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Understanding Two-Point Tangent-Curve Contact using JavaScript

Bed Prasad Dhakal,PhD
Central Department of Education, Tribhuvan University
Email: bed.dhakal@cded.tu.edu.np
ORCID ID: https://orcid.org/0000-0002-1510-5046

Abstract

This participatory action research (PAR) study investigated the design and implementation of JavaScript integrated Virtual Learning Environment (VLE) to enhance students' conceptual understanding of "tangent-curve contact". The study is conducted at Tribhuvan University in a course "Differential Geometry" during May–Sept 2024. The participants of this study were thirteen students, and the study followed four iterative cycles: 2D Javascript visualization of tangent contact, Javascript visualization of osculating circle, 3D JavaScript visualization, and Moodle based quiz as assessment. The study found that JavaScript visualization helped students in building a deeper understanding of the concept of tangent-curve contact.

The findings highlight the pedagogical value of interactive visualizations within VLE and provide insights for technology integration in higher education, to implement evidence-based practices.

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Introduction

Learning mathematics are showing numerous innovative and pedagogical opportunities, such as spaced retrieval practice (Hopkins et al., 2016), Coherently organized digital exercises and expositions (Sangwin and Kinnear, 2022), active learning (Freeman et al., 2014) and number of similar initiatives (Johnson et al., 2023; Fredriksen et al., 2024; Ma et al., 2014; Radmehr, 2024; Rogers and Long, 2025). This is also realized in a course" Differential Geometry" while teaching it to master students at Tribhuvan University. This course (Pundir et al., 2021; Koirala and Dhakal, 2024) primarily involves the analysis of curves and surfaces in 3-dimensional space, focusing on applying calculus results to investigate their intrinsic and extrinsic properties. While fundamental calculus concepts like limit, derivative, and integration are building blocks for this course.

It is said the traditional mathematics teaching often render passive learning. For example, "the abstractness and multi-dimensional nature of mathematics is difficult to render through traditional teaching, also called passive learning (Freeman et al., 2014), which are also inadequate for fostering a deep and intuitive conceptual understanding. For instance, visualizing tangent lines and its order of contact with the curves, is found difficult when students relying solely on textbook explanations, which is often coded as passive learning (Freeman et al., 2014). I experienced similar phenomenon during teaching at university. So, this research seeks, how to promote active in learning, particularly using digital simulations like javascript and videos to edify mathematical abstractions.

It is said that "universities are gradually using and integrating digital technologies to complement their traditional on-campus teaching" (Sangwin and Kinnear, 2022). Among several, some of the emerging practices are Virtual Learning Environment (VLE). The use of VLE have opened new avenues to deliver educational content through dynamic, interactive and simulated learning resources. VLEs are online learning environments designed to facilitate students learning anytime anywhere.

The use of LMS (Learning Management System) for VLE can be done through deploying certaing pedagogical steps like; "organizing learning contents through curriculum mapping, selecting learning objectives, developing learning resources, designing learning activities/sssignments, organizing learning communication and discussion, providing learning feedback and support, and conducting learning assessment/evaluation" (Dhakal, 2023).

This VLE and LMS based environment possess the capacity to provide flexible, accessible, and personalized learning experiences, accommodating diverse learning styles, including visual and kinesthetic learners who benefit significantly from interactive and graphical content. The integration of dynamic and interactive elements within VLEs thus emerges as a promising approach to address the limitations of traditional teaching methods (Dhakal, 2016; Dhakal, 2025). In this research, Javascript visualizations were integrated into the Moodle as VLE, through a custom HTML pages.

As discussed in a literature (Johnson et al., 2023), flipped learning has provided increased active learning and opportunities and targeted feedback. In similar manner, this paper explores how technology integration fostered innovative teaching methods and examines their influence on mathematics learning. Specifically, it presents a framework for structuring educational content in online environment with interactive simulations. This framework, hereby referred to as "Javascript integrated VLE", goes beyond the simply organizing digital learning materials with text, videos and quiz, as discussed in (Sangwin and Kinnear, 2022), it also connects learning contents with dynamic and interactive simulations, which is also an indicator of connectivism (Mukhlis et al., 2024) and active learning (Freeman et al., 2014), which involves students actively involved in the learning process through interactive tasks, rather than having them simply observe and listen to an expert as in passive learning (Freeman et al., 2014).

Problem Statement

Taangent line is defined as a line that touches a given curve at a single point. The slope of tangent line is defined as derivative of a function representing the curve at that specific point. Both concepts are foundational in calculus. This definition typically does not impliy that tangent line intersects the curve at any other point than tangency. However, in differential geometry, this single point cntact notion becomes insufficient to describe all forms of curve-line interactions, to study build upon concepts like osculating plane, osculating circle, osculating sphere etc.

In this article, the phrase "tangent has two point contact", refers a scenarios that challenge students basic understanding of tangency. First, it can refer to a single straight line being tangent to a curve at two separate, distinct points simultaneously. This phenomenon is possible for certain non-linear functions, such as higher-order polynomials, and its analysis often involves finding specific critical points related to the slope of the line joining two variable points on the curve. Second, the phrase can describe “higher-order co11111ntact” or ”osculation.” This occurs when a geometric object, such as a line, circle, or plane, approximates a curve with exceptional closeness at a single point.

An osculating circle, for example, is defined as a circle that passes through a point P on a curve and a pair of additional points infinitesimally close to P , effectively representing an infinitesimal “two-point contact” or even higher orders, indicating a much tighter approximation of the curve at that single point (Pund1ir et al., 2021; Koirala and Dhakal, 2024).

Students often encounter significant cognitive struggle in limit, such research work are shown by number of literature (Slavíčková, 2021; Sulastri et al., 2021; Erol and Saygı, 2024). I have also experienced similar cognitive struggle on students in distinguishing and conceptualizing these two-point-contact forms of tangency, as they require spatial reasoning and a grasp idea of limiting processes.

Research Question

The aim of this study is to improve the conceptual understanding regarding tangent-curve contact through the design, implementation, and evaluation of digital tools. For this design and implementation of an interactive Javascript integrated VLE is used to represent the concept of tangent-curve contact, to answer the research question

What are the students’ views and perceptions towards tangent line and order of contact, and how did they change throughout the intervention?

Theoretical Foundation

This Participatory Action Research (PAR) is based on qualitative research methodology characterized by a collaborative partnership between researchers and participants, who actively engage in all stages of the research process: defining problems, developing questions, gathering and analyzing data, and formulating recommendations (Lawson et al., 2015; McNiff and Whitehead, 2012). A central tenet of Jean McNiff’s approach to

PAR provide a research space to the practitioner as an “insider researcher” (Lawson et al., 2015; McNiff and Whitehead, 2012). This means that researcher actively investigate and evaluate their own professional practice with the explicit goal of generating “personal theories of practice” aimed at continuous improvement. This PAR method places an emphasis on personal accountability to be an erhicical researcher to justify knowledge claims. The focus of the claim needs to be rigorous and transparent.

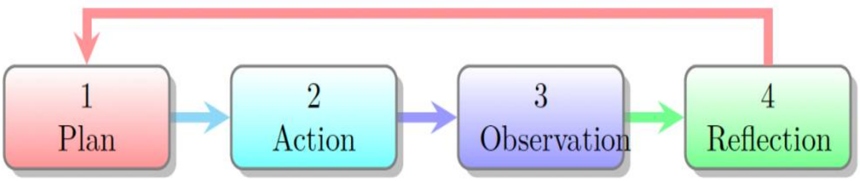


Figure 1 Cycle of Action research

Based on the premises, this study has adopted McNiff's iterative PAR cycle, which is "action-reflection" as a core methodological framework of PAR (McNiff and Whitehead, 2012). In this PAR the cyclical process served as dynamic and ongoing research entities. This allows researcher to execute research with continuous adaptation and refinement of intervention based on experience and outcomes. So, P-plan, A-Action, O-Observation, R-reflection (PAOR) is deployed in this research.

Methods

This study is based on qualitative action-research method, structured into four iterativecycles. The cycle is A-Action, O-Observation, R-reflection (PAOR). It was designed based on observations and reflections. As mentioned, the core principles of PAOR are the extension of of participation, participating both researcher and respondents as co-researchers acted with "insider researchers" (Lawson et al., 2015). This continuous re-designing process allowed for adaptation and refinement of pedagogical intervention for more engaged and better interactive learning environments. The iterative methodology was fundamental to improve learner's conceptual understanding using javascript based animations, simulations and VLE.

This study is based on Tribhuvan University, Faculty of Education, Centreal Department of Education, a leading teacher education institute in Nepal. In this study, the participants were thirteen master students (five girls and eight boys) taking a course Math Ed 537: Differential Geometry during 2024 academic year. The literature mentioned that small size sample is sufficient in qualitative study because it prioritizes in-depth engagement and the collection of rich and thick data (Lawson et al., 2015; McNiff and Whitehead, 2012; Creswell et al., 2018; Denzin and Lincoln, 2018). In this research this qualitative approach allowed researcher for close observation of learning processes ensuring intented conceptual understandings, overcoming the perceived challenges of students.

In this study, data were collected through observation checklist, feedback questionnaire and researcher's self reflection as "insider" of research process. The triangulated among these data source was done as methodological principles of action research (Creswell et al., 2018; Denzin and Lincoln, 2018; Lawson et al., 2015; McNiff and Whitehead, 2012). Observations were conducted during students' interactionswith both JavaScript-based visualizations and Moodle lessons-based classroom interactions. This observation was focused on capturing evidence of student engagement, and dentifying conceptual confusios/clarity. In addition to this observation checklist, feedback questionnaire was used for informal and open-ended prompts to make learning experiences better.

In addition, as a researcher I have maintaineda a reflected journaling during the research period. This journling captured evidence and progress, pedagogical designs, and implementation opportunities and challenges.

Results and Discussions

In ordinary geometry, tangent line is defined as straight line that passes through a given curve touching at a single point. The slope of such tangent line is defined by the first derivative at the point of contact. While advancing this concept in calculus, tangent line is defined as limiting position of a secant line, when two points approach each other, where secant line is defined as a straight line passing through two points of a given curve.

The initial warm-up questions revealed students' conventional, often limited, understanding of a tangent: "How do you define tangent line at a point in a curve?", "How many tangent line exists (if any) at a point in a curve?", and "what is number of contact points between curve and tangent?".

Students initially defined a tangent as "a straight line that touched a given circle exactly once" or "a straight line that passes through exactly one point of given curve". However, when discussions shifted to space curves and multiple lines passing through a single point were visualized using a JavaScript (see Figure 2), students became visibly confused. They struggled to ascertain if multiple tangent lines were possible or if the tangent is uniquely determined.

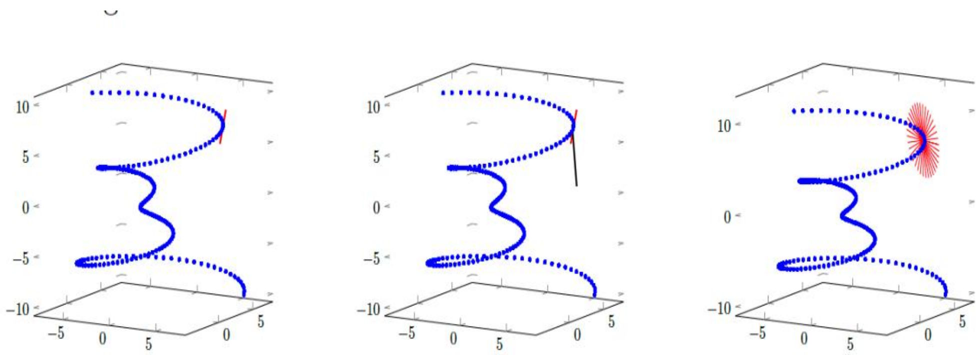


Figure 2: Various lines passing through a single point on a space curve

The textbook version of tangent line is "given C: $\vec{r}=\vec{r}(t)$ be a space curve. Also, let A and B be two nearby points on C corresponding to the parameter values t and t + δt respectively. Then tangent at A is the limiting form of secant line AB as B → A or δt → 0" (Pundir et al., 2021; Koirala and Dhakal, 2024).

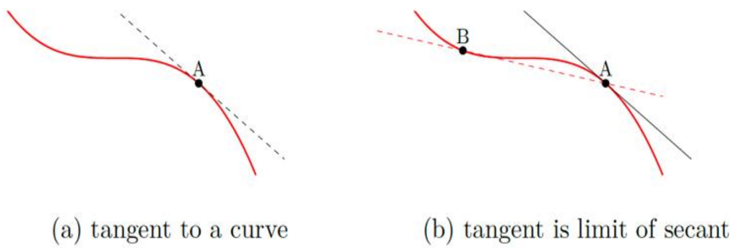
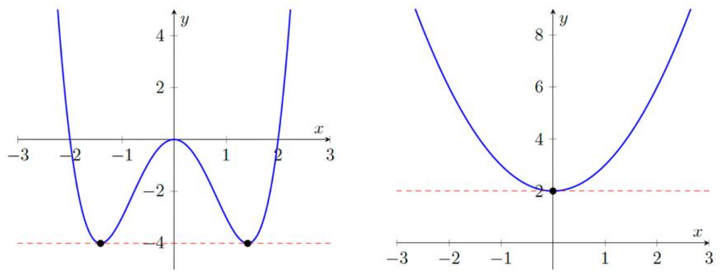


Figure 3: understanding tangent as B → A

After a facilitated discussion using the first visualization (see Figure 3), like an active learning (Freeman et al., 2014), students revised their versions of the definition of a tangent. Very few (2 of 13) posited that "there are infinitely tangents at a point in a space curve," while others (11 of 13) insisted "there should be exactly one tangent, no matter whether a curve is plane or space". This discussion showed that it is harnessing the full facilities of contemporary technology in educational pedagogy (Sangwin and Kinnear, 2022).

Based on the discussion, the concept “tangent has two-point contact at the point of contact” extends beyond the ordinary definition. This extension provided a space of encapsulation of the tangent curve relationships. Student also dicussed that for certain higher-order polynomials, a straight line can be tangent to the curve which touch at two separate and distinct points on the curve simultaneously. This phenomenon deviates the common intuition derived in “tangent-point-curve” relationships. So, a simpler function like parabolas is introduced and with JavaScript simulation, the “tangent-point-curve” Is discussed showing that tangent touches at only one point of the curve, but of order 2.



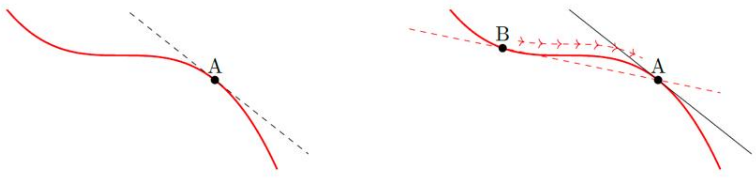
(a) tangent to $x^4 - 4x^2$ at $x = \pm\sqrt{2}$ (b) tangent to $x^2 + 2$ at $x = 0$

Figure 4: understanding about two-point contact

This confusion in student’s learning prompted immediate reflection to the researcher and led to an PAR intervention of cycle 1.

Cycle 1: JavaScript Visualization (2D)

The first cycle of this participatory action research involved the design and implementation of interactive 2D Javascript visualizations of tangent line. These visualization illustrated fundamental concepts of tangent lines, such as, limit of secant lines, where two points on a curve gradually converge , and the concept of standard single-point tangency emerge, where a line touches a curve at precisely one point. For the development of these interactive visualization.



(a) tangent to a curve (b) tangent is limit of secant

Figure 5: understanding tangent as B → A

During observation, students appeared engaged, performed active learning, and provided preliminary feedback indicating that the visual clarity was helpful to understand tangent line. This cycle revealed that 2D visualizations were effective in reinforcing foundational concepts of tangency, saying that it is limiting position of secant, and it is uniquely determined.

Through continued discussion and guided exploration, students began to identify the term "imit" as central to defining a tangent, a part of active learning (Freeman et al., 2014). This led to a revised definition: "tangent is limiting position of secant line taking two points of the curve". The dynamism is demonstrated by dragging point B along the curve towards point A in the JavaScript applet. This visualization with hands on touch-feel experience, it showed that "secant line is transforming into the tangent line" addressing the concept of limit through "tangent-point-curve relationships".

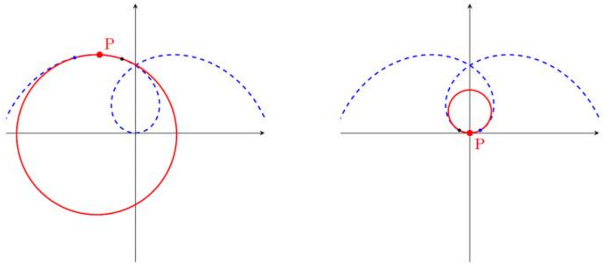
Despite this learning progress, some of the students still questioning to accept the fact that "tangent has two-point contact with the curve". They feel odd saying that "we learnt that tangent has one point contact with the curve, which is knwn as point of contact". The confusion is likely because due to the lack of such explicit discussion or explanation statement in textbooks. This ongoing difficulty level of learner became a critical point for further action. To reinforce this concept, the intervention proceeded to explore the concept of the osculating circle using JS visualization.

Cycle 2: JavaScript Visualization of Osculating Circle

In this cycle, the warm-up questions was "what should be the nature of three points to determine a triangle?", "Is it possible to circumscribe any kind of triangle by a circle?", and "Is circle a plane figure, even if it is drawn in three dimensional space?".

This concept describes a situation where a curve and another geometric object (such as a line, circle, or plane) have an exceptionally close "kiss" at a single point. Beyond simply sharing the tangent direction (referred to as 1st-order contact), they may also share the same curvature (2nd-order contact), as exemplified by an osculating circle.

An osculating circle is defined as the circle passing through a point P on the curve and a pair of additional points infinitesimally close to P. This can be interpreted as an infinitesimal "three-point contact" or even higher orders of contact, indicating that the curve and the osculating object agree on multiple derivatives at that single point, leading to a much tighter approximation of the curve's local behavior.



(a) osculating circle at $t = -2$ (b) osculating circle at $t = 0$

Figure 6: understanding osculating circle and point of contact

JS (javascript) visualization allowed students to manipulate parameters and visualize the behavior of secant lines approaching a tangent, or the tangent itself, through graphs. This hands-on and active learning approach as discussed in (Freeman et al., 2014), promoted estimation, hypothesis formation, and experimentation, leading to more meaningful learning concept. This graphical simulation became effective for explaining the core concepts of tangents, showing that "tangent may have two point contact".

For example, the JS exploration dynamically demonstrated the “osculating circle at P as limiting 1position of a circle passing through three points, say P, Q, R on a curve as Q, R approaches to P (Pundir et al., 2021; Koirala and Dhakal, 2024). The visual representation of the circle changing size during this process prompted further inquiry from students, leading to discussions about the dynamics of the o1sculating circle. This exploration, combined with connecting the visual experience to concept definitions from textbooks, convinced students that an osculating circle at P has three-point contact with the curve at P . Crucially, this understanding, facilitated by JS easy-to-use interface, served as a powerful metaphor that enabled students to finally internalize that “tangent line at P has two point contact with thecurve at P.

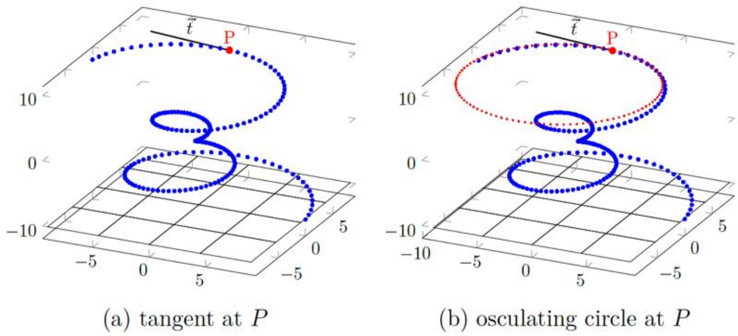


Figure 7: understanding tangent and osculating circle, and point of contact

However, in three-dimensional context, despite engaging with the 2D models, student express curiocity how a tangent could interact with a curve in 3-dimensional scenarios. The identified limitations of 2D visualization informed the subsequent need for a 3D-visualization approach. Consequently, this insight informed the planning phase for the subsequent cycle, leading to the development of a 3D visualization aimed at fostering multi-dimensional understanding of the concept ”tangent-curve contact”.

Cycle 3: JavaScript Visualization (3D)

In the third cycle, the researcher focused on embedding 3D visualization of tangent-curve contact relationship. In this visualization, JavaScript based interactive visualization of tangent-curve contact relationship shown in 3D. In this, the secant line to a curve at two distinct points is shown and later using simulation, the secant line is approached to a tangent line.

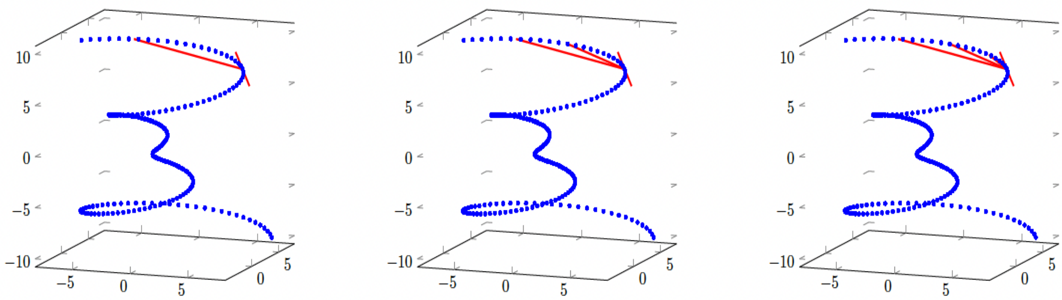


Figure 8: secant line transforming into a tangent

This visualization gave a touch-drag-feel environment to the students to manipulate the two given points on the space curve. While manipulating the points, students observed that how a single straight line is formed through two different points in limiting form. Initially, secant line touches the curve at two separate locations, but while dragging the points, they observed "two-point contact" of tangent in the limiting form. This interactive visualization with various dragging attempts helped students to understand that tangent lines in 3D environment also passing through a single point but of order 2. This updated understanding provided a space for "cognitive conflict" for the preconceived notion of a tangent line having a "single point touching contact", see Figure 2.

This cognitive conflict help to formulate a schema revision as conceptual revision in the students. The revised and updated schema of "two-point-contact" helped them a complete visualization of "secant line transforming into a tangent line", this was a pivotal moment for the justification of new schema "two-point-contact".

This active manipulation and observation, facilitated by JS, provided a concrete experience of an abstract mathematical process, addressing the underlying concepts of tangent. This study demonstrated that the usedigital tool like javascript visualization can be a pedagogical approach to minimize learning hurdle. It is also mentioned in a literature, the use of digital tool has been shown instrumental to minimize the learning gap (Imron et al., 2024). This version is also justified by this research.

In this research, the innovative use of the osculating circle as a pedagogical metaphor proved effective in overcoming this persistent difficulty. By first establishing that an osculating circle has "three-point contact" (see Figure 6), as mentioned in textbook (Pundir et al., 2021; Koirala and Dhakal, 2024), with a curve through dynamic JS visualization, students developed conceptual framework for "order of contact" to understand that, tangent has two point contact with the curve.

However, reflections highlighted the need for intervention in deductive problem solving capacity. It is seen is the classroom that there is a limited understanding for problem solving approach, to analyze 3D space curves. These empirical experience informed the next planning phase, which focused on theoretical explanations and problem solving skills, to enhance learning coherence and depth to analyze 3-D space curves. So cycle 4 is planed to dive into it.

Cycle 4: Moodle Quiz Assessment

The fourth cycle focused on evaluating student understanding through a Moodle-based quiz designed to assess key conceptual areas. The quiz was designed to incorporate a variety of question types suitable for assessing conceptual understanding, moving beyond mere recall of definitions, the questions were fro four level of cognitive order, knowledge, understanding, application and higher ability (Bloom, 1984).

The selected response item (eg. MCQ) and constructed response item (eg. essay questions) were used to understand students' understanding to articulate their reasoning skills. The questions were from four taxonomy level: knowledge, understanding, application and higher ability. To ensure fair, reliable and valid assessment, the given questions were randomized using JavaScript code, als order of appearance were suffeled for each student. Two sentence feedback explanation of student's response were utilized. This feedback mechanism helped students to learn with immediate insights into their performance. This feedback also provides a cognitive space for the learner for self-assessment and to correct their misconceptions.

The selected response item based MCQ quiz served as a formal assessment tool of 21st century pedagogy. It helped for effective use of LMS to promote conceptual understanding in higher mathematics. The student feedback on this type of quiz found positive. Many students reported that this quiz helped to consolidate their learning. The dynamism like randomization shuffeled order of items validated the effectiveness of integrated simulation and learning framework, this was another milestone to enhance students conceptual understanding.

In this study, four iterative cycles of participatory action research were used. The cycles emphasized also on qualitative data, this qualitative data aligned with the core principles of PAR. These qdata were prioritized to understand learner’s experiences and perspectives on learning higher mathematics using simulations and interactive animations. The deployment of these four cycles also ensured the methodological rigor of this research work. Each cycle of this PAR represented a pedagogical thoughtful iteration of action-reflection process, allowing researcher for continuous adaptation and refinement of the pedagogical thoughtful intervention.

The finding of this PAR study is that interactive and dynamic JavaScript simulations integrated pedagogical design in LMS or VLE cn help students to build their conceptual understanding. In this study, it is found that student developed new schema of “tangent-curve contact” through their active learning using JavaScript simulations.

The pedagogical value of this PAR is that learner can use “touch-drag-feel” like of authenticate learning experience to understand intented learning concepts and do live experiment on learning content. This live interactive learning experience can help increased learning retention, which is a part of active learning, as literature mentioned (Freeman et al., 2014). This interactive learning experience also supports retrieval practice (Hopkins et al., 2016) and therefore can improve problem-solving skills. Similar findings are also presented in a research work (Imron et al., 2024). However, this PAR research highlights that the pedagogical value is not only use of technology, but about its meaningful thoughtful and pedagogically informed use of the technology.

Conclusion and Recommendations

Based on the data presentation, discussions and findings, some of the specific recommendations can be proposed. These recommendations can be useful to enhance pedagogical thoughtful technology use on mathematics education. The recommendations are

1. Prioritize interactive visualization
   Educational practioner like teachers should use technology with pedagogical thoughtful interactive visualizations and dynamic simulations.
2. Leverage VLE
   Learning Management system, Virtual learning environment, of learning web page need to use with pedagogical thoughtfulness for content delivery. The theoretical explanations and practical computation must be guided through automated quiz questions to provide personalized learning pathways.

Based on both recommendations, it can be suggested that technology use must be based on pedagogical thoughtful integration.

Data availability

The data and materials of this PAR are available on the author's personal website, and Moodle based LMS. Specifically, detailed explanations, interactive visualizations, and mathematical derivations are accessed at https://bpdhakal.com.np/, (username: testuser, password: Research@2024, and https://www.bedprasaddhakal.com.np/ 2024/05/tangent-to-space-curve.html, and https://www.bedprasaddhakal.com.np/2024/07/osculating-circle-and-osculating-sphere.html.

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