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Use of Visual Representations to Improve Students' Problem-Solving Skills in Kinematics in Selected Lower Secondary Schools in Kicukiro District, Rwanda

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Abstract

Despite growing evidence for the effectiveness of visual representations (VRs) in supporting students' understanding and problem-solving in physics, limited empirical documentation exists on how physics teachers in Rwandan lower secondary schools actually integrate these tools in kinematics instruction. This mixed-methods study, guided by a pragmatic paradigm and convergent parallel design, explored the extent and nature of VR use in teaching and learning kinematics in 22 lower secondary schools in Kicukiro District, Rwanda. Data were collected from 22 physics teachers and 352 students through structured questionnaires, classroom observation checklists, and semi-structured interviews. Quantitative data were analysed using descriptive statistics in SPSS and Microsoft Excel, while qualitative data from interviews were analysed thematically. The study findings reveal that VR use is predominantly limited to traditional static tools, particularly motion graphs and chalkboard sketches, while dynamic and digital representations such as computer simulations, videos, and animations are virtually absent from classroom practice. VRs are most consistently deployed at lesson introductions, with limited integration into explanation, problem-solving, and consolidation phases. Teacher-student interaction around VRs is largely one-directional, with students rarely invited to construct or interpret representations independently. Both teachers and students identified limited resources, insufficient instructional time, and inadequate professional training as key barriers. Students additionally reported significant difficulty interpreting motion graphs and connecting diagrams to equations and strongly expressed a need for greater teacher guidance. Current VR practice falls short of the representational depth required to meaningfully support students' kinematics problem-solving skills. A significant gap exists between the multi-representational approaches recommended in the literature and actual classroom practice. Recommendations are made for teachers, school administrators, curriculum developers, and policymakers.

1. INTRODUCTION

Science education, with a particular focus on physics, plays a significant role in preparing students for future careers in science, engineering, and technology (Asriadi & Istiyono, 2022; Lucas & Lewis, 2019). However, students' academic achievement in physics remains persistently low in many educational contexts (Citra et al., 2025; Claudia et al., 2020). One major reason for this underperformance is the abstract nature of physics concepts, which often involve complex mathematical reasoning and problem-solving skills beyond rote memorisation (Napis et al., 2023). Among the most conceptually challenging topics is kinematics, where understanding distance, displacement, velocity, acceleration, and motion graphs requires students to translate between verbal, graphical, and symbolic representations and to apply logical reasoning (Marušić & Sliško, 2017).

Several studies have shown that students' academic achievement in physics is closely linked to their problem-solving skills (Asriadi & Istiyono, 2022; Niyomufasha et al., 2024). Researchers have devoted increasing attention to identifying effective instructional approaches, and many emphasise that students perform better when problems include visual elements such as drawings, diagrams, graphs, and

animations (Claudia et al., 2020; Marušić & Sliško, 2017). Visual representations thus play an important role in helping learners conceptualise abstract phenomena and make sense of physical relationships.

In Rwanda's lower secondary education, students' difficulties in physics are reflected in consistently low national examination scores. According to the National Examination and School Inspection Authority (NESA), student achievement in physics for the 2024–2025 academic year stands at only approximately 27%, with mean scores in previous years ranging from 17.4% to 21.8% (NESA, 2023). Similar challenges have been observed across the East African Community, where studies recommend that physics teachers deliberately use multiple representations, especially visual representations, to make abstract concepts like kinematics more concrete and to strengthen students' problem-solving abilities (Niyomufasha et al., 2024; Nyirahabimana et al., 2022; Theogene et al., 2024).

Despite the clear theoretical and empirical support for VR use in physics instruction, classroom practice often falls short. In Kicukiro District, where schools have access to basic technological and instructional resources, the extent to which teachers employ VRs in teaching kinematics remains largely unexplored. This study therefore seeks to fill this gap by investigating: (1) how physics teachers and students incorporate VRs in kinematics teaching and learning to promote problem-solving skills; (2) what types of VRs are most frequently used; and (3) what challenges physics teachers and students face when using VRs in kinematics instruction.

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1 Theoretical Framework

This study is grounded in two complementary theoretical perspectives: Mayer's Cognitive Theory of Multimedia Learning (CTML) and constructivist learning theory. CTML posits that learners process information through two separate channels, verbal and visual, and that meaningful learning occurs when these channels are actively engaged and integrated (Mayer, 2005, 2011, 2017). Presenting physics concepts in both visual (e.g., diagrams, graphs, motion sketches) and symbolic forms allows learners to build coherent mental models, reduce cognitive overload, and enhance problem-solving competence.

Constructivist theory complements CTML by emphasising that learning is an active process in which learners construct knowledge through interaction, exploration, and reflection (Bada & Olusegun, 2015; Mugambi, 2018). From this perspective, multiple representations in physics provide different entry points into abstract concepts, enabling students to connect new information with prior knowledge. Together, these frameworks frame VR use in kinematics as a strategy supporting both cognitive processing and active knowledge construction, thereby enhancing students' representational competence and problem-solving abilities.

2.2 Visual Representations in Physics Education

Visual representations encompass both static and dynamic tools, including diagrams, vector sketches, motion graphs, animations, videos, computer simulations, data plots, and teacher demonstrations (Munfaridah et al., 2021; Opfermann et al., 2017). Research consistently shows that when students engage with multiple and varied representations, they develop richer mental models, reduce misconceptions, and improve problem-solving ability (Hahn & Klein, 2023). Banda and Nzabahimana (2022) demonstrated that PhET simulations improve academic performance and learning motivation, while Aminuddin et al. (2024) showed significant improvements in kinematics understanding through a multi-representation approach.

Despite this evidence base, actual classroom practice often falls short. Teachers frequently under-utilise VRs, use them superficially as illustrations rather than meaning-making tools, or lack the pedagogical strategies to integrate them into problem-solving instruction (Ibrahim & Rebello, 2012). Studies in Rwanda and the East African Community recommend that physics teachers integrate multiple representations but limited empirical work documents how teachers in resource-limited settings actually use these tools, especially in specific topics like kinematics (Nyirahabimana et al., 2022; Theogene et al., 2024).

2.3 Challenges in VR Integration

Research identifies several barriers to effective VR integration in physics classrooms, particularly in resource-constrained contexts. These include limited access to digital tools and ICT infrastructure, insufficient instructional time, large class sizes, and inadequate teacher professional development in representational pedagogy (Mbwile & Paskali, 2025; Muinde et al., 2023). Students additionally face challenges in graph interpretation and representational translation, abilities central to kinematics problem-solving (Amaliah et al., 2021; Suyatna et al., 2017; Testa & Catena, 2022).

3. METHODOLOGY

3.1 Research Design and Paradigm

This study adopted a pragmatic paradigm, which supports the use of both qualitative and quantitative approaches based on what best answers the research questions (Maruashvili, 2024). A convergent parallel mixed-methods design was employed, whereby quantitative and qualitative data were collected independently but concurrently, analysed separately, and merged during interpretation to compare, confirm, and complement findings (Plano Clark, 2017; Sharma et al., 2023).

3.2 Study Context and Participants

The study was conducted in Kicukiro District, Kigali City, Rwanda. The district was selected because it hosts a variety of public lower secondary schools with broadly similar resource levels and teacher profiles, making it a representative context for exploring VR use in physics instruction.

The target population comprised 22 physics teachers, one from each of the 22 government lower secondary schools in the district, and 2,530 students enrolled in Senior One (S1) and Senior Two (S2) classes where kinematics is taught. All 22 physics teachers participated in the study. For students, Yamane's (1967) formula was applied to determine a representative sample size from the total population of 2,530, yielding a sample of 352 students, 16 per school, equally distributed across S1 and S2 classes and balanced by gender (8 males and 8 females per school). Additionally, 176 students (8 per school) participated in focus group interviews.

Table 1
Student sampling procedure for questionnaire and focus group interviews (22 schools)

Instrument	Class Level	Male per School (n)	Female per School (n)	Subtotal per School (n)	Total (N)
Questionnaire	Senior 1	4	4	8	176
Questionnaire	Senior 2	4	4	8	176
Questionnaire Total		**8**	**8**	**16**	**352**
Focus Group Interview	Senior 1	2	2	4	88
Focus Group Interview	Senior 2	2	2	4	88
Interview Total		**4**	**4**	**8**	**176**

3.3 Data Collection Instruments

Four instruments were used. A structured teacher questionnaire collected data on the frequency, types, purposes, and perceived challenges of VR use in kinematics instruction using five-point Likert scales. A structured student questionnaire assessed students' exposure to VRs during lessons and their views on how these tools support their kinematics problem-solving. A classroom observation checklist documented actual VR use in real teaching contexts, focusing on VR types, frequency, timing, teacher-student interaction, integration into problem-solving, and observed challenges. Semi-structured interviews, individual with teachers and focus group with students, explored in-depth experiences, pedagogical reasoning, and contextual factors affecting VR use. All instruments were validated for content validity before use, and reliability was established through piloting.

3.4 Data Collection Procedures

Ethical clearance was obtained from the Directorate of Research and Innovation Unit at UR-CE on April 8, 2026, and data collection authorisation was granted by Kigali City through the Mayor of Kicukiro District on May 5, 2026. The researcher visited all 22 schools, introduced themselves to headteachers, and was subsequently introduced to physics teachers and students. Data were collected in three phases: (1) administration of questionnaires, online for teachers via Google Sheets, and printed for students; (2)

classroom observations conducted in one class per school (11 in S1, 11 in S2), totalling 22 observations; and (3) semi-structured teacher interviews and student focus group interviews to elaborate on findings from the first two phases.

3.5 Data Analysis

Quantitative data from questionnaires and observation checklists were coded and analysed using SPSS and Microsoft Excel. Descriptive statistics, frequencies, percentages, means, and standard deviations were computed and presented in tables and bar charts. Qualitative data from interviews were analysed thematically following Braun and Clarke's (2006) six-phase framework: familiarisation, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and writing up. After separate analyses, both data types were merged and compared during interpretation, with areas of convergence and divergence discussed in relation to the existing literature.

4. RESULTS

4.1 How Physics Teachers and Students Incorporate VRs in Kinematics Instruction

The findings reveal that VRs are present in kinematics classrooms but are incorporated in a limited and predominantly teacher-centred manner. Classroom observation data showed that VRs were often used at lesson introductions in 63.6% of observed classes, confirming that teachers rely on visual tools to introduce concepts. However, VR use decreased markedly in subsequent lesson phases. VRs were used during explanation (C2) and problem-solving (C3) only sometimes, dominant in 54.5% and 50.0% of lessons, respectively, while revisiting VRs during lesson summaries (C4) was rare in 54.5% of classes and never observed frequently.

Teacher-student interaction around VRs was predominantly one-directional. Step-by-step teacher explanation of diagrams (D1) was clearly observed in 54.5% of lessons, while students being invited to draw or explain VRs (D4) was not observed in 72.7% of lessons, and teacher feedback based on students' visual explanations (D5) was absent in 77.3% of classes. Over-reliance on formula manipulation without visual support (F5) was recorded in 86.4% of all observed lessons.

Both teachers and students perceived VRs positively. In teacher interviews, all 22 teachers expressed belief in the value of VRs for making abstract kinematics concepts accessible:

"When I draw a velocity-time graph, students can see the motion. Without the graph, acceleration is just a formula. With it, they begin to understand what is actually happening." **(T2)**

Students similarly affirmed the value of VRs, with questionnaire data showing that diagrams help understand kinematics questions (C1, M = 4.02) and drawing graphs aids correct problem-solving (C2, M

= 4.01). However, 74.8% of students expressed a need for more teacher guidance when using VRs (D4, M = 4.04):

"I need the teacher to explain the diagram slowly, step by step. Sometimes they draw it quickly and move on, and I am still trying to understand what it means." **(S3)**

4.2 Types of Visual Representations Most Frequently Used

Motion graphs and teacher-drawn diagrams consistently emerged as the most frequently used VRs. In the teacher questionnaire, velocity-time graphs recorded the highest mean usage (M = 3.55), followed by teacher-drawn chalkboard sketches (M = 3.41) and motion diagrams (M = 3.36). Classroom observations confirmed this: chalkboard sketches (A1) were observed two to three times in 50% of lessons and lesson-drawn graphs (A3) in 40.9% of classes. From the student perspective, motion graphs (B2, M = 4.05) and drawings or diagrams (B1, M = 3.97) recorded the highest frequencies of observed teacher VR use.

In sharp contrast, digital and dynamic VRs were virtually absent. Computer simulations such as PhET (A7) and digital media including videos and animations (A6) were not observed in a single lesson across all 22 classes. In the teacher questionnaire, simulations recorded the lowest mean usage (M = 2.68). Teacher interviews confirmed access barriers as the primary reason:

"If I had a computer and a projector, I would use PhET every week for kinematics. Students would understand so much better. But we just do not have that." **(T20)**

Student interview data corroborated this absence, with students reporting complete unfamiliarity with simulation-based learning:

"I only know graphs and diagrams. I have never seen a simulation or a video used in physics class. Maybe those would also help, but I do not know." **(S9)**

4.3 Challenges in Using VRs in Kinematics Instruction

Both teachers and students identified several interconnected challenges. For teachers, the most significant barriers were limited teaching resources (E2, M = 4.05, 81.9% agreement), students' difficulty interpreting graphs and diagrams (E3, M = 3.95, 77.3% agreement), and limited instructional time (E1, M = 3.55, 59.1% agreement). These were confirmed by the classroom observation data, where limited resources (F1) were observed in 59.1% of lessons and student interpretive difficulty (F3) in 77.3% of lessons.

A notable discrepancy emerged regarding professional training: while only 40.9% of teachers identified insufficient training as a challenge in the questionnaire (E4, M = 2.64), teacher interviews revealed a more candid acknowledgement of pedagogical gaps:

"We learned physics, and we learned how to teach, but nobody showed us how to use different types of visual representations strategically. I just do what I think works." **(T16)**

For students, the most pressing challenge was the need for more teacher guidance (D4, M = 4.04, 74.8% agreement), followed by confusion when multiple diagrams appear in one question (D2, M = 3.48), lack of learning resources (D0, M = 3.43), difficulty interpreting motion graphs (D1, M = 3.35), and struggles connecting diagrams to equations (D3, M = 3.33). Student interviews further identified restricted ICT access as a structural barrier:

"We use ICT representations too rarely for kinematics or physics classes. I think if we could use the ICT lab for physics, we would understand motion much better." **(S10)**

5. DISCUSSION

5.1 VR Integration Patterns

The finding that VRs are used predominantly at lesson introductions but rarely integrated into deeper instructional phases is consistent with what Ibrahim and Rebello (2012) describe as the superficial use of VRs, where teachers treat visual tools as illustrations rather than instruments for supporting representational reasoning. Girwidz and Kohnle (2021) similarly note that when visuals are used in physics classrooms, they are often not explicitly connected to problem-solving steps. The observation that over-reliance on formula manipulation without visual support was recorded in 86.4% of lessons suggests that formula-centred instruction remains deeply entrenched, a pattern consistent with concerns raised by Nyirahabimana et al. (2022) and Theogene et al. (2024) regarding Rwandan physics classrooms.

The predominantly teacher-centred, one-directional nature of VR interaction in the observed lessons stands in direct tension with both CTML and constructivist theory (Bada & Olusegun, 2015; Mayer, 2005). When students are passive recipients rather than active constructors of VRs, the dual-channel processing and active knowledge construction that these theories identify as essential for deep learning and problem-solving cannot be fully achieved.

5.2 Types of VRs and the Digital Gap

The dominance of static, chalk-and-board VRs aligns with patterns documented across resource-limited secondary school contexts in East Africa (Mbwile & Paskali, 2025; Muinde et al., 2023). The complete absence of digital and simulation-based VRs from observed lessons stands in stark contrast to the growing evidence for their effectiveness. Banda and Nzabahimana (2022) demonstrated that PhET simulations significantly improve kinematics understanding and motivation, while Aminuddin et al. (2024) and Guentulle et al. (2024) showed that multi-representational and technology-integrated approaches yield better learning outcomes. The absence of such tools from the sampled classrooms represents a significant missed opportunity for enriching students' representational experience.

From a CTML perspective, static diagrams engage the visual channel but do not provide the dynamic, interactive experiences that Schnotz and Kürschner (2007) identify as particularly effective for building mental models of motion. Students' limited familiarity with digital VRs, a direct consequence of their absence from instruction, further constrains the development of the representational competence needed for effective kinematics problem-solving (Opfermann et al., 2017).

5.3 Challenges and Their Implications

The resource and time constraints identified in this study are consistent with the contextual factors documented in the literature for resource-limited secondary school settings (Nyirahabimana et al., 2022; Theogene et al., 2024). However, the discrepancy between teachers' self-assessed training adequacy in the questionnaire and their candid acknowledgement of pedagogical gaps in interviews is a particularly significant finding. This self-assessment bias suggests that professional development needs in VR pedagogy are likely underestimated when measured through self-report instruments alone, and that qualitative methods are essential for surfacing the full extent of teachers' training needs.

Students' graph interpretation difficulties, identified convergently across questionnaires, observations, and interviews, align strongly with what Amaliah et al. (2021), Suyatna et al. (2017), and Testa and Catena (2022) identify as among the most pervasive weaknesses in kinematics learning. These difficulties are both a consequence of limited VR exposure and a barrier to further VR integration, creating a reinforcing cycle that can only be broken through deliberate, scaffolded representational instruction.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study concludes that physics teachers in lower secondary schools in Kicukiro District use VRs in kinematics instruction, but their use is limited in scope, depth, and consistency. Traditional static tools, particularly motion graphs and chalkboard sketches, dominate practice, while dynamic and digital representations are virtually absent. VR integration is most visible at lesson introductions and weakest during consolidation and student-generated activities. Both teachers and students perceive VRs as valuable but face interconnected structural, material, and professional barriers that constrain their effective use. Students' graph interpretation difficulties represent a particularly urgent pedagogical concern confirmed across all data sources.

6.2 Recommendations

Based on these findings, the following recommendations are made:

For physics teachers: Expand VR repertoire beyond static tools; integrate VRs deliberately across all lesson phases; shift from one-directional VR delivery to interactive, student-centred engagement; make explicit connections between VRs and mathematical formulas during problem-solving.

For school administrators: Prioritise procurement of basic VR resources including digital tools; extend student access to ICT laboratories beyond dedicated ICT lessons; create structured opportunities for in-school professional development on VR pedagogy.

For curriculum developers and policymakers: Embed specific representational targets into the physics curriculum; revise textbooks to include richer and more diverse VRs; align national assessment practices with representational competence goals; develop and implement targeted professional development programmes for physics teachers on the pedagogical use of VRs.

For future research: Experimental studies testing the impact of specific VR interventions on kinematics problem-solving performance; longitudinal studies tracking representational competence development; comparative studies across different districts and school resource profiles in Rwanda.

Declarations

Clinical Trial Number

Clinical trial number: not applicable.

Ethics Approval

Ethical clearance for the study was obtained from the University of Rwanda–College of Education Research Screening and Ethics Clearance Committee (UR-CE RSEC-C) through the Research and Innovation Unit on 8 April 2026 **(**Ref: DRI-CE/033(a)/MT/gi/2026**).** The study was conducted in accordance with the ethical requirements and guidelines of the UR-CE Research Screening and Ethics Clearance Committee and the University of Rwanda. Data collection authorization was subsequently granted by Kigali City through the Mayor of Kicukiro District on 5 May 2026.

Consent to Participate

Participation in the study was voluntary, and informed consent was obtained from the participants before data collection. For student participants, the required consent and assent procedures were followed in accordance with the applicable institutional and research requirements.

Consent to Publish

Consent to publish the findings of this study was obtained in accordance with the applicable ethical and institutional requirements.

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Author Contribution

N.N. conceptualized the study, developed the methodology, conducted the investigation and data collection, analyzed the data, and wrote the original manuscript. F.U. contributed to the investigation, data collection, data analysis, and writing—review and editing of the manuscript. M.L. supervised F.U. during the study and contributed to the critical review and editing of the manuscript. All authors reviewed and approved the final manuscript.

Data Availability

The datasets generated during and/or analysed during the current study are not publicly available due to ethical and institutional restrictions concerning the privacy and confidentiality of human participants but are available from the corresponding author on reasonable request.

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