samples Test

		Paired Differences			
		95% Confidence Interval of the Difference			
		Upper	t	df	Sig. (2-tailed)
Pair 1	Post-test Scores - Pre-test Scores	3,15442	7,217	42	,0000000071

Situation	N	Mean	SD	t-score	p-value
Pre-test	43	2,8140	0,95757	7,217	,0000000071
Post-test	43	5,2791	2,06243		

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These findings suggest that the use of the SANED_Anot+ platform may have contributed to improving the performance of learners with low pre-test scores. Accordingly, the null hypothesis (H^10) was rejected, while the alternative hypothesis (H^11) was supported.

However, these results should be interpreted with caution. The analysis does not identify the specific factors underlying the observed improvement, nor does it account for potential variability in learners' responses to the intervention. To strengthen the conclusions, further analyses, including subgroup investigations, are planned.

While the results for low-performing learners (Table 3) indicate a significant improvement following the intervention, it is important to examine whether similar effects can be observed among students with higher initial performance.

This analysis focuses on a subgroup of students who achieved a passing score on the pre-test (i.e., students scoring five or more out of ten). It should be noted that the maximum score in Algerian universities is twenty. The aim is to assess whether the intervention produced similar effects for students with higher initial performance.

To this end, the following hypotheses were formulated:

- **Null hypothesis H^20:** The utilisation of the video annotation system has no impact on the performance of students who have achieved high pre-test scores. ·
- **Alternative hypothesis H^21:** The utilisation of the video annotation system improves the performance of students who have achieved high scores on their pre-tests. ·

The data were analysed using SPSS software, and the results are presented in Table 4. The obtained p-value ($p = 0.064$) exceeds the conventional significance threshold ($\alpha = 0.05$), indicating that there is insufficient statistical evidence to reject the null hypothesis.

Consequently, the results do not provide significant evidence that the use of the video annotation system improved the performance of students who initially achieved high scores. Similarly, the alternative hypothesis (H^21) is not supported. Overall, these findings suggest no statistically significant difference between pre-test and post-test scores for this group, although a slight increase in post-test scores can be observed. To further examine the differences between learner groups, an additional analysis was conducted, and the results are presented in Table 5.

An independent-samples t-test was performed to compare the mean improvement (difference scores) between Group 1 (G1) and Group 2 (G2). Prior to the analysis, the assumption of homogeneity of variances was assessed using Levene's test. The results indicated that this assumption was met ($F = 0.947$, $p = 0.334$),

Table 4 - Paired T-test results for high-scoring learners in the pre-test.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Post-test Scores	6,1538	26	1,75937	,34504
	Pre-test Scores	5,5000	26	,81240	,15933

Paired Samples Test

		Paired Differences			
					95% Confidence Interval of the Difference
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	Post-test Scores - Pre-test Scores	,65385	1,71912	,33715	-,04052

Paired Samples Test

		Paired Differences	t	df	Sig. (2-tailed)
		95% Confidence Interval of the Difference			
		Upper			
Pair 1	Post-test Scores - Pre-test Scores	1,34822	1,939	25	,064

Situation	N	Mean	SD	t-score	p-value
Pre-test	26	5,5000	,81240	1,939	,064
Post-test	26	6,1538	1,75937		

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Table 5 - Independent T-test results for comparison between the two groups.

Groups Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Difference	G1	43	2,4651	2,23978	,34156
	G2	26	,6538	1,71912	,33715

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Difference	Equal variances assumed	,947	,334	3,538	67	,001	1,81127	,51200	,78931	2,83323
	Equal variances not assumed			3,774	63,092	,000	1,81127	,47993	,85223	2,77031

allowing the use of the results under the assumption of equal variances. Descriptive statistics showed that Group 1 exhibited a higher mean improvement (M = 2.4651, SD = 2.23978) compared to Group 2 (M = 0.6538, SD = 1.71912). The independent t-test revealed a statistically significant difference between the two groups, t(67) = 3.538, p = 0.001. The mean difference was 1.81127, with a 95% confidence interval ranging from 0.78931 to 2.83323.

These findings suggest that the improvement observed in Group 1 was greater than that of Group 2. However, this result should be interpreted with caution, as the difference may be influenced by initial performance levels and other contextual factors not controlled for in the analysis.

Overall, these findings suggest that SANED_Anot+ may contribute to supporting students experiencing learning difficulties by providing targeted guidance and assistance, particularly for those with lower initial performance. However, these results should be interpreted with caution. While the intervention appears to benefit certain learner profiles, its effectiveness is not uniform across all groups. Furthermore, to the best of our knowledge, no video annotation systems have been reported in the literature within a context directly comparable to ours, particularly with regard to targeted support for struggling learners. This lack of comparable studies limits our ability to benchmark our findings against existing approaches and to draw broader generalizations.

The Table 6 provides a comparative overview of the key features of SANED_Anot+ and the tools discussed in Section 2.

6. Conclusion and future work

In recent years, increasing attention has been devoted to the use of annotations to enhance the quality of video-based online learning. Traditional video-based instructional approaches often suffer from limitations such as a teacher-centered design and a lack of interactivity and personalization. In this context, video annotation has emerged as a promising approach to enrich the learning experience by transforming passive content into interactive and multimodal educational resources. Such annotations may include explanatory texts, subtitles, comments, embedded questions, or links to additional materials, thereby fostering deeper engagement and understanding.

This study introduced SANED_Anot+, a video annotation prototype designed to enhance learners' engagement and academic performance. The system enables the customization of annotations according to learners' needs, allowing teachers to provide targeted explanations and personalized support, while also enabling learners to interact with the content through comments and feedback. By promoting active participation, the platform encourages a shift from passive viewing to a more interactive learning process, while offering learners a sense of guidance and continuous support.

The experimental evaluation aimed to assess the effectiveness of the proposed approach. The results suggest that SANED_Anot+ may contribute to improving the performance of learners experiencing difficulties, particularly through the provision of targeted feedback. More specifically, learners with low initial performance demonstrated significant improvements in their post-test results, highlighting the potential of the system to support struggling students and reduce learning disparities.

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Table 6 - Comparison of advanced features of selected VATs to support learners with SANED_Anot+.

Analysis criteria	VideoAnt	EdPuzzle	CourseMapper	GoReact	Travis GO	ViDeX	FEVA	SANED_Anot+
Enhancement of Comprehension (Rey et al. 2020 ;)		√	√	√		√		√
Information retention (Chatti et al. 2016; Hager et al. 2020)			√	√				√
Reflection (Pérez-Torregrosa et al., 2017; Leung et al., 2021; Von Wachter et al., 2023)	√	√	√	√		√		
Accessible and flexible	√	√	√	√	√	√	√	√
Interaction and communication (Chatti et al. 2016; Lai et al. 2019; Leung et al. 2021; Onat et al. 2023 ; Von Wachter et al. 2023)	√	√	√	√	√	√	√	√
Feedback (Ardley et al. 2020 ; Leung et al. 2021 ; Lam et al. 2021 ; Von Wachter et al. 2023)	√	√	√	√				√
Personalisation of learning (Chatti et al. 2016)			√					√
Self-regulation (Mirriahi et al. 2018)			√					√
Engagement (Mirriahi et al. 2018 ; Rey et al., 2020 ; Lam et al. 2021)	√	√	√	√	√	√		√
Active learning (Kalboussi et al. 2015)	√	√	√	√	√	√		√
Collaboration (Chatti et al. 2016 ; Klug et al. 2021)	√		√		√		√	
Annotation sharing (Chatti et al. 2016; Hager et al. 2020)	√	√	√		√	√	√	√
Allow integration with LMS. (Chatti et al. 2016 ; Hager et al. 2020 ; Rahayu et al. 2022)		√	√	√				
Analytics (Chatti et al. 2016)		√	√					

Yes: ✓, no: blank

In contrast, no statistically significant improvement was observed for learners who had already achieved high pre-test scores, suggesting that the impact of the system may vary depending on learners' initial performance levels.

Despite these promising findings, several limitations should be acknowledged. First, the study was conducted within a single course and a single institution, which may limit the generalizability of the results to other educational contexts. Second, the effectiveness of SANED_Anot+ relies heavily on teachers' involvement in creating and managing annotations, which may increase workload and raise concerns regarding scalability. In addition, the system's effectiveness may depend on the level of learners' active participation, which can vary significantly across individuals.

Future work will focus on extending the evaluation to more diverse learning contexts and larger populations. Furthermore, the integration of artificial intelligence techniques will be explored to automate and optimize the annotation process. In particular, predictive analytics and machine learning approaches could be leveraged to generate adaptive and personalized feedback, thereby supporting teachers in tailoring their instructional strategies to individual learner needs.

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