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Students'Learning Experiences in Conceptualizing Differentiation in Secondary Level Mathematics Education

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Abstract

Differentiation is a fundamental concept in calculus which is essential for multidimensional fields. Conceptualizing differentiation is an emerging issue in mathematics education globally. In this context, the study explores students' learning experiences in conceptualizing differentiation at the secondary level of mathematics education in Birendranagar, Surkhet. Using a phenomenological inquiry within the interpretative research paradigm, data were collected through semi-structured interviews with six purposively selected public secondary-level students in Surkhet, Nepal and analyzed thematically to gain insight into learning practices and conceptual understanding. The findings reveal that students struggle with abstract ideas such as limits, continuity, and rate of change, as well as with connecting visualizations, and algebraic representations. This study also suggests a contextulized teaching approach to improve conceptual development and meaningful learning in differentiation. This study would provide practical implications for educators, policy makers, mathematics educators, students, and concerned stakeholders.

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Introduction

Mathematics is the science of logic and reasoning that studies numbers, quantities or shapes, and size (Michael, 2015). It is believed that school mathematical knowledge is the foundation of any field. It plays an important role in the multidisciplinary development of society. It is logical science and the foundation of science and technology for mathematical application (Jameel & Ali, 2016). Differential calculus is a branch of mathematics that is concerned mainly with the study of the rate of change of functions to their variables, especially through the use of derivatives and differentials (Brijlall et al., 2017). The differentiating concept is one of the fundamental concepts of university-level mathematics. It is the foundation and prerequisite knowledge for the higher education of mathematics as well as other subjects (Hashemi et al., 2014). It is rule for calculating to derivative of the function, f can be expressed as follows: as the change in x approaches near to x, the change in y divided by the change in x approaches the derivative. That is, "derivative" means the rate of change of y to x (Chu, 2019). Then the geometrical meaning of derivative is the slope of the tangent of a line of function f(x) at a point (x, f(x)) (Geveci, 2015). Therefore, it corresponds to a basic concept of derivative applicable to many other fields in university curricula in mathematics, engineering, and other sciences (Fuentealba et al., 2019). The great mathematician G. W. Leibnitz (1646-1716) has connected the concept of the derivative with the slope of the tangent of the curve at a given point. The meaning of derivative is referred to as the rate of change of the curve (Ojha, 2018).

In the context of Nepal, the concept of the derivative is started from grades 11 to 12 in basic mathematics or calculus courses. In my teaching experiences, most of the mathematics students of grades 11 and 12 have believed that the concept of differentiating is more challenging. They are not motivated to participate in the differentiating concept in the teaching-learning process. Here, it is the last batch of mathematics students of grade 12 who have taken mathematics for the major subject. Recently, the mathematics curriculum of grades 11 and 12 is designed by the National Curriculum Framework (2018) as an optional subject that includes different contents such as algebra, trigonometry, analytic geometry, vectors, statistics and probability, calculus, computational methods, and mechanics. Among them, calculus consists of 32 working hours, such as derivatives, anti-derivatives, and differential equations in grade 12. Thus, the concept of differentiating is the basic foundation of calculus and other subjects.

The problem of understanding the derivative concept is one of the major challenges of mathematics education at the K-12 and higher education levels in the global context. The result of the mathematics students showed the ineffectiveness of the calculus courses (Fuentealba et al., 2019). Then there is the gap between students' prerequisite knowledge and classroom practice to make conceptual connections towards differentiating concepts (Ramli et al., 2013). Generally, the mathematics students faced difficulties in learning a derivative concept from the definition and notation as well as its geometrical meaning (Sebsibe, 2019). For the effective teaching-learning process of the mathematics classroom, there should be effective communication between teachers and students (Mulwa, 2015). In that situation, this study has focused on the learning experiences of mathematics students and they struggle to grasp understanding its conceptual development, meaning, application in differentiation. This study, guided by following the research questions:

1. How do secondary level students' learning experience in differentiation to mathematics?
2. What challenges do students face while learning differentiating concepts?

Literature Review

Learning Experiences in Differentiation

In the context of South Africa, the researcher conducted a study that focused on learners' difficulties in finding the derivative of functions using first principles and rules of differentiation based on grade 12 class mathematics students. It was found that the learners performed not well towards the differentiation. Teaching-learning strategies and lack of procedural and conceptual knowledge of leaner in the classroom are the main responsible factors for this problem. It is concluded that the learner should be proactive to know about conceptual and procedural knowledge of the problem-related derivatives by using the first principle and rules of differentiating the function (Makgakga & Maknakwa, 2016). Similarly, another study to explore the students' difficulties and common issues toward calculus related courses. The main purpose of the study was to assist students at the early stage of learning calculus at grade 12 towards difficulties and get better conceptual knowledge. It was found that students should construct the concept through real-life problems and teachers should be trained in problem-solving skills and mathematical thinking practice (Sebsibe, 2019).

The research conducted to investigate university students' understanding of derivatives and their applications. This research is based on the APPOS (action-process-object-schema) theoretical framework at the Westville Campus of the University of KwaZulu-Natal in South Africa. The appropriate rules for finding derivatives and their applications were taught to undergraduate science students. It is seen that the students faced learning problems in applying the rules of derivatives they should be developed suitable mental structures at the process, object, and schema levels (Maharaj, 2013). In the context of Turkey, the research conducted the study for the purpose to investigate students' awareness and understanding of the relationship between the concept of derivative and its modeling task that requires tackling the big ideas underlying the concept of derivative and relationships between them. This research mainly focused on the relation between the meaning of the rate of change and the concept of the derivative. It is found that students have not ideas towards the conceptual meaning of derivative. The data showed that the participants' understanding of derivatives was rather instrumental. The study suggested that learners should understand the conceptual meaning of derivatives and relate that concept to solving problems (Sahin et al., 2015).

The study focused on reasons for difficulties faced by students towards a conceptual understanding of derivatives. This research design is qualitatively based on open-ended questions for the sample of 63 undergraduate students. The respondents reported that they have the main difficulties in conceptual perception of derivatives. It is found that for better achievement of the concept of derivative understanding, there should be a logical relation between symbolic aspect and embodied aspect in the teaching-learning process. It is concluded that this study provides information about the reasons for difficulties towards derivative to the undergraduate instructors and students (Hashemi et al., 2014). Moreover, Thompson and Harel (2021) conducted a literature review-based study on ideas foundational to calculus learning and their links to students’ difficulties. They argued that lack of prior knowledge of limit, rate of change, and visualization representations plays a significant role in differentiating concepts. In this regard, Mkhatshwa (2024) conducted survey research on USA bachelor first-year students and highlighted that integrating real-world context instruction enhances conceptual development and learning engagement in differentiation. In the context of Nepal, found gap between conceptual understanding and procedural difficulties in learning derivative of grade eleven students (Kafle, 2019) and weak pre-knowledge about limit, continuity and geometry as contributing factors to learn derivative in Nepalese context (Mahato, 2019). This empirical evidence reported that lack of study to explore learning experiences on differentiation in mathematics in the context of Nepal.

Research Gap

In the process of empirical review, we got an opportunity to review some studies which are carried out previously in differentiating concepts of learning experiences of students. As we know of many research studies which are done foreign countries towards differentiating concept. This research is unique in terms of the research problem and research field as this research look after the differentiating concepts: grade 11 students' learning experiences in the context of Nepal at Karnali region.

Theoretical Framework

APOS Theory

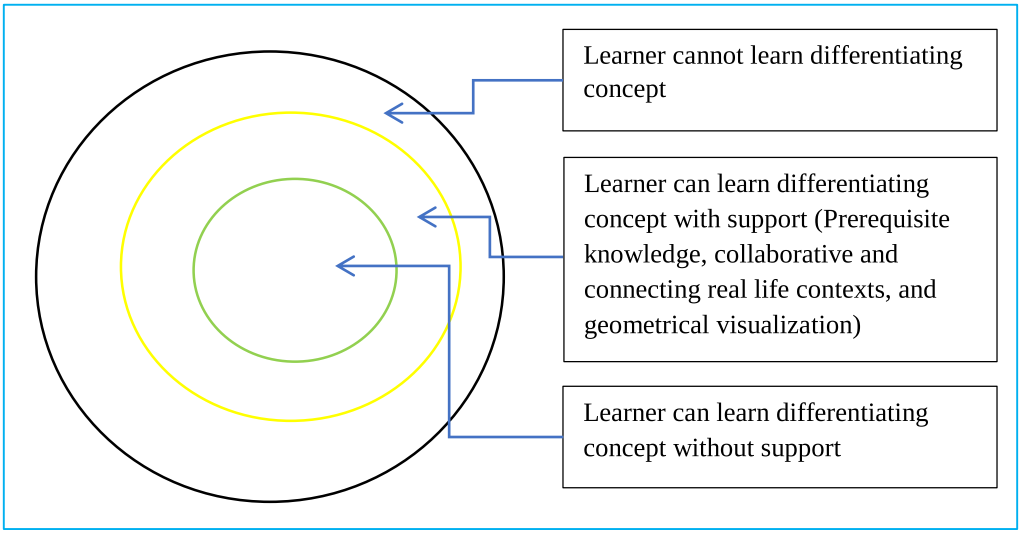
ED Dubinsky and Michael A. Mc Donald have presented APOS respectively as; Action, process, object, and schema. Here, action refers to the external stimuli, either explicitly or inexplicitly which allows learners to perceive information systematically. And the process refers to that situation where the learner reaches that level of performing the same activity without any external stimuli. The third one 'object' refers to that condition where the learner realizes the whole process as a totality and takes the unit of learning as an object. The last one schema refers to the mental state of construction, which tries to explain that the learners store the process, activity, object, and schema which are linked with each other and learners make a separate framework in their mind for the linked information which can be brought to bear upon a problems situation involving that concept (Dubinsky & Mcdonald, 2001) offers that an individual has to have appropriate mental structures to make sense of a given mathematical concept. This theory begins with the hypothesis which is about the processing mechanism on information to extend the work of Piaget on reflective abstraction in children's learning. It explains the mental construction, that how learners' learn and process information in schemas to make sense of the situation and solve the problem (Borji et al., 2018). This theory highlights previous knowledge and learner real life contexts play significantly role to enhance conceptual understanding learning differentiating concepts in calculus instruction.

Social constructivism

In social constructivism, learning occurs through interaction with teachers and their peers and experience sharing in the classroom. It focuses on the role of pre-existing cognitive structure in the learners and prior mental representation as to the foundation of new knowledge development (Sebsibe, 2019). Here, students are encouraged to construct knowledge through interaction and collaboration where the teacher is a facilitator to create a constructivist environment for all students in the classroom teaching (Powell & Kalina, 2009). It is believed that knowledge is constructed through dialogue and interaction with each other (Vygotsky, 1978). In the constructivist classroom, the students more responsible for their knowledge construction with meaningful experiences by interacting with their teachers and peer (Schreiber & Valle, 2013). The theory offers for designing instructional approaches incorporate collaborative learning, ZPD process, with scaffolding aimed to enhance conceptual and procedural skills for differentiating concepts in mathematics. The theoretical framework of the study is presented herewith:

Figure1

Theoretical Framework of Study



Research Methodology

This research was conducted using a phenomenological inquiry guided by an interpretative research design (Calo, 2025) which explores the live experiences of personal or groups related to their problem and the meaning making of those experiences (Alase, 2017).The researcher collects the data through the participant's setting based on emerging research questions and meaning-making and interpretation are developed inductively from particulars to general themes (Creswell & Creswell, 2018).This method is suitable for this study because they are concerned with the meanings that learners conceived or misconceived on differentiating concepts (Makonye & Luneta, 2014).

Research Site and Participants

For the selection of research sites and participants, we used purposive sampling of qualitative research based on the fulfillment of the research questions (Cohen et al., 2007). In qualitative research, we have selected the research site and participants to understand the research problems and questions purposefully (Creswell & Creswell, 2018) and conducted study in three public secondary schools within Birendranagar Municipality of Surkhet. The six students who have been studying mathematics at grade 11 were selected as participants to conduct semi structure interviews.

Data Collection and Analysis Procedure

Data were collected through conducted semi-structured interviews with six students to explore learning experiences and challenges regarding on differentiation. We have no bias towards informants. The participants' responses were more respected and confidential. For the data collection, we took concerns from informants before interviewing them. Similarly, we have made it more representative for sampling and there are no subjective biases in the data analysis. We have not disclosed the identity of the respondents. We followed analysis process of the semi structured interview document through open coding, grouping codes into themes , and interpretation of the themes through narratives (Calo, 2025) and finally triangulation with existing literature and theoretical perspectives.

Findings and Discussion

The findings examined through three main themes: conceptual understanding, learning strategies, and learning challenges in differentiation based on students learning experiences and perspectives. The findings have presented in following thematic topic generated with inductive approach:

Conceptual Understanding: Learning Differentiation

The overall findings this study revealed students have poor conceptualization regarding to differentiating concepts. The fundamental conceptual knowledge of function, limit, and continuity is important to understanding differentiation. In this relation, participant (S1) shared that,*" My teacher direct started lesson using formula and rule for calculating derivatives in classroom teaching. Then I found difficult and abstract to understand meaning and concept related to differentiation"* Similarly, another participant (S2) shared that *"I have short of concepts about limit, continuity and rate of change so that I cannot understand clearly differentiation".*

Geometrical interpretation and visualization play significant role to improve conceptualization. In this regard, participant (S3 and S4) said that *"sometimes it is easier to understand if the teacher teaches through geometric interpretation and visualization. Initially, derivatives seemed abstract, but when the step-by-step explanation and showing the slope of the graph made it easy to understand"*

These student responses show that the graphical representation adopted to explain the concept of derivatives in a simple way makes the relationship between symbolic formulas and real functions clear. Thus, conceptual understanding in learning derivatives is a combination of prior knowledge activation and instructional design. Teachers use stepwise formula explanation and graphical tools based on function, limit, and continuity. Students understand abstract formulas by experiencing this and make connections to derivative concepts such as slope, rate of change. This shows that alignment between teacher strategies and student experiences is important to ensure success in learning derivatives. This refers to conceptual understanding is a fundamental element of learning derivatives. The teacher's instructional scaffolding and visualization, as well as the student's active engagement and prior knowledge activation, make the abstract concepts of derivatives clear and meaningful. This enables students to not only learn formulas, but also understand why the rules work.

Students' Learning Strategies

As participant (S1) stated, *"I would make notes, practice many examples, and discuss questions with my peers,"* which shows the importance of active learning and peer discussion. Participant (S2) also emphasized the importance of group study and revision: *"I would solve extra examples at home, and group study with my peers made things clearer."* Participant (S3) stated, *"I read class notes carefully, completed homework regularly, and discussed with my peers."* Students also found visual examples useful. Participant (S4) stated, *"The step-by-step examples and use of graphs provided by the teacher made it easier to understand,"* and participant (S5) stated, *"The visual examples and group discussion made it easier to understand derivatives."* Participant (S6) also highlighted the importance of visual and peer interaction: *"Extra visual examples and peer discussion groups enhance understanding."*

The findings revealed that we need to create interactive learning environment and provide opportunity group discussions, models development, contextualized project work and graphic representations.

Challenges: Learning Differentiation

Many students struggle to learn differentiation in mathematics. Several contributing factors hinder problems to learn differentiation meaningfully in classroom practices. In this regard, Participant (S1) said that, *"I found it difficult to understand the chain rule and product rule. I made mistakes while applying graphical interpretation and formulas. Sometimes I would confuse the concepts of limit and* *continuity."* Similarly, participant (S2) shared that *" I do several errors for calculating derivatives due to poor conceptualization"* Furthermore, another participant S4 claimed that *" I have difficulty understanding the concept of derivatives because I have not sufficient conceptual ideas about function limits and continuity*". That means prior knowledge is importance to understand differentiation. In this relation participant (S6) argued that *"the teacher only emphasizes problem solving instead of teaching daily life contexts and visualizations related to derivatives"*

This finding noted that weak conceptualization, rote memorization, isolation from everyday contexts and teacher centered instruction are key challenges to hinder for effective differentiation learning. From the students' perspective, the challenge is mainly in the learning experience: difficulty remembering formulas, understanding graphical slopes, and making conceptual connections. Overall, the findings show that learning challenges in learning derivatives are multifaceted. Formula-based difficulties such as chain rule, product rule, and quotient rule, struggles with graphical interpretation, and weak foundational knowledge all hinder learning. Students not only experience difficulty remembering formulas, but also difficulty applying graphical slopes, tangent lines, and abstract concepts. The gap between teachers' instructional strategies and students' learning experiences clearly shows the challenges.

The main concern of the research is to explore learning experiences of grade 11 students and what challenges faced in classrooms learning practices. This section highlights interpreting key findings related with research questions with connecting relevant literatures.

Conceptual Understanding: *Building Foundational Knowledge for Derivatives*

In the first theme as *conceptual understanding of differentiating concepts*, it is found that participant views lack of conceptual understanding to grasp its meaning, geometric interpretation. The findings reveal that many of students struggle to understand conceptual fundamental ideas for learning differentiation. The study revealed that students do several mistakes due to poor conceptualization **(**Siyepu, 2013). Furthermore, they need to have clarity of fundamental concepts of limit and continuity and geometrical meaning of rate of change. Similar findings found by (Gupta, 2017; Oehrtman et al., 2019) and argued that a strong conceptual foundation in Function, Limit, and Continuity is important for understanding derivatives. These findings are consistent with study conducted by (Aleksić, 2025) and (Feyissa et al., 2024; Juter, 2005). They highlight integration ICT and real life contexts play significant role for improving conceptual development and bridging fundamental knowledge to learn differentiation meaningfully. In my teaching experiences, students who clearly understand these concepts can easily relate derivative formulas to graphical representations. Thus recapping functions, limits, and continuity made it easier to understand derivatives which clearly demonstrates that prior knowledge plays a direct role in comprehension. Graphical visualization was particularly useful, which increased conceptual understanding by linking abstract formulas to slopes and rates of change.The alignment between teacher strategies and student experiences suggests that teaching abstract concepts through visual and incremental approaches increases both comprehension and retention.

Learning Strategies: Approaches Used by Students and Teachers to Facilitate Learning

In second theme as *learning strategies and practices*, it is seen that the onions of participants argued as while teaching the concept of differentiation, the teacher seems to only follow formulas and problem calculation procedures, but it would have been more effective if the learning had been based on applications and geometric visualizations related to derivatives and daily life. These finding also pointed by Hashemi (2015) in undergraduate mathematics students in Iran context. In the context of Nepal, a stud conducted on secondary school mathematics students recommends designing learning strategizes that enhance should conceptualizing derivatives and their application in daily life situations (Kunwer & G.C, 2023). The insights from findings of this study, we need to create interactive context based learning environment to develop collaborative active learning and use ICT to visualize geometric meaning of derivative. Thus, in derivative learning, it is considered appropriate to use application-related learning strategies that are linked to students' learning experiences and the daily lives of derivatives.

Multifaceted Challenges in Learning Derivatives

The study showed that students experienced various learning challenges in learning derivatives. Participant shared that they struggle to understand graphical interpretation. Contributing factors include lack of knowledge gap between theoretical understandings and every day applications, misconceptions, and formula and procedure memorization. These challenges also mentioned by (Winsaputri, 2025). Furthermore, prior knowledge (function, limit, and continuity) plays a very important role in learning derivatives. Teachers have repeatedly stated that without these concepts, it is difficult to understand the rules and formulas of derivatives. Understanding limit and continuity made it easier to understand the concept of derivative. The study conducted by Siyepu (2013) argued that students create several errors due to poor conceptualization. That is lack of conceptual understanding and geometrical interpretation also affecting factors hinder for effecting learning differentiating concepts in mathematics. Moreover, conventional teacher dominated teaching approach also crucial factor to demotivate students towards learning derivatives.

Application and Real-Life Connection

In learning derivatives, practical examples and real-life connections play an important role in improving students' understanding. Teachers often try to make the learning process more meaningful by using practical exercises in the classroom. Students also considered real-life applications important. Overall, the findings show that application and real-life connection is a critical element in learning derivatives. Both teachers and students consider it important. It not only teaches abstract formulas, but also strengthens underlying concepts and problem-solving skills.

Our findings are also consistent with other recent studies in the field of derivative teaching, which have drawn similar conclusions about the problems and learning opportunities that students experience when learning the concepts of limit, continuity, and derivative. According to (Susilo & Darhim, 2019), students have difficulty understanding limits of functions, especially when they are required to explain them in terms of continuity and derivative. This has a direct impact on students' analytical thinking and logical reasoning abilities. Next study by (Areaya & Sidelil, 2012) held in Ethiopian secondary schools regarding student understandings of concepts of derivatives, found that common misconceptions among students are based on analysis of some terms regarding derivatives. The finding of the research indicated that students sometimes fail to clearly visualize what the limit values are? How limit exists in surrounding numerical values? Due to these confusing they fall to ambiguity in mathematical concepts and challenges in higher-level mathematics learning. Similarly, (Habre & Abboud, 2006) found that students tend to rely on formulas before directly understanding graphs, which hinders students' ability to understand derivatives, as they tend to only abstractly understand mathematical thinking because they cannot relate them to real-life examples and graphs. All these findings are similar to the findings of this study. Teaching methods need to be reimagined to develop students' deep and conceptual understanding of limits, continuity, and derivatives, and the fact that visual presentations, vivid examples, and step-by-step learning have the potential to help reduce

Conclusion

The findings demonstrate prior knowledge is main concern to develop conceptualizing differentiation. It is seen that there is gap between conceptual and procedural knowledge to develop conceptualizing differentiation. The study offers strong foundational knowledge of function, limits, and continuity, geometrical representation, context based teaching, and meaningful interactive learning to landscape conceptualizing differentiation. The teachers should provide conceptual clarity using step-by-step instruction, connecting real life applications, visual aids, and graphical examples, while students strengthen their understanding through collaborative learning, visualization, using contextualized teaching materials. The study is beneficial for teachers, students, and policy makers and teacher trainer to strengthen instruction in calculus.

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