



Pedagogical Affordances of Autograph Technology in the Teaching of Functions: An Activity Theory Perspective

Fanuel Matindike^{1*}, Virendra Ramdhany²

^{1*,2} University of Johannesburg, South Africa

*Email: fmattindike@uj.ac.za

Abstract

The proliferation of digital devices within education systems in most African countries during and after the Covid-19 pandemic has created greater opportunities for incorporating digital technologies into mathematics education. This paper reports on initial findings from a broader study that explored the implementation of dynamic mathematical applications in the teaching of functions in marginalized high schools in South Africa. The study utilized a qualitative case study research method, based on Grade 11 learners' experiences during an instructional intervention programme, to investigate the pedagogical affordances offered by Autograph technology in teaching functions at an underprivileged high school. Adopting an inductive and descriptive approach, data were collected using ethnographic methods, which included observations, textual analysis, and transcripts from both task-based and open-ended interviews. The findings of the study were categorized and discussed under four themes, namely, motivation enhancement, representation competency, classroom interactivity, and constraints. The study established that the affordances of Autograph technology as a teaching tool can only be fully realized when its application is well aligned with the pedagogical context, subject matter, and the students involved. An Autograph-mediated pedagogical model is proposed to offer insights to mathematics educators on how the pedagogic use of dynamic mathematical applications can be optimized.

Keywords: affordance; autograph; constraints; marginalized; quality education.



INTRODUCTION

Information and Communication Technology (ICT) tools are globally regarded as valuable resources for education that enrich pedagogical contexts and facilitate learning activities. In South Africa, research has reported slow adoption of ICTs in educational settings (Dlamini & Nkambule, 2020; Padayachee, 2017; Mathende & Beach, 2022) despite significant investments aimed at improving access to these technologies within the education sector (Dlamini, 2022; Gillwald et al., 2018). There is a glaring disconnect between the availability of ICTs in schools and teachers' readiness to integrate these tools into their pedagogy, particularly in the disadvantaged communities (Graham et al., 2020; Kennedy & Cronjé, 2023) This state of affairs perpetuates the reality of unequal access to quality education in South Africa which is rooted in the disparities in access to technological resources and defined along socio-economic lines.

Drawing on Davis (1985) Technology Acceptance Model (TAM), teachers' willingness to utilise ICTs in their teaching depends on their *perceived usefulness* and *perceived ease-of-use*. Perceived usefulness refers to the extent to which an individual believes that utilizing a specific system will enhance their performance. Simply put, if teachers do not believe that employing a digital system or application will improve their teaching effectiveness, they are unlikely to adopt those devices. According to the TAM, perceived ease-of-use is considered as how much effort a person perceives is required to use a particular system (Davis, 1989). This largely depends on the user's technical competency regarding new technology and can easily be addressed through improved access and professional development for teachers (Graham et al., 2020). Perceived usefulness of a technological tool has proved a more complex challenge. Teachers' beliefs about the relevance of technology for student learning are among the most significant obstacles hindering its effective use in teaching practices. This study emphasizes that simply increasing ICT resource availability in under-privileged schools is inadequate. It achieves this by providing empirically supported affordances demonstrating how ICT-mediated instruction can bolster learner engagement with educational content.

We conceptualised the idea of 'affordances' as originally introduced by Gibson (1979) and later gained wider recognition through Norman's work in 1988. Gibson initially used the concept referring to what the environment offers an organism, highlighting the interrelatedness between the organism and its surroundings (Gibson, 1979). Based on this perspective, affordances pertain to the characteristics of a tool that enable various actions. Subsequently, Norman (2002) characterized affordances as "the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used" (p. 9). Norman tends to emphasize the perceptual abilities of users, which can be influenced by factors such as culture and prior experiences. He posits that if individuals cannot recognize the inherent affordances of a tool, they will be unable to utilize it effectively. We align with some scholars who suggest that affordances can develop through direct engagement with technology, often resulting in experimentation and adaptation that influence user interactions with these tools (Thapa & Hatakka, 2017; Moll et al., 2022; Aluko, 2021). From these perspectives, it is evident that the affordances offered by a technological tool are contingent upon users' perceptions shaped by their contextual circumstances.

This study focused on investigating the affordances associated with Autograph - a dynamic software application utilized for teaching various mathematics topics from pre-algebra to calculus (Kadir et al., 2022). Existing literature indicates that most research involving Autograph has centred on college-level mathematics education (Ramadhani et al., 2022; Morksin et al., 2018; Awortwe et al., 2019), while its applicability in primary or secondary education remains underexplored. In South Africa specifically, awareness and usage of Autograph among mathematics educators is minimal compared to other graphical software such as GeoGebra or Sketch Pad. This study aims to fill this gap by examining Autograph's role in teaching hyperbolic functions at an underprivileged rural high school in South Africa. Grounded in Activity theory, it investigates how utilizing Autograph enhances interactions among social components within an activity system linking learners (subjects) to content (object). Developed by Douglas Butler in 2005, Autograph is a free, open-source dynamic software that is gaining popularity within mathematics education. The application was designed to assist educators and students in visualizing mathematical concepts through dimensions related to probability and statistics, as well as

coordinate geometry and transformations in three-dimensional space (Wahyuni et al., 2020). Autograph can operate at two levels: 'Standard' for junior and senior high school students, and 'Advanced' for higher education. According to Erebakere & Agyei (2022), this software establishes a link between dynamic geometry systems and computer algebra systems, highlighting the interconnections among concepts in calculus, statistics, algebra, geometry, and vectors. Research indicates that Autograph enhances students' mathematical reasoning abilities (Batubara et al., 2020) while also enriching their learning experiences through engaging constructions, illustrations, and the identification of relationships (Ramadhani et al., 2020). Similar observations were noted by Erebakere and Agyei (2022), who pointed out the various opportunities it provides for students to learn mathematics in more interactive and exploratory ways. Additionally, the software's capability to represent mathematical ideas in multiple formats has been found beneficial (Sinaga et al., 2018). A study conducted by Karnasih and Sinaga (2014) emphasized that Autograph includes dynamic features that allow students to explore and assess perceived connections between mathematical concepts. Ahmadi et al., (2021) highlighted that enhanced interactivity offered by Autograph fosters an engaging learning environment where students become more active in discussions, express their opinions and can interpret mathematical data in the form of pictures or graphics.

This study was theoretically grounded on the Activity theory. The original iteration of Activity theory was based on Vygotsky's social constructivism educational ideas, which sought to represent learning in its contextual environment (Liu, 2023). The subsequent generation of Activity theory drew upon Alexei Leont'ev (1981) contributions, who expanded the theory by differentiating between *action*, *operation*, and *activity*. The third stage of Activity Theory is credited to Engestrom, who identified the interrelated elements of *subject*, *object*, and *tools* (mediating artefacts) within a complex social network that includes the *community*, *division of labour*, and established *rules* (Ke et al., 2023). Figure 1 below illustrates how the components of the Activity theory were applied in this study.

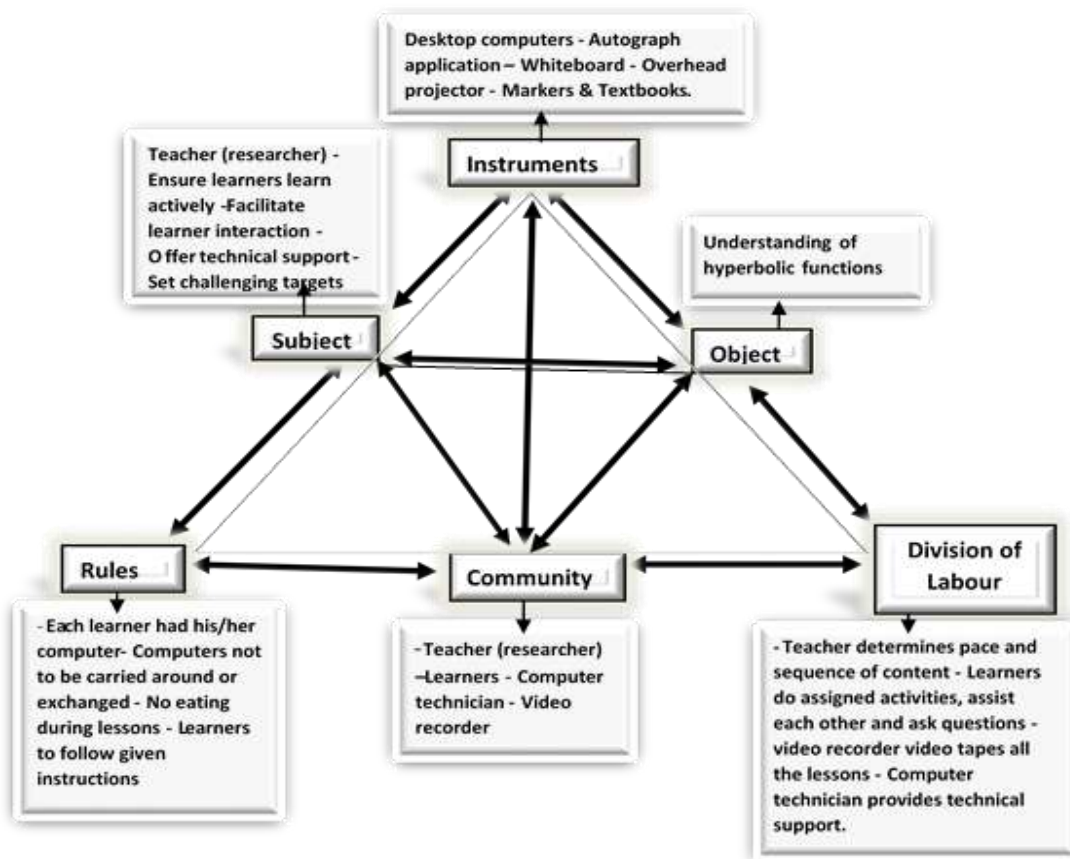


Figure 1. Theoretical Framework of the Study

In the above theoretical framework, the term *subject* pertains to the individuals engaged in a pedagogical setting (Loc et al., 2022). In this study, the subjects comprised the participating learners, the teacher-cum-researcher, lab technician, and a research assistant. The learners were recognized as distinct individuals with diverse learning needs and varying degrees of computer literacy skills influenced by their heterogeneous social backgrounds. Within Activity Theory, the object represents what individuals strive to accomplish in an activity system (Godino et al., 2024). Engestrom (1987) characterized the *object* as the problem space to which activities are directed. In this study's context, objectives included mastering concepts, completing learning tasks, and enhancing mathematical skills related to functions. The *instrument* (or tools) dimension encompasses tools or mediating artefacts (Vygotsky & Cole, 1978) that assist subjects in achieving their objectives and attaining results that would otherwise be unattainable (Godino et al., 2024). The instruments utilized in this study included computers, the Autograph application, whiteboards, projectors, markers, and textbooks.

In Activity Theory terminology, *community* refers to those actively participating in an activity system (Engestrom, 1987). In an educational context, community broadly includes schools along with students' parents and guardians; teachers; teacher unions; curriculum advisors; the Department of Basic Education (DBE); and other key stakeholders (Cole & Engestrom, 1993). For this study's purposes however, community specifically consisted of participating learners along with their parents or guardians; school administrators; technical support personnel; and teachers. The *rules* component signifies accepted norms and procedures regulating subjects' behaviours within an activity system (Maimaiti et al., 2021; Liu, 2023). For instance: learners adhered to general classroom guidelines as well as specific "dos and don'ts" for computer lab use while teachers were expected to exhibit mutual respect towards learners while complying with agreed-upon research ethics. Division of labour addresses how responsibilities are allocated among community members while managing power dynamics therein (Zaim et al., 2024). Traditionally defined roles have placed teachers in positions of authority for imparting knowledge whereas students are positioned primarily as recipients. However—as noted by Ke et al. (2023)—the integration of computers into classroom settings can significantly alter these conventional teacher-student dynamics.

Based on the discussion above, we realised that the slow uptake and minimal usage of available ICT resources for teaching in most South African schools is mainly because teachers hold negative perceptions on the usefulness of these technological devices. While the Department of Education is ceased with improving the availability of and access to ICTs in schools, there is very little empirical research that offers practical guidance to teachers on the usefulness and relevance of these technological tools, particularly in mathematics education. To close this gap, this study explored the pedagogical affordances of autograph technology in the teaching of functions to learners at a marginalised high school in South Africa.

METHOD

Research Design

The study used the qualitative case study research method, set up in the form of an inductive and discovery-based ethnographic research process focusing on local interpretations (Fergusson et al., 2020) of learners' learning experiences and actions during an autograph-mediated instructional intervention programme. The first author assumed the role of 'researcher-as-participant-observer' (Hagan, 2022) conducting a detailed qualitative study of the classroom activities.

Aim and Research Questions

The study sought to provide new insights and deeper understanding of the pedagogic possibilities and potentialities of the Autograph dynamic mathematical application in teaching functions within an underprivileged school environment. The following research questions guided the study:

1. What pedagogical affordances does Autograph technology offer in the teaching and learning of high school functions?
2. What are the implications of the Autograph affordances on optimizing the use of dynamic mathematical applications in the teaching and learning of functions?

Participants and Study Context

In this study, 13 Grade 11 learners (7 girls and 6 boys) at a rural high school in the Limpopo province of South Africa were conveniently sampled as the research participants. These learners were purposively selected on the basis that they were studying Pure Mathematics while the rest of the other Grade 11 learners at the school opted for Mathematical Literacy. The school was found most appropriate for the study because of the availability of computer resources. Compared to the other high schools in that Cluster, the school had relatively good ICT infrastructure in the form of a well secured and furnished computer lab equipped with over 50 computer tablets, 2 overhead projectors, whiteboard and other supporting ICT tools. All the computer tablets were installed with Autograph software through the assistance of the mathematics District Curriculum Advisor. Prior to the study, background information received showed that the learners had never been exposed to computers during their lessons in any of the subjects offered at the school. This was apart from the optional computer lessons that were done once a week in the afternoon after normal school learning hours, with the aim of imparting basic computer skills into Word. Only 5 of the participating learners confirmed to have attended the computer lessons at some point.

Data Collection and Instruments

Data collection was informed by an Autograph-mediated instructional intervention programme on the teaching of functions developed for the larger study. The intervention programme was developed by a team of teachers with extensive mathematics teaching experience and subject-specialists who serve as district curriculum advisors. The teachers had recently participated at a workshop on the integration of ICT in teaching and learning organised by the Limpopo Department of Education (LDoE). Besides reviewing and contributing to the instructional programme, the curriculum advisors also facilitated the installation of Autograph software on all computers that were to be used for the intervention programme. The intervention programme involved a pre-diagnostic test, two lessons to introduce Autograph to the learners, followed by six lessons on algebraic hyperbolic functions and a post diagnostic test. The activities took approximately two weeks and aimed to teach the learners how to draw and interpret algebraic hyperbolic graphs, as well as exploring the effects of parameters a , p and q on $f(x) = y = \frac{a}{x-p} + q$. Data was collected by observing learners in different pedagogical episodes including learner-learner interaction, learner-teacher interaction, learner-tool interaction, and learner-content interaction. The learners' experiences throughout the intervention programme and the way they construed their experiences were elicited through open-ended interviews. A post-diagnostic test was given after the instructional intervention had occurred.

Data Analysis

The primary aim of our data analysis was to reveal the educational benefits of Autograph technology as experienced by learners during the instructional intervention. Utilizing grounded theory (Glaser & Strauss, 1998), we adopted an inductive approach to data analysis, qualitatively examining the transcribed interview data and cross-referencing it with written observation notes from a reflexive journal and the students' written responses in their workbooks. The initial phase of our analysis involved initial coding (Strauss & Corbin, 1990). During this phase, we independently reviewed the transcribed interview data and lesson observation notes multiple times, identifying and emphasizing relevant words or phrases. Concurrently, we engaged in memo writing (Chametzky, 2023) to initiate the analytical process. The extracted terms and phrases were then utilized to inductively create a range of initial codes from the data. In the second phase, known as intermediate coding, we examined similarities and differences among the initial codes. This stage of the coding process was done by both researchers at the same time as we reflectively looked at each of the initial codes. This led us to group similar codes together into main categories. We then further evaluated and refined these main categories by exploring relationships and connections between them. The final stage involved advanced coding, which culminated in identifying themes represented as a collection of interrelated concepts. This coding process was repeated for each interview question while considering all participants' responses.

RESULTS

The coding procedure outlined in the previous section was carefully replicated for each of the three primary interview questions. While the oral responses to these questions were analysed individually, question by question, the codes identified along with the resultant categories and themes are interconnected. This interplay among the emerging themes provided fresh perspectives on developing an ICT-mediated pedagogical model proposed by this study. From the data, four themes emerged: motivation enabler, representational competency, class interactivity, and constraints. These concepts are indeed broad; however, the discussion surrounding them has been limited to the affordances present within the context of this study. As previously explained, these themes stem from learners' collective experiences, opinions, and perceptions regarding Autograph-mediated intervention lessons. The themes are considered crucial factors that may have facilitated or impeded learners' comprehension of concepts. Each theme is elaborated upon in further detail below.

Theme 1: Motivation enabler

The participants articulated what Mitchell (1993) referred to as *situational interest*, which is influenced by the characteristics of the learning environment and can manifest in both short-term and long-term forms. Situational interest is initially sparked by 'catch' factors, such as an engaging computer program or innovative teaching methods (Linnenbrink & Pintrich, 2002; Mitchell, 1993). In this study, the 'catch' factor was represented using computers alongside Autograph software. Throughout the instructional intervention, the learners visibly expressed great excitement and interest. Their excitement was evidently stimulated by the mere exposure to a computer for the first time. For example, when asked how they felt about the instructional activities, Mpho had this to say:

... I found the lessons very interesting because some of us, like myself, I had never lay my fingers on a computer, so I was so excited, and I learnt quite a lot during the lessons.

Responding to the same question, Mmathapelo provided a similar comment when she said:

Personally, I enjoyed the lessons very much. What I liked most was the drawing of graphs using the computer, it was amazing. ... I think it also helped us to gain some computer skills because computers are very important these days.

Given the socio-economic backgrounds of the learners involved, simply introducing computers into their classrooms served as a significant catalyst that heightened their interest in the lessons. Nonetheless, a drawback of these catch factors is their tendency to be more extrinsic and transient. To maintain sustained interest, Mitchell (1993) suggested incorporating 'hold' factors, which encompass fostering learner engagement with tasks and achieving content mastery—elements that contribute to continued learner motivation.

The hold factor was evident in our study when participants noted how computer usage assisted them in overcoming challenges they faced with traditional teaching methods. The following extract from Joel's response exemplifies this point:

Researcher : How do you compare your experience in sketching the graphs using freehand and by using the Autograph software?

Joel : You see, before using this application, we used to draw the graphs free hand. To me I found the use of computer much easier because it produces the graphs as they should be and very fast. When we draw with our free hand, we sometimes make mistakes, making it difficult to see how the graphs look like and difficult to understand them.

Joel's feedback highlighted a common concern among several learners regarding traditional graphing instruction that required them to create graphs manually. This method not only consumed considerable time, but it also involved complex calculations prone to errors and misconceptions. This confirms Ramadhani et al., (2020) who found that Autograph enriches the learning experiences by engaging learners in more interactive constructions, illustrations, and identification of relationships. The introduction of graph sketching applications alleviated some of these challenges, allowing learners

greater opportunities for exploring relationships and drawing conclusions. The characterization of Autograph-enhanced sketching of graphs as rapid, precise, and stimulating led to enhanced self-efficacy among the learners (Bandura, 1997). The sense of self-efficacy gradually generates increased effort, even when facing challenging tasks. As learners began recognizing improvements in their performance or understanding of content, they experienced a sense of accomplishment that motivated them toward further achievements. Figure 2 below summarises the variables discussed above under the theme motivation enabler.

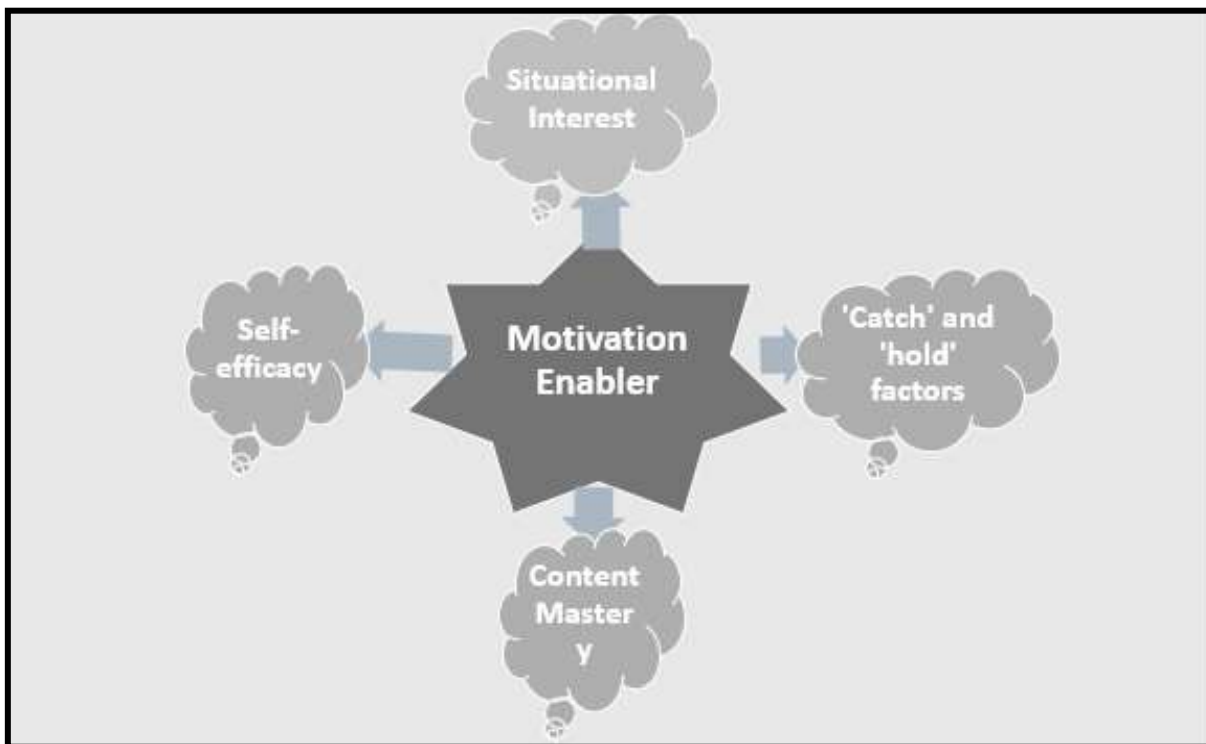


Figure 2. Autograph as Motivation Enabler

Figure 2 depicts that Autograph as a teaching tool possesses inherent motivational potential. What first sparked the participants’ interest was the mere introduction of a computer, which they were using for the first time in their learning (situational interest). This temporary ‘catch’ factor had to be sustained by the improved learner engagement with and mastery of content. These further lead to self-efficacy and more determination in the way in which learners interact with mathematical content. It is important to note that what arouses learner motivation is contingent upon context. In the context of this study, it was clear that merely introducing the software to the learners ignited initial interest among them. However, sustaining this motivation requires ongoing 'hold' factors such as increased content engagement and mastery and enhancing self-efficacy.

Theme 2: Representational Competency

Representational competency arose when learners articulated how they benefited from ‘seeing’ or ‘visualising’ the graphical representation of the functions and the transformational effects of the parameters a , p , and q . When asked to clarify exactly how the use of the graphical software assisted them to understand better, the learners provided following responses during interviews:

- Researcher : Can you tell me how the use of the graphical software assisted you to understand hyperbolic functions better?
- Pebetsi : I could easily see how the graph looks like ...
- Ricky : It made it easier for me to see the things I struggled to understand before ...
- Precious : I could see the graph moving left or right and up or down.

Oscar : I could see the graphs moving ...

These remarks from the students highlight the cognitive impact of visual representations. It is evident that by visualizing the graphical depiction of functions, learners were able to associate and relate the features of the graph to the function's equation. Using graph animations, students could also observe transformations applied to graphs in real-time. Research indicates that functions are intricate and multifaceted concepts that can be challenging for learners to grasp (Parhizgar et al., 2021), and no single representation can encapsulate all elements of the function concept (Anggiana & Kandaga, 2024). Nonetheless, visual representations, particularly graphs, may not effectively support students' learning if implemented incorrectly. Rau and Matthews (2017) warn that using multiple representations might lead to confusion among students instead of facilitating their understanding; this was reflected in this study when two learners expressed that they found the graphs perplexing. For instance, Precious remarked: 'Hmmm, at first those graphs were confusing to me. I could not differentiate them'.

Observations conducted during the intervention lessons validated the concerns raised by Precious. While most of the learners exhibited enthusiasm for generating graphs using the software, they faced difficulties in interpreting these graphs and answering related questions. Drawing on Rau and Matthews (2017), we identified two essential representational competencies that are crucial for unlocking the visual affordance of Autograph, namely *visual fluency* and *connectional fluency*. Visual fluency refers to the capacity to link a visual representation with its underlying concepts, enabling learners to discern meaning within them (Rau & Matthews, 2017; Rau, 2018). In this case, the learners had no difficulties in linking the graph to its equation, identify where the function is increasing or decreasing and the asymptotes. On the other hand, connectional fluency involves the ability to relate multiple representations and transition smoothly between them (Rau & Matthews, 2017). The factors under representational competency are as illustrated in Figure 3 below.

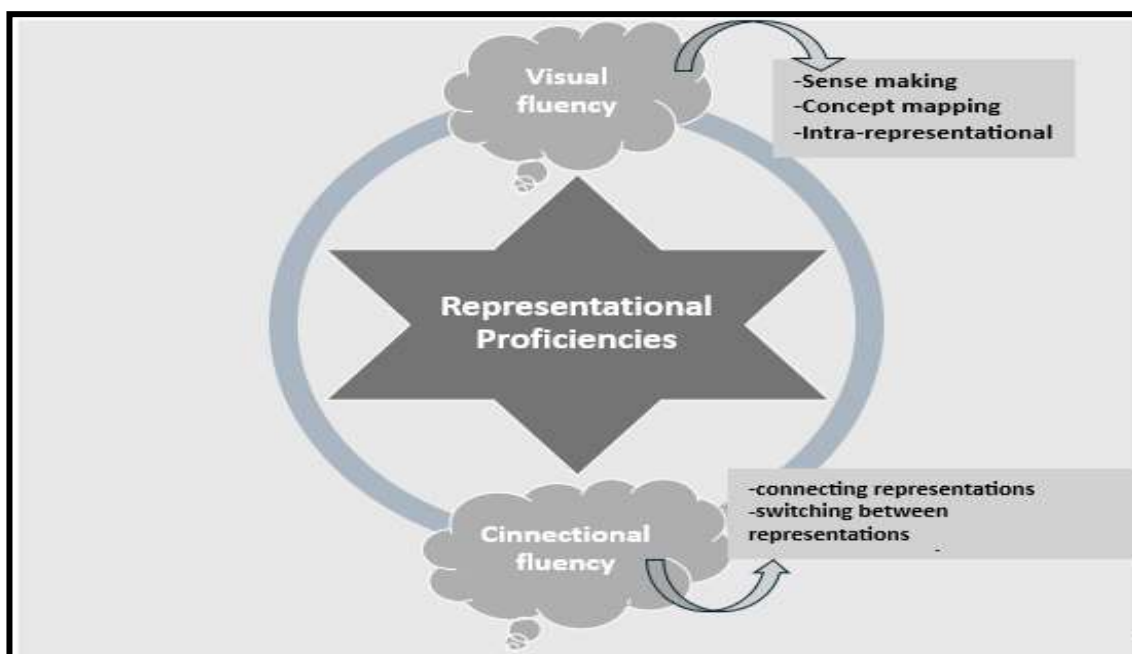


Figure 3. Autograph-Enabled Representational Proficiencies

Functions can be depicted in various forms, that is, algebraically, graphically, as ordered pairs, or through flow diagrams. The use of a graphical application like Autograph initially allows learners to see and visualise the different representational forms. This facilitates the ability to make sense of the concept(s) represented, creation of mental images and identification of intra-representational relationships. Once a strong visual fluency has been established, it leads to connectional fluency which empowers learners to perceive all these different representations as illustrating a single function. We

observed that by introducing learners to these varied representations through the graphical software, their ability to explain transformations acting on the functions improved. We therefore argue that Autograph presents efficient and effective opportunities for multiple representations of the function concept. However, learners need to be equipped with visual and connectional competencies to benefit from these representational opportunities. Teachers integrating graphical software in their classrooms should make conscious and targeted efforts to develop visual and connectional fluencies in their learners.

Theme 3: Class Interactivity

As alluded to in the theoretical framework of this study, the incorporation of technological tools introduces an additional intricate element to the already complex dynamics present in a classroom environment. At the centre of these complexities is the teacher, who is tasked with coordinating all aspects within the classroom to reach the intended educational objectives. Our examination of classroom interactivity is categorized into four distinct sub-themes: *technical interaction* (interaction between learner and tool), *pedagogical interaction* (interaction between teacher and learner), *conceptual interaction* (interaction between learner and concept), and *social interaction* (interaction among learners).

Sub-theme 3.1: Technical Interaction

Technical interaction refers to the engagement between the student and the technological tool, Autograph software in this case (Beauchamp, 2011). In the intervention sessions, each student was provided with a laptop that had Autograph software installed. Students worked independently on their computers on tasks which included creating graphs, making annotations, and applying transformations to those graphs. Although the initial two lessons focused on instructing students in using the software, several students encountered challenges during their interactions. Below are excerpts from the students' verbal feedback:

- Researcher* : *What challenges did you encounter in using the graphical software?*
Sekgobela : *At first, I had problems entering the equation onto the computer. I was always behind because I had forgotten how to enter the equation.*
Mpho : *I struggled a lot in the first lessons. I could not use the keyboard; I was very slow. I also struggled to use the eraser and the scribbler to draw asymptotes on the graph.*
Ricky : *What gave me a challenge in using the software was adjusting the scale and the axes before drawing the graph. It took me a long time to do it correctly.*

We noted that these students exhibited a lack of adequate technological skills related to both computer usage and software applications. When asked to express their feelings about this limitation, they described their experiences with terms like 'confused', 'frustrated', 'demotivated', and 'anxious'. Our analysis led to the conclusion that for effective technical engagement between the student and the ICT tool, possessing the necessary technical abilities is essential. Furthermore, we found that during technical interactions, certain learners—particularly those who were quicker and more adept with technology—tended to stray from the lesson's focus, diverting their attention to unrelated activities. Some engaged in taking selfies, while others uploaded music and images onto the computers or browsed the internet. Effective learner-computer interaction within the classroom necessitates vigilant supervision by the teacher, who must consistently reinforce the task or activity at hand.

Sub-theme 3.2: Pedagogical Interaction

Pedagogical interaction encompasses the engagement between educators and students. When prompted to share their thoughts on these interactions, most of the participants reported that they were satisfied with the clarity provided in the teacher's guidance, explanations, and visual aids. Notably, some learners praised the effectiveness of using a projector, stating that it greatly enhanced their learning experience. The following extract illustrates how Joel articulated this perspective:

- Researcher* : *Can you explain further what exactly you found most helpful in the way the teacher presented the lessons.*

Mmathapelo : *Personally, what I found very helpful from the teacher's explanation was the use of a projector. It was very easy to follow what the teacher was saying because I could see it on the whiteboard. It made it easy for me to use my computer as I could easily follow the teacher's demonstrations.*

From a social constructivist viewpoint, traditional whole-class instruction is often viewed unfavourably due to its emphasis on teacher dominance and student inactivity. Nevertheless, the incorporation of technological tools such as computers, projectors, and whiteboards can enhance engagement by capturing students' interest, providing visual stimuli, and directing attention toward specific concepts. During interactions with individual learner or small groups, some expressed concerns about not receiving timely assistance from the teacher. This feedback aligned with observations made during our reflections on the lessons. It became evident that as students become more involved in their learning processes, they require increased individual attention. The interaction between learners and technology naturally fostered a more personalized teaching approach, revealing distinct challenges that each student faced and required resolution. Research has consistently shown that integrating ICTs requires teachers to be more creative, proactive and innovative, which is perceived by others as increased burden of classroom management on teachers (Chuaungo et al., 2022), a challenge frequently mentioned by educators as a reason for their hesitance to utilize ICT in their teaching environments (Vandeyar, 2015; Abel et al., 2022)

Sub-theme 3.3: Conceptual Interaction

We perceived conceptual interaction as the engagement that takes place between learners and the targeted ideas or concepts. Many learners confessed that they faced difficulties at first in understanding how the parameters a , p , and q influenced the graph of a hyperbolic function. Additionally, an examination of the errors made by learners in the bigger study indicated that these mistakes primarily arose from the learners' inability to connect the algebraic equation with its corresponding graph. The use of graph animation enabled learners to see changes on the graph in real-time as they adjusted the parameters. Responding to the question on whether the use of Autograph assisted to clarify some concepts that were not clear to them before, Ledwaba remarked:

You see when you change the values of a on the computer, you can see the graph changing quadrants. Even with the values of p and q , you could see the graph moving to the left or right. It helped me because at first, I did not understand it at all.

The challenges associated with function transformation and graph interpretation have been recognized as significant obstacles for learners engaging with functions in general. In this study, the graphical activities facilitated by Autograph allowed students to explore function concepts from both graphical and algebraic perspectives almost concurrently, thereby improving their relational skills. Nevertheless, during the ICT-integrated teaching activities, discrepancies arose between the teacher's objectives and the learners' perceptions of the activity's goals. For instance, while the teacher intended to guide students in recognizing patterns and forming hypotheses through sketching graphs with Autograph, many students regarded graph drawing merely as a final task. In some instances, after completing their graphs, students would easily divert their attention to unrelated activities on the computer that were not pertinent to the lesson's focus.

Sub-theme 3.4: Social Interaction

Social interaction was conceptualised as any significant engagement that occurred between individual learners or within group environments. Typically, such learner-to-learner interactions were initiated by the students themselves at various moments throughout the lesson. Notably, even during instances when learners were expected to work independently on their computers, social exchanges continued as they compared their graphical outputs and offered technical help to one another in the teacher's absence. Observations from intervention lessons indicated that computer use among learners significantly encouraged social interactions. Furthermore, during whole-class instruction, students frequently sought to compare their own computer displays with what the teacher was demonstrating or projecting.

When asked for their thoughts on how these interactions with peers benefited them during the lessons, the responses from learners varied widely. Mmathapelo and Pebetsi gave the following responses:

- Researcher* : Did you benefit anything from your interaction with other learners during the lesson activities?
- Mmathapelo* : My colleague helped me a lot. You see, I was struggling a lot in completing the activities. Each time I got stuck, my colleague would stop whatever she was doing to assist me. If both of us got stuck, then we would call the teacher to assist us.
- Pebetsi* : As for me, I had no problem in drawing the graphs. However, the graphs were very confusing to me at first. They were too many and could not see the difference between them. My colleagues helped me a lot because when we answered the questions during the activities, they explained to me how to differentiate between the graphs.

From the social constructivist perspective, the above accounts highlight the significance of 'more knowledgeable others' (MKOs) in promoting cognitive development within a learner's zone of proximal development (Twetwa-Dube, 2024). In this context, Autograph facilitated social interactions, which enhanced both technical and conceptual exchanges. This observation supports the idea that the MKO in a classroom does not solely refer to the teacher, especially when incorporating new technological instruments. The challenge presented by this 'rich' educational environment for teachers is to effectively manage social interactions so that they remain meaningful, productive, and focused on tasks. The intricate relationship between Autograph as a teaching tool and classroom interaction is encapsulated in Figure 4 below.

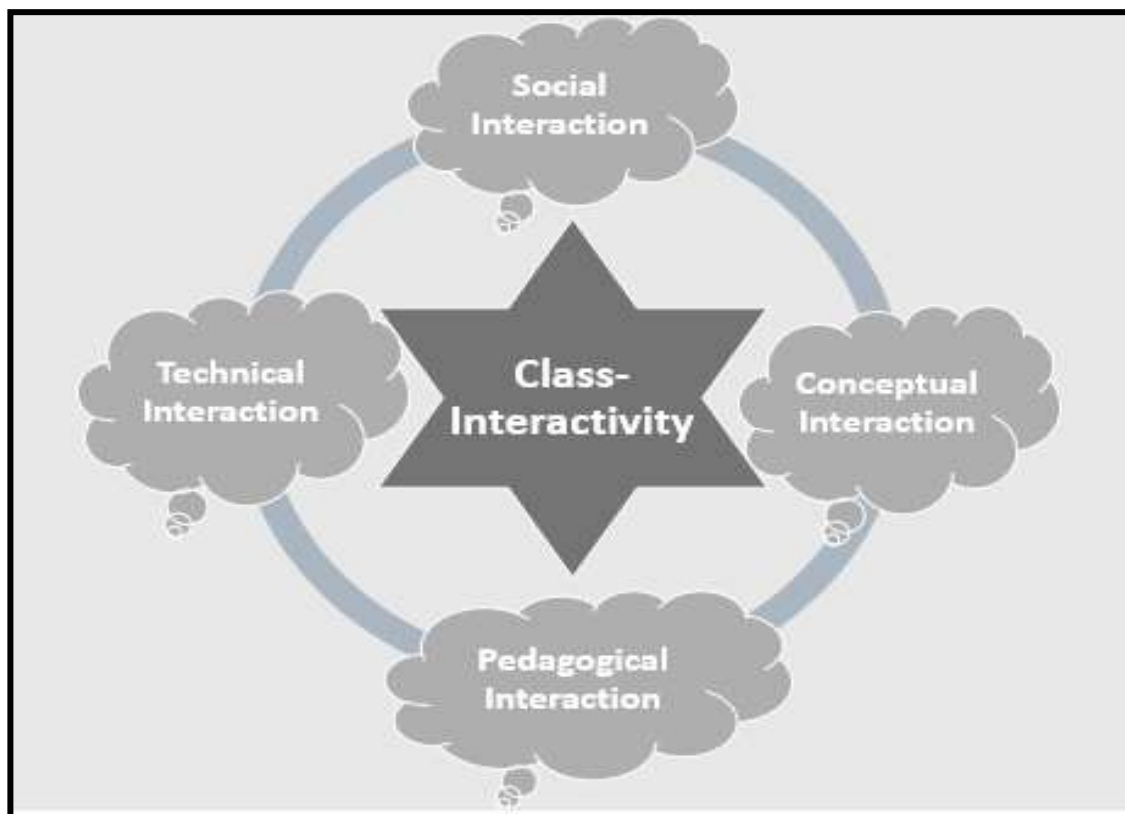


Figure 4. Autograph as an enabler of class interactivity.

As illustrated in Figure 4 above, we found that while Autograph enhances and enriches classroom interactivity, it is essential to ensure that all other elements involved in the pedagogical activity are appropriately balanced and monitored to meet the desired objectives. For instance, ineffective interaction between learners and the ICT tool (technical interaction) can hinder progress towards achieving these goals. Likewise, if the mediational tool is not utilized in a way that fosters peer-to-peer interaction among learners, overall learning will be limited and constrained. It is key to note that the interaction between learners and the tool is not an end itself. Rather, at the centre of the pedagogical activity is the mathematical concept or skill to be acquired by the learner. The teacher has to carefully orchestrate all the different dimensions of classroom interactivity to achieve the intended objective.

Theme 4: Constraints

Our understanding of constraints was shaped by Kennewell's (2001) assertion that constraints are intrinsically linked to affordances. Kennewell posits that while affordances represent the characteristics of an environment that enable potential actions, constraints denote the conditions and interrelations among these characteristics that provide a framework for guiding actions. Therefore, both affordances and constraints are essential and complementary for any activity to occur (Chen et al., 2024). In this study, a constraint was viewed as any factor that hinders progress or complicates the achievement of desired goals. To navigate these obstacles, specific courses of action must be adopted. From the various affordances discussed previously, several constraints arose from those possibilities. Below, we will outline some of the identified constraints and their connection to each of the affordances.

One notable affordance identified using Autograph technology was motivation. This motivation stemmed largely from situational interest generated simply by utilizing computers as an engaging element. As mentioned earlier, this interest emerged from the learners' contextual backgrounds, with many experiencing computer usages for the first time. This situation became a constraint since it led to the disconnect between the teacher's objectives and what students perceived as the focus of their educational activity. Once quicker learners completed their graphing tasks, they often deviated into exploring unrelated content on the computers. When one of the participants was asked to elaborate on the distractions she experienced during the lessons, she had this to say:

Researcher : *Can you tell me more about some of the distractions you experienced during the lessons?*

Mpho : *Sometimes my group mates were disturbing me. They were not focused at all. Instead of looking at the given questions for discussion, they started looking at photos, taking pictures, and playing games using the computer. This made us miss some of the explanations and illustrations given by the teacher.*

We determined that if this contradiction is not adequately addressed and resolved, it could hinder learners' ability to discern patterns or relationships among concepts and to formulate conjectures. Some constraints were of a technical nature. The discourse surrounding technical interactions indicated that learners faced multiple technical challenges during the initial two or three lessons. They lacked adequate proficiency in utilizing the Autograph software, which posed difficulties as some learners found themselves focused on understanding the technology rather than leveraging it for learning purposes. Consequently, we recognized that when designing and preparing an ICT-mediated lesson, the technical skills of both educators and students are essential factors to consider. The way a teacher coordinates all elements within an ICT-mediated classroom can impose pedagogical limitations on learners. The introduction of new technological tools brings forth distinct challenges and individual variances among students. It is crucial for the teacher to strike a balance between addressing each learner's needs and achieving the educational goals set for the activity. Constraints should not be perceived merely as obstacles or deterrents to incorporating ICTs in education; rather, they are fundamental aspects of ICT-mediated teaching that offer structure and direction for subsequent actions. As users of digital technologies face these constraints and work towards overcoming them, they ultimately cultivate more efficient and effective practices that lead to improved results.

Optimising technology affordances in a classroom

This study revealed the opportunities and capabilities that Autograph technology offers educators to consider in their planning and preparation for instruction facilitated by information and communication technology (ICT). As previously mentioned in our discussion of affordance, it is not merely the characteristics of technology that affect learning; instead, it is the way in which these distinct attributes and possibilities are utilized by the teacher to create various learning experiences. Drawing from the affordances identified in this study, we propose a framework aimed at maximizing the effectiveness of mathematical digital software within a classroom setting, as illustrated in Figure 5 below.

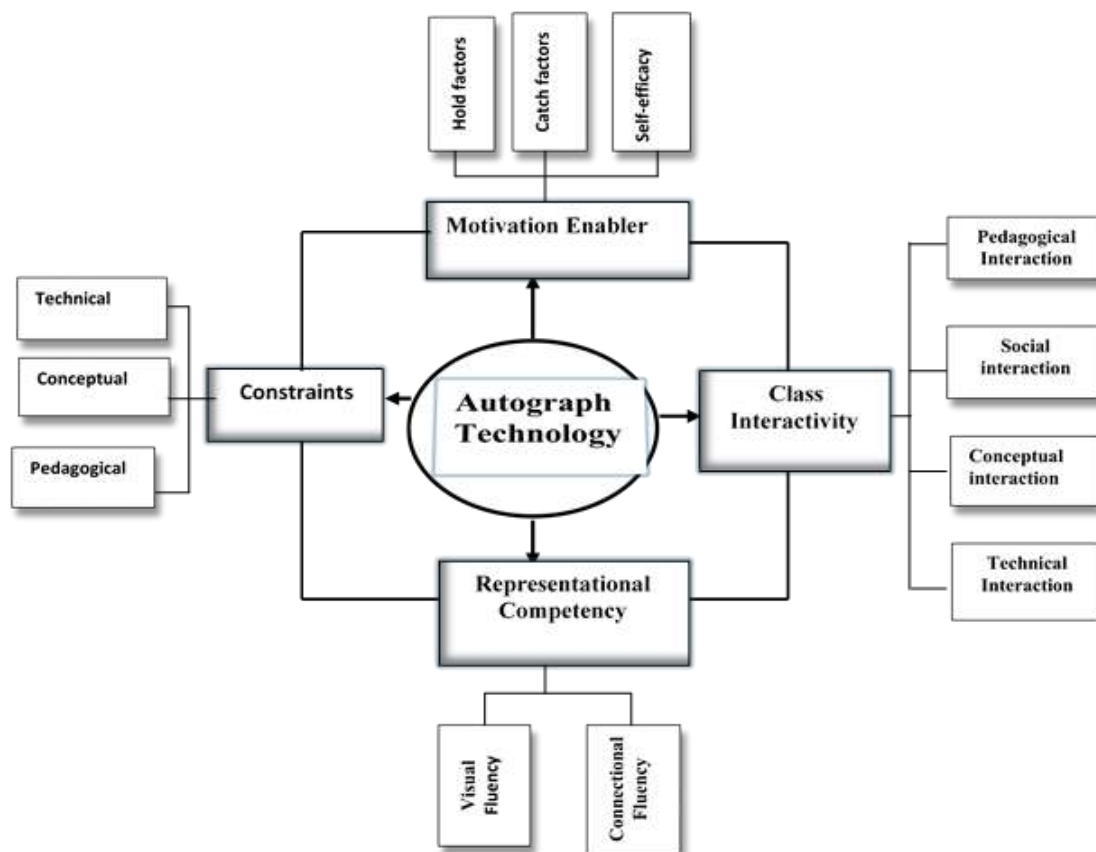


Figure 5. A model of Autograph affordances in a classroom setup.

The research was structured and influenced by several factors, including the accessibility of ICT resources (such as computers, projectors, whiteboards, and software applications), the socioeconomic status of the students, and the existing school infrastructure. These contextual elements significantly impact classroom organization and management, which in turn affect the possibilities provided by technological tools. The study found that Autograph technology serves as a powerful motivation enabler for learners. This result aligns with various other research findings (Akinoso, 2023; Padayachee, 2017; Prianggono et al., 2023; Adeel et al., 2023). This study further established that technological devices stimulate two distinct levels of motivation. The first is situational interest, generated simply by introducing a new technological innovation. This type of motivation is extrinsic and short-lived, potentially leading to distractions as learners may concentrate more on the tool than on the intended concepts. The second level is competence motivation, which arises when utilizing a technological tool enhances understanding and self-efficacy in content mastery. Studies have shown that self-efficacy has a significant effect on students’ learning outcomes in mathematics (Sari & Lutfi, 2024). When digital tools help learners reach advanced levels of comprehension, this motivation becomes more enduring.

Additionally, representational competency was identified as another intrinsic benefit of using Autograph. Students emphasized how visualizing graphical representations of functions, and their

transformations enhanced their learning experience. Previous literature has established that the capacity to represent concepts through various formats and to transition between them fosters richer connections and deeper conceptual understanding (Maharjan et al., 2022; Moll et al., 2022). This study further underscored that students must develop representational competencies to effectively interpret multiple representations. We outlined two essential skills, namely, visual fluency and connectional fluency. Visual fluency refers to an intra-representational skill enabling students to understand visual information—such as identifying intercepts or asymptotes in graphs. On the other hand, connectional fluency encompasses trans-representational skill allowing students to relate different representations together effectively. Without these competencies, exposure to multiple representations can lead to confusion rather than productive learning.

While this study corroborates previous research findings which established that Autograph enhances students' reasoning capabilities (Batubara et al., 2020), makes the pedagogic context more interactive and explorative (Erebakyere & Agyei, 2022) and enhances more discussion (Ahmadi et al., 2021), it further found that utilising Autograph makes class management more complex and dynamic. Depending on the context, we examined how this software affects various classroom dynamics aimed at improving learning outcomes efficiently. Drawing on Rau and Matthews (2017), we examined class interactivity based on four interconnected components, namely: technical (learner-tool), pedagogical (teacher-learner), conceptual (learner-content), and social (learner-learner) interactions. We established that, for effective use of dynamic tools like Autograph, teachers need to ensure that students have the necessary technical proficiency to engage with the tool, and the discipline to remain focussed on the task at hand. Moreover, we observed that increased learner engagement inevitably necessitates greater individual attention from educators who need to address unique challenges presented by each learner's interaction with technology. In the South African context, where learner-educator ratio is too high (Zenda, 2020), this may be limiting factor to the effective use of the software. However, teachers need to be conscious and remain attuned to these dynamic needs while managing them appropriately. Furthermore, it has been found that Autograph enables diverse forms of collaborative interaction with subject matter at a pace suitable for each learner's preferences. However, it is crucial for educators to realise that students often lack technical discipline and may use digital devices for non-educational purposes. Their engagement with such devices in an educational context should be purpose-driven and carefully monitored.

CONCLUSION

This study aimed to unveil the advantages offered by using Autograph technology as an instructional tool for knowledge construction in teaching functions based on student experiences gathered during an intervention program. Based on the activity theory, whose roots are grounded in the socio-constructivist learning framework, we concluded that aligning successful integration of technological tools within educational contexts is pivotal for effective teaching-learning environments. The affordances associated with Autograph were categorized into themes including motivational support mechanisms; representational proficiency; classroom interactivity dynamics; alongside inherent constraints impacting pedagogical practices positively despite challenges faced within digital contexts themselves. Although confined specifically to the use of Autograph software, the findings may be applicable broadly across similar mathematical graphical applications. The study suggests opportunities and possibilities available to mathematics educators aiming at maximizing their usage of dynamic mathematical applications, while acknowledging their inherently fluid nature shaped by situational variables involved therein. This research was conducted at a rural high school located in a marginalized area of Limpopo province in South Africa. As a qualitative case study, the study's small sample size and certain contextual factors limit the ability to generalize its findings across other settings within South Africa or elsewhere internationally. Although focused specifically on Autograph's pedagogical advantages, these findings may extend similarly to other dynamic mathematical applications used for teaching functions. The primary author played multiple roles—researcher, developers, evaluator—and teacher during this investigation; some critics expressed concerns regarding potential bias stemming from this duality in role involvement during design and evaluation phases. To mitigate possible biases

in research outcomes, feedback was sought from co-authors and fellow researchers along with mathematics instructors and subject specialists. Finally, we propose further research on the effectiveness of using Autograph software in the teaching of other problematic mathematical topics such as Geometry and Measurement.

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