



BRIDGING THE LABORATORY GAP THROUGH VIDEO-BASED INSTRUCTION FOR IMPROVED CHEMISTRY LEARNING IN RESOURCE-CONSTRAINED SCHOOLS

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Abstract:

In resource-constrained educational environments, science educators often face significant barriers to effectively delivering laboratory-based instruction. This study investigates the impact of video-based instructions (VBIs) on secondary school students' academic achievement in chemistry and explores Rwandan science teachers' beliefs, usage patterns, and the challenges encountered when implementing VBIs. Grounded in the Technology Acceptance Model and Cognitive Information Processing Theory, a mixed-methods approach was employed, combining survey responses from teachers with quasi-experimental data from chemistry achievement tests. Results revealed that VBIs not only enhanced students' conceptual understanding of complex chemistry content but also significantly improved academic performance, with the experimental group showing a large effect size (Cohen's $d = 1.25$). Despite enthusiasm toward VBIs, issues such as digital inequality and teacher preparedness remain pressing. This study highlights VBIs as a scalable, pedagogically robust alternative to traditional laboratory teaching in under-resourced contexts, contributing novel empirical evidence to global efforts toward digitally enhanced STEM education.

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Keywords: video-based instruction (VBI), science education, educational technology, teacher beliefs and practices, low-resource learning environments

1. Introduction

One of the most significant recent discussions in science education has been centered around attitudes developed by students in response to various instruction delivery methods [1-5]. Another compelling piece of evidence has been the consideration of chemistry as an integral part of the secondary school curriculum, which endeavored to inculcate in students the essential skills of industrial processes [6-9], which form the core of life in the current era dominated by advanced manufacturing technologies [10, 11]. The recognition of chemistry as a school subject from its conceptualization as a discipline has been termed contextualization in the light of science education [12-14]. The learning goals of science education have been envisioned into three leading categories: learning science, learning about science, and learning to do science [15]. Intellectual development within the domain of science education could be enhanced when the three learning goals are meticulously articulated [16], and the process inevitably integrates concepts, models, and theories relevant to a specific science instructional content [17].

The conceptual understanding of chemistry concepts and principles leads to acquiring chemical literacy and procedures involved in synthetic chemistry, which take place in the laboratory media as a learning environment. The versatility of today's scientific instructional delivery modalities encourages instructors to adopt student-centered approaches [18, 19]. Unambiguously, chemistry has been a subject of secondary school curricula that entails an instructor's possession of solid theoretical knowledge and practical skills [20]. Teachers' PCK of integrating laboratory practices has been viewed as the catalyst that accelerates students' understanding, attitudes, and appreciation of the contribution of chemical sciences to real-world problems [21]. Teaching chemistry content with the help of interactive instructions has been linked to students' improved problem-solving skills [22], critical thinking, and scientific methods of investigating a set of challenges [23, 24].

A recent study has considered chemistry as being abstract in nature [25], indicating that the complexity of the subject content reduces students' interest during the learning process. Laboratory practices have been regarded as an integral part of chemistry curricula in science education [26], and global scientists have diligently oriented their attention to teaching natural science content, specifically chemistry content, through practical activities [27, 28]. The framework of science, technology, engineering, and mathematics (STEM) education emphasizes the irreplaceable and commendable role of laboratory-based investigations. Specifically, pertinent chemistry practices have been associated with improved students' practical skills [29], science process skills [30], and systematic methods of scientific investigation [31].

To date, there have been limited investigations about the contribution of video-based instruction as an alternative to teaching chemistry practical content in a resource-

constrained classroom environment. Although many studies exist concerning the pivotal contribution of laboratory-based learning environments to equipping students with chemistry practical skills, much is yet to be revealed in terms of enriching students' attitudes toward learning chemistry, with the integration of more practical activities to arouse students' interest and appreciation. Not only boosting students' interest and motivation, but it also alleviates the abstract nature of the content presented to students. The research to date has shifted to investigating how video-based instructions can be beneficial in facilitating laboratory practices, especially through video-based demonstrations [32-36]. In this realm, designing laboratory practices on the side of teachers is merely a starting point of facilitating students' learning, and becomes meaningful when it is creatively presented to students [37-39]. Therefore, it has been reported elsewhere that for students' easy internalization of the practical part of chemistry content, a sense of interest and motivation is of paramount importance [40]. One study [41] discovered that the quality of teaching and learning chemistry content depends on the effort invested by the instructor to meaningfully present the learning material, thus contributing to students' engagement. A study conducted by [42] revealed that students can easily grasp practical skills when they experience an exposure to visual information that is in one way video-based demonstrations.

Other studies have indicated that video-based instructions can serve as an alternative to conventional laboratory-based learning resources, mostly in developing countries [43, 44]. Quasi-experimental studies have shown that students taught using video-based learning outperformed those taught through traditional teaching and learning approaches [45, 46]. While previous studies doubted students' exposure to online content [47, 48], researchers indicated that students should be able to access learning resources for self-regulated learning [49, 50]. However, students should be guided on how to be selective when choosing free online learning resources, including video-based instructions.

Studies have shown that quality video-based instructions enhance students' visual representation of laboratory practices in natural science subjects [51, 52]. The study conducted by [53] asserted that video-based practical demonstrations in organic chemistry facilitated students' access to quality chemistry experiments, [54] affirmed that integration of video-based courses significantly improved teachers' instructional delivery, especially those requiring practices.

Video-mediated instructions have been considered pivotal in chemistry teaching and learning and allowed students experiencing repetitive rehearsal of the learning material [55]; the repetition in turn leads to internalization of the practical process, hence conceptual and procedural understanding. [56] suggested that video-mediated instructions provide a multisensory learning experience for students' skills acquisition. Further consideration of video-based learning has been the provision of spatial-temporal control of learning through self-regulated learning, thus aligning with the requirements of practical skills acquisition frameworks [57]. While video-based instructional approaches have been acknowledged and remain salient in the literature, much remains

to be empirically investigated to correlate these instructions with quality virtual laboratory practices in Rwanda. In this study, we focus on an instructional approach emphasizing the third learning goal: learning to do science. The study is designed to focus on the rationale of video-based instructions as the alternative for conventional resources in the pursuit of supporting quality teaching and learning of chemistry laboratory practices.

1.2. Contribution of the study to the literature

Recent studies [58, 59] reveal that limited learning resources hinder students' learning, specifically for science content requiring practice. Moreover, [60] emphasized that integrating theories and practices in chemistry fosters conceptual understanding of complex concepts. Teaching and learning science become meaningful if teachers possess transferable practical skills [61]. The current study reveals that teachers and students can engage in chemistry practical lessons to enhance understanding of complex concepts. We show that in a resource-limited learning environment, teachers thrive by using video-based instructions (VBIs). Findings of this study shed light on pre-service and in-service science subject teachers in view of teaching practical content in chemistry.

The initial phase of the study concentrates on teachers' perspectives on VBIs, beliefs, habitual use, and associated challenges. The subsequent phase assesses the effect of VBIs on students' academic achievement. Video-based instruction demonstration is reported as the most used instructional tool during improvisation [62]. Relatedly, [63] reported that internet sources address challenges associated with the scarcity of physical learning materials, and students can gain learning experiences from virtual laboratory activities. Interestingly, in this study, science subject teachers indicated that instructional videos could be used as an alternative to standard experimental procedures where learning resources are limited, and findings of this study indicated that students' conceptual understanding of ion identification in chemistry was improved.

1.3. Specific objectives of the study

- To analyze secondary school science teachers' beliefs about video-based instructions.
- To explore secondary school science teachers' habitual use of video-based instructions.
- To identify challenges encountered by secondary school science teachers while implementing video-based instructions
- To assess the effect of using video-based instructions on students' academic achievement in chemistry

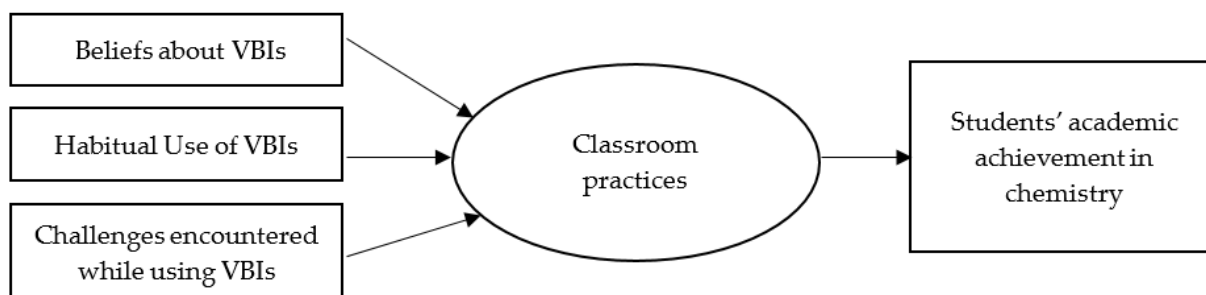
2. Theoretical orientation

The theoretical orientation follows key theories widely applied in teaching and learning contexts, and these theories enhance conceptual understanding of the rationale of video-based instructions towards providing quality virtual laboratory practices.

First, the study embraces the Technology Acceptance Model (TAM), which is a theoretical framework explaining how users come to accept and use technology. Previous studies have expanded on TAM by incorporating additional factors such as social influence, user experience, and contextual variables [64, 65]. [66] highlighted the role of social media in shaping perceptions of technology, suggesting that peer influence can enhance perceived usefulness and ease of use. Researchers have adapted TAM to various domains, including e-learning, mobile applications, and telehealth, demonstrating its versatility [67]. The integration of machine learning and artificial intelligence into TAM has also been explored [68], indicating that these technologies can further influence user acceptance through personalized experiences. Overall, TAM remains a foundational model in understanding technology adoption, with ongoing research refining its components to reflect the evolving technological landscape. Aspects of video-based instructions align with TAM as it requires users to be technologically conversant. This study further recognizes the power of Cognitive Information Processing Theory (CIPT) as instrumental, as it explains how individuals perceive, process, and store information [69]. The theory delves into aspects of attention span when users are exposed to new information. The theory further supports the idea that prior knowledge of new learning plays a pivotal role in strengthening connections to the existing framework of knowledge acquisition. Evidence from these reviewed theories substantiates the current study as they align with variables under investigation.

2.1 Conceptual framework

Figure 1: Conceptual framework showing variables of the study



Note: VBIs: Video-based instructions

The conceptualization of factors influencing classroom practices and associated impact on academic achievement among secondary school chemistry students is demonstrated in Figure 1. With three identified antecedents, namely beliefs about Video-Based Instructions (VBIs), habitual use of VBIs, and challenges encountered while using VBIs.

These key constructs influence classroom practices, with the teacher acting as the facilitator of learning. Integration of VBIs informed by these antecedents can bridge the learning gap in chemistry, especially practical content in a resource-constrained learning environment. The framework guided the process of data collection to gain insights about VBIs' status in secondary schools in Rwanda.

3. Design and methods

All methods in this study were carried out in accordance with relevant guidelines and regulations. A mixed research approach has been proven to provide in-depth information during research requiring deep exploration [70]. By considering the benefits embodied in the mixed approaches, the study was conducted in the same vein to include both quantitative and qualitative data obtained using achievement tests and questionnaires, respectively. The research process comprised three interconnected phases. First, the researcher composed questionnaires specific to each category of participants. These questionnaires contained items related to the first and second specific objectives of the study. Second, teaching and learning rounds were conducted, followed by the administration of chemistry achievement tests to both control and experimental groups. The intention of using a two-sword instrument was to assess the nature of Video-Based Instructions (VBIs) and how the latter supports quality teaching-learning in terms of students' academic achievement in chemistry. As reiterated, one of the researchers considered the practical part of the study and conducted rounds of teaching through VBIs with subsequent administration of chemistry achievement tests to respond to the third specific objective of the study. VBIs were conducted after facilitating and delivering a chemistry lesson titled "ion identification by using an instructional video" to senior four secondary school students enrolled in a science combination comprising chemistry as a core subject. Thereafter, data from achievement tests were compared through an independent samples t-test, which means achievement scores of students from control and experimental groups were compared to gauge the effectiveness of VBIs.

3.1 Study population and sampling strategy

Participants involved in the study were of two categories. The first category comprised secondary school teachers, while the second category comprised senior four secondary school science students. Two criteria were used for including students in the study population:

- 1) being a student in the senior four at the selected secondary school;
- 2) being enrolled in a science combination comprising the chemistry subject.

For teachers, two criteria were used for inclusion in the study population:

- 1) being a teacher at an advanced level in selected secondary schools with a minimum of one year of teaching experience, and
- 2) being a science teacher was mandatory.

Both students and teachers were purposively sampled to participate in the study.

3.2. Research instruments

Two types of research instruments were used in this study, namely the questionnaire and the chemistry achievement test.

3.2.1. Quantitative data

The study used quantitative data gathered systematically using an online survey questionnaire and chemistry achievement tests. A questionnaire comprised items directly related to the second and third specific objectives of the study. Three major guiding variables were considered. Constructs included:

- *Beliefs about video-based instructions* with five sub-constructs;
- *Habitual use of video-based instructions* with five sub-constructs; and
- *Challenges to video-based instructions* with five sub-constructs.

The chemistry achievement test included multiple choice questions regarding identification of ions.

3.2.2. Intervention

The intervention in this study involved rounds of teaching and learning conducted by one of the researchers currently serving as a chemistry teacher at the selected school. The intervention aimed at applying video-based instructions to teaching science lessons, specifically, practical content in chemistry. An instructional video was used by the teacher to treat students in the experimental group.

Before requesting that students watch the instructional video, the teacher explained the instructional objectives and the purpose of the video, as students were not familiar with using instructional videos in their learning. Afterward, students were permitted to watch the video three days per week. Students took short notes while watching the instructional video and were encouraged to relate what they watched to the instructions from the video. The teacher designed a chemistry achievement test related to the content from the instructional video. The test comprised 20 multiple-choice question items, each carrying one mark, and the whole test was out of twenty. Marks obtained by students were recorded in an Excel sheet for further analysis. While students in the experimental group received video-based instruction, those in the control group were taught using a conventional method, namely face-to-face lecturing. It is worth noting that students were taught the same lesson but in different ways. The lesson was delivered thrice to the control group with the purpose of balancing the degree of exposure to the content as students in the experimental group. Thereafter, the chemistry achievement test comprising 20 multiple-choice question items was administered to assess students' understanding of the lesson. Each question item carried one mark, and the whole test was out of twenty. Subsequently, marks obtained by students were recorded in an Excel sheet for further analysis.

3.3. Data analysis

The analysis of raw data was achieved following three synchronized phases. Initially, survey answers coded in an Excel dataset were exported into SPSS IBM version 26.0 for data management and statistical analysis. Furthermore, scores from chemistry achievement tests administered to both students in the control and experimental groups were recorded in an Excel sheet and exported into SPSS version 26.0 for data management and statistical analysis. For survey questionnaire data, descriptive statistics were used, while for scores from chemistry achievement tests, an independent samples t-test was deemed suitable to compare students' achievement during pre- and post-tests for both students in the control and experimental groups before and after intervention. Therefore, Descriptive statistics and inferential statistics were used for data interpretation.

4. Results

This section presents results from two research instruments used in this study. The results from an online survey questionnaire administered to teachers about teachers' beliefs, habitual use and challenges associated with video-based instructions are presented here. Results from chemistry achievement tests are also presented to show the effect of video-based instructions on students' academic achievement.

4.1. Beliefs about video-based instructions

Table 1 shows the perspectives of participants regarding beliefs about video-based instructions. Five question items were evaluated based on the five-point Likert scale, ranging from strongly agree (SA) = 5 to strongly disagree (SD) = 1. The interpretation indicates that the majority of participants either strongly agree or agree with the pre-set affirmative assertions. VBIs in relation to visual and auditory information (SA = 35.3 %, A = 54.9 %); VBIs in relation to students' self-regulated learning (SA = 23.5 %, A = 52.9 %); VBIs in relation to broaden spectrum of access to information (SA = 35.3 %, A = 52.9 %); VBIs in relation to minimizing inequality in quality education content availability (SA = 21.6 %, A = 35.3 %); and VBIs in relation to distraction while searching for instructional videos (SA = 5.9 %, A = 52.9 %).

Table 1: Secondary school science teachers' beliefs about video-based instructions

S. No	Items	SA	A	N	D	SD
1	Visual and auditory information	18 (35.3 %)	28 (54.9 %)	3 (5.9 %)		2 (3.9 %)
2	Students' self-regulated learning	12 (23.5 %)	27 (52.9 %)	6 (11.8 %)	6 (11.8 %)	
3	Broaden the spectrum of access to information	18 (35.3 %)	27 (52.9 %)	3 (5.9 %)	3 (5.9 %)	
4	Inequality in the availability of quality educational content	11 (21.6 %)	18 (35.3 %)	9 (17.6 %)	5 (9.8 %)	8 (15.7 %)
5	Distraction while searching for instructional videos	3 (5.9 %)	27 (52.9 %)	8 (15.7 %)	8 (15.7 %)	5 (9.8 %)

The results presented indicate that participants perceive the use of video-based instructions as imperative in teaching and learning science lessons, specifically chemistry subjects, in the case of the current study. Most participants' appreciation of VBIs in terms of integrating visual and auditory information, facilitating self-regulated learning, easy access to information, and minimizing inequality in terms of availability of educational resources aligns with students' improved learning outcomes observed during teaching practices. The reported distraction while searching for instructional videos could be controlled by the teacher.

4.2. Habitual use of video-based instructions

Table 2 indicates the perspectives of participants about the use of video-based instructions in teaching chemistry. The first two items were measured using a dichotomous scale, while the remaining three were measured using a Likert scale. The majority of participants (Yes = 76.5 %) reported the use of video-based instructions when demonstrating chemistry experiments, while a few participants reported differently (No = 23.5 %). These results imply that in the case of scarcity of learning resources, teachers could rely on instructional videos to facilitate students' learning. Others reported that they have assisted students to engage in video-based instruction in chemistry (yes = 84.3 %), with a few participants reporting differently (No = 15.7 %). Although much needs to be done in terms of helping teachers to feel confident in using VBIs, it is evident that teachers, in their teaching practices, integrate VBIs to engage students in lessons.

Table 2: Secondary school science teachers' habitual use of video-based instructions

S. No	Items	Yes	No			
Hv1	I use video-based instructions when demonstrating chemistry experiments	39 (76.5 %)	12 (23.5 %)			
Hv2	I have assisted students to engage in video-based instruction in chemistry	43 (84.3 %)	8 (15.7 %)			
	Items	Very often	Often	Sometimes	Rarely	Never
Hv3	I use video-based instructions when presenting chemical models	18 (35.3 %)	28 (54.9 %)	3 (5.9 %)		2 (3.9 %)
Hv4	I have ever used designed a video-based instruction in chemistry lesson	12 (23.5 %)	27 (52.9 %)	6 (11.8 %)	6 (11.8 %)	
		SA	A	N	D	SD
Hv5	I have access to the basic technological tools used in designing and preparing video-based instructions in chemistry	7 (13.7 %)	27 (52.9 %)	6 (11.8 %)	2 (3.9 %)	9 (17.6 %)

The results further demonstrate that most participants reported that they used video-based instructions when presenting chemical models (Very often = 35.3 %, Often = 54.9 %), a few reported differently (sometimes = 5.9 %, Never = 3.9 %). As chemistry is perceived as abstract in nature, using these chemical models alleviates such an abstract

nature and makes chemistry concepts easy to understand. Participants further reported that they have designed video-based instruction in chemistry lessons (Very often = 23.5 %, Often = 52.9 %). This practice leads to creatively designed lessons, capturing students' attention during lesson delivery. An equal proportion of 11.8 % reported that they sometimes and rarely design video-based instructions in chemistry lessons. While most of the participants asserted that they have access to the basic technological tools used in designing and preparing video-based instructions in chemistry (SA = 13.7 %, A = 52.9 %), there are still a high proportion of participants without access to these tools (N = 11.8 %, D = 3.9 %, and SD = 17.6 %). These results encourage the use of available technological tools and recommend that those in charge of ensuring quality instructional delivery to provide more of these tools.

4.3. Challenges encountered when implementing video-based instructions

We further identified challenges encountered during the use of video-based instructions. Identification of those challenges centered on five key hypothesized challenges, namely the lack of personalization, inadequate teacher preparedness, poor quality of educational video, issues related to digital inequality, and passive learning.

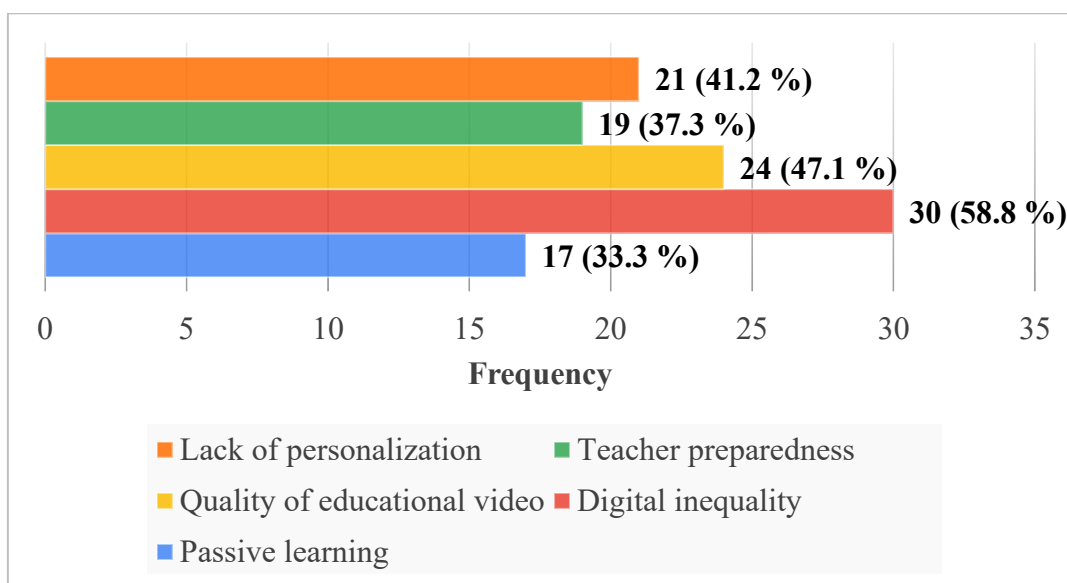


Figure 2: Challenges encountered when implementing video-based instructions

Figure 2 portrays results regarding challenges encountered while implementing video-based instructions. 21 (41.2 %) reported the lack of personalization, 19 (37.3 %) reported inadequate teacher preparedness, 24 (47.1 %) reported doubt on the quality of educational video, 30 (58.8 %) reported issues of digital inequality, while 17 (33.3 %) reported that video-based instructions can lead to passive learning. Most participants reported digital inequality and the quality of educational video as the most pressing challenges hindering the effective use of video-based instructions. The results revealed areas requiring attention to maximize the benefits of using VBIs in the teaching and learning process. It is crucial to invest in teacher training and infrastructure to reduce

digital inequality reported by many participants. In the same vein, trained teachers are expected to carefully select educational videos to use during instructional delivery.

4.4. Effect of video-based instructions on students' achievement

We purposefully conducted rounds of teaching to further understand the effectiveness of video-based instructions among the senior four students. The intention was to evaluate the effect of VBIs on students' understanding of ion identification and measure their achievement through designed chemistry practical pre- and post-tests. We considered two senior four classes, senior four Physics, Chemistry, and Biology (S4 PCB) students (N = 23) considered as the control group, and senior four Physics, Chemistry, and Mathematics (S4 PCM) students (N = 9) referred to as the experimental group.

Table 3: Control Group Statistics

Scores	N	Mean	Std. Deviation	Std. Error Mean
Pretest	23	16.61	1.644	.343
Posttest	23	17.43	1.441	.300

Students' prior knowledge regarding ion identification was tested through a pre-test administered to both control and experimental groups before intervention. After testing students' prior knowledge, rounds of teaching were conducted. Briefly, students in the control group were treated using a conventional teaching method, specifically the provision of explanation through lecturing, while their counterparts in the experimental group were treated using video-based instructions as an intervention. It is worth noting that both groups were given a chemistry practical post-test to measure their learning outcomes, to investigate the effect of the intervention referred to herein as VBIs among students in the experimental group.

Table 4: Control group pretest and post-test scores analyzed through an Independent Samples t-Test

Table 4: Control group pretest and post-test scores analyzed through an Independent Samples <i>t</i> -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
Scores	Equal variances assumed	.941	.337	-1.812	44	.077	-.826	.456	-1.745	.093
	Equal variances not assumed			-1.812	43.252	.077	-.826	.456	-1.745	.093

Note: Levene's Test for Equality of Variances, and the mean difference is significant at ** $p < 0.05$

An independent samples t-test was conducted to investigate the effect of VBIs on students' understanding of ion identification and academic achievement in chemistry. Table 3 shows pre-test results among students in the control group. Twenty-three participants completed practical pre- and post-tests without intervention; they had only been taught using a conventional teaching method. Participants demonstrated nearly similar mean score during the pretest ($M_1 = 16.61$, $SD = 1.644$) mean score during the post-test ($M_2 = 17.43$, $SD = 1.441$), $t_{(23)} = -1.812$, $p = .077$, 95% CI [-1.745, -.093], Cohen's $d = 0.53$.

Table 5: Experimental Group Statistics

Scores	N	Mean	Std. Deviation	Std. Error Mean
Pretest	9	16.00	1.118	.373
Posttest	9	17.33	1.000	.333

Table 5 shows pre- and post-test results among students in the experimental group. Nine participants participated in practical pre- and post-tests in which video-based instructions were used as intervention before undertaking the post-test. Participants demonstrated a lower mean score during the pretest ($M_1 = 16.00$, $SD = 1.12$) compared to a higher mean score during the post-test ($M_2 = 17.33$, $SD = 1.000$), $t_{(9)} = -2.667$, $p = .017$, 95% CI [-2.393, -.273], Cohen's $d = 1.25$. Cohen's d is the appropriate effect size measure if two groups have similar standard deviations and are of the same size. As suggested in the literature [71], if $d = 0.2$ the effect is considered small, $d = 0.5$, the effect is moderate, and $d = 0.8$, the effect is large benchmarks suggested by Cohen 1988. For the control group, the calculated Cohen's $d = (M_2 - M_1) / S_{pooled} = (17.43 - 16.61) / 1.545836 = 0.53$ while for the experimental group ($d = 1.25$).

Table 6: Experimental group pretest and post-test scores analyzed through Independent Samples t-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
Scores	Equal variances assumed	.080	.780	-2.667	16	.017	-1.333	.500	-2.393	-.273
	Equal variances not assumed			-2.667	15.347	.017	-1.333	.500	-2.394	-.272

Note: Levene's Test for Equality of Variances, and the mean difference is significant at ** $p < 0.05$

Moreover, further results of the independent samples t-test as indicated in Table 4 & 6, show that Levene's test for equality of variances indicates that variances are not

significantly different from each other ($t(44) = -1.812$, $p = .077$; $t(16) = -2.667$, $p = .017$ respectively, supporting that the homogeneity assumption of the variance was met. Therefore, for the control group ($p > .05$, $p = .077$) indicating non-significant difference in students' achievement during chemistry practical pre- and post-test achievement, while for the experimental group ($p < .05$, $p = .017$) indicating significant difference between chemistry practical pre- and post-test achievement. These results highlight the effectiveness of video-based instructions in enhancing students' achievement during the chemistry practical post-test.

5. Discussion

In this research investigation, we investigated the effect of video-based instructions on students' academic achievement in science education by focusing on their integration by science teachers in Rwanda. The discussion of the results is centered around four research objectives shortened as beliefs about video-based instructions; habitual use of video-based instructions; video-based instructions and students' academic achievement; and video-based instructions and associated challenges. The survey gathered essential demographic characteristics of respondents, comprising gender, age range, school location, teaching experience, subject (s) taught. Demographic data is invaluable to recognize diverse backgrounds of respondents and how they can affect the adoption of VBIs in science education.

A five-point Likert scale is used for rating a series of affirmative statements to assess teachers' perspectives about VBIs. The results indicate that a significant percentage of teachers are cognizant of the beneficial aspects of VBIs, notably how they may promote student engagement by incorporating visual and audio information, support self-regulated learning, and expand access to instructional materials. Improved content or instruction in this domain is essential, as there are concerns about possible distractions when students look for customized instructional videos.

The results of the current study show that teachers' beliefs regarding VBIs in science education significantly determine how they creatively devise innovative and creative instructional approaches. Positive beliefs about instructional approaches could lead to engaging and effective classroom practices. Understanding teachers' beliefs about a specific modality of instructional delivery is fundamental to enhancing the quality of teaching and learning processes. The findings emphasize that beliefs can predict teachers' effort to devise and integrate cutting-edge teaching and learning approaches into their teaching practices. It is in this regard that the investigated beliefs in this study focused on five predetermined affirmative statements reflecting secondary school science teachers' beliefs about video-based instructions. A substantial agreement of participants to the presented statements was observed, indicating promising beliefs of teachers regarding video-based instructions in science education. As presented in Table 1, the results indicate teachers' beliefs about VBIs in relation to visual and auditory information (90.2

%). This implies that most teachers are aware of the advantage of using multimedia in teaching and learning endeavors.

Previous studies demonstrated that VBIs potentially enhance students' visualization of presented instructions and serve as a combinatorial approach using multiple senses to retain information [72]. Another study supporting our findings [73] revealed that when students are presented with visual and auditory information, they are likely able to remain active during instruction delivery. In line with constructivist learning, students' self-regulated learning is essential, 76.4 % believe that VBI supports students in managing their own learning, indicating that teachers consider VBIs as an instructional approach to promoting independence and engagement among students during the learning process. Among participants, 88.2 % believe that VBIs lead to a broadened spectrum of access to information, indicating the willingness of teachers to establish a learning environment that allows students to have access to information.

These results corroborate recent studies [74, 75] emphasizing the contribution of open educational resources in the current era of vibrant technological advances. Interestingly, 56.9 % of participants recognize the potential barrier of inequality in accessing quality educational videos, and the fact that 58.8 % of participants believe that students can experience distraction while searching for instructional video, indicates that teachers are aware of the drawbacks of unguided students' information search. In this regard, teachers remain central to guiding students on how to use VBIs efficiently. Presented results substantiate previous findings regarding teachers' beliefs in the realm of technology integration in education, especially video-based instructions [76].

The survey also investigates the habitual use of VBIs as methods of instruction. Many teachers report using VBIs when presenting scientific models, demonstrating experiments, and assisting students in engaging with video content. This indicates that VBIs are becoming more widely accepted and integrated into science curricula, however individual teachers' use of them may differ depending on their access to resources and technology.

The effect of video-based instructions was evaluated in a quasi-experimental study. Evaluation results after teaching rounds indicated a significant mean difference of students in the experimental group, which is attributed to the video-based instructions used as an intervention. Prior to analyzing data using an independent samples t-test, we checked the assumption of homogeneity of variances as indicated in Tables 4 & 6, variances were not significantly different from each other ($t(44) = -1.812$, $p = .337$; $t(16) = -2.667$, $p = .780$ respectively). The use of video-based instructions was associated with a significant mean difference in performance of students in the control group ($p > .05$, $p = .077$ and the experimental group ($p < .05$, $p = .017$).

The results of this study are supported in the literature [51, 53, 77, 78]. For instance, the analysis of teachers' pedagogical content knowledge assessed by video-based and text-based tests revealed that both means positively affect students' achievement, with a highly significant effect of the video-based test on students' achievement [79]. [80] considered the pivotal role of audio-visual feedback to students and evaluated the effect

of instructional feedback using audio-visual feedback in a video format, which enhanced students' engagement and improved students' achievement. Through a quasi-experimental study design, [81] conducted a study evaluating the effect of supplementing problem-based learning (PBL) with video resources on students' academic achievement.

As the study compared students in control and experimental groups, those in the experimental group taught using video-based resources exhibited improved academic achievement. A study was conducted to evaluate the effect of interactive video-based instruction on learning performance, following a quasi-experimental design. The analysis of covariance indicated a significant effect of individual interactive video-based instruction among students in the experimental group on their learning performance, while the conventional approach applied to the control group had a non-significant effect [82]. These results are promising as they emphasize that students develop various social skills and perform a wide range of activities, which enhance their intellectual capacity in a self-paced learning environment. Video-based instructions are associated with students' motivation and improved retention of learned content, which subsequently improves students' learning outcomes [83, 84]. Therefore, video-based instructions are fundamental to improving students' academic performance when integrated into teaching-learning endeavors.

The study attempts to identify difficulties instructors confront when utilizing VBIs. Although the context presented did not delve into details, these challenges must be addressed with the goal of improving the effective incorporation of VBIs in science education. The hallmark challenges could be limited technology, inappropriate instruction, or minimal availability of high-quality video information. The findings indicate a positive attitude toward the use of video-based instructions among secondary school science teachers in Rwanda, highlighting both the perceived benefits and the challenges that need to be addressed for more effective integration into the curriculum. This study contributes valuable insights to the academic community regarding the current state of video-based instruction in science subjects and underscores the importance of ongoing support and resources for teachers.

6. Conclusion and Implications

This research provides timely and original evidence that video-based instruction (VBI) can significantly bridge pedagogical and infrastructural gaps in science education, especially in resource-constrained environments. In the context of Rwandan secondary schools, where traditional laboratory practices are often hindered by a lack of equipment and materials, VBIs emerged as a powerful instructional alternative. The study revealed not only substantial academic gains among students exposed to VBI (Cohen's $d = 1.25$) but also enhanced conceptual understanding and learner engagement. Additionally, science teachers reported positive beliefs regarding VBIs, highlighting their value in promoting self-directed learning, visual reinforcement of concepts, and instructional

flexibility. However, challenges remain. Teachers cited digital inequality, limited access to multimedia resources, and a lack of professional development as significant barriers to effective VBI integration. These issues point to broader systemic constraints that must be addressed to scale up the use of educational technologies in low-income contexts.

Implications for practice include the need for targeted teacher training programs focused on digital pedagogy and multimedia integration in STEM education. Institutions should consider embedding VBI strategies within existing science curricula to enhance learning experiences where traditional lab infrastructure is limited. Implications for policy suggest the urgent need for national education strategies to invest in ICT infrastructure, particularly in rural and underserved schools. Policymakers must also consider establishing public-private partnerships to provide schools with access to locally contextualized, curriculum-aligned video content. Moreover, future research should explore the use of longitudinal studies to explore the sustained impact of VBI on student achievement and knowledge retention, as well as cross-subject investigations to determine the effectiveness of VBI across other science disciplines. Research should also investigate scalable, cost-effective teacher support systems that can sustain the integration of educational technologies in similar low-resource settings.

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Conflict of Interest Statement

The authors declare no conflicts of interest.

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