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Engineering Faculty Perspectives on Bachelors' Student Mathematical Prerequisites

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Abstract

This study explores engineering faculty perspectives concerning the adequacy and relevance of Nepal's secondary level mathematics curriculum as a foundation for undergraduate engineering education. Through interpretative qualitative research involving purposively selected six engineering professors from two universities in Nepal, this study examines the alignment between secondary mathematics education and engineering program requirements through in-depth interviews. The major themes that emerged were contents sufficiency, sequential consistency, contextual pedagogical practice and unfamiliarity exam system. The results of the research can assist mathematics curriculum developers and teachers in secondary and undergraduate levels.

Introduction

Engineering is a highly specialized discipline that demands strong mathematical abilities. Without mathematics, people would struggle to pursue engineering careers, reducing the number of skilled individuals capable of addressing intricate engineering problems. Mathematics is not only crucial for engineering; it is essential to the discipline (Goold, 2012). Engineering would be greatly constrained in its capacity to develop safe, efficient, and creative solutions to the intricate challenges faced by engineers across different sectors without mathematics. Without mathematics, engineers would find it difficult to create efficient control systems, resulting in inefficiencies and instability within processes. Disciplines such as materials science and mechanics depend on mathematical principles to comprehend material behavior and structure design. Without mathematics, engineers would find it challenging to anticipate how materials behave and create secure and dependable structures.

Math is vital for modeling and examining physical phenomena, results, and enhancing designs. For instance, in civil engineering, calculus is utilized for hydraulic analysis applications that are essential for the design of storm drains. Overall, grasping calculus, which focuses on change, can assist in solving and modeling issues related to motion and transformation, besides aiming to model these scenarios in a three-dimensional context (Horwitz & Ebrahimpour, 2002). Differential equations are based on calculus, since the equations are employed to model changes over time. Linear algebra is essential for grasping and representing systems through matrix computations. Ultimately, a solid grasp of statistics enables engineers to make educated choices grounded in numerical data.

Mathematics also finds numerous applications in technology. In the age of artificial intelligence and machine learning, mathematics acts as the foundation language for these advancements. Engineers proficient in mathematics and computer science can utilize AI for activities like determining the best shape for a mechanical component or examining data trends to enhance product quality like neural concept. The necessity for a solid foundation in mathematics stems from the fact that math is essential for constructing machine learning models. Probability helps in understanding frequencies, and machine learning models frequently employ probability models to determine the best decisions and forecast future trends. Differential equations serve in-silico modeling, an application of artificial intelligence, to assess therapeutic targets and test various hypotheses. Ultimately, because mathematics forms the foundation for advanced technologies employed for various engineering applications, it's essential that prospective engineers have a strong background for a successful career.

Further, Mathematics is essential to engineering, assisting engineers in design, analysis, and creativity. From high school algebra to university calculus and further, mathematics provides engineers with the resources necessary to tackle real-world problems in various subfields. By utilizing mathematics, engineers are able to simulate physical phenomena, harness advanced technologies, and foster groundbreaking innovations. With the progression of technologies and the ongoing evolution of engineering, mathematics will stay fundamental to the discipline, enabling engineers to tackle challenges and enhance the future world. The curriculum designed by Curriculum Development Center (CDC) and the examination taken by National Examination Board (NEB) provides the basic foundation of the bachelors engineering mathematics.

Current NEB Curriculum of Mathematics

Mathematics course is anticipated for students in grades 11 and 12 who seek to select it as an alternative to the Social Studies and Life Skills education subjects in accordance with the curriculum framework prescribed by the National Curriculum Framework, 2076. This course envisioned to provide both conceptual and theoretical insights via demonstrations and presentations, discussions, group activities, and practical projects within a real-world context. This course covers various topics: Algebra, Trigonometry, Analytic Geometry, Vectors, Statistics and Probability, Calculus, and Computational Methods or Mechanics (CDC, 2077).

The competencies that the course aimed to develop on students are – (1) Use basic properties of elementary functions and their inverse including linear, quadratic, reciprocal, polynomial, rational, absolute value, exponential, logarithm, sine, cosine and tangent functions; (2) Use principles of elementary logic to find the validity of statement and acquire knowledge of matrix, sequence and series, and combinatory; (3) Identify and derive equations for lines, circles, parabolas, ellipses, and hyperbolas; (4) Solve the problems related to real and complex numbers; (5) Articulate personal values of statistics and probability in everyday life; (6) use vectors and mechanics in day to day life; (7) Apply derivatives to determine the nature of the function and determine the maxima and minima of a function in daily life context; (8) Explain anti-derivatives as an inverse process of derivative and use them in various situations; (9) Apply numerical methods to solve algebraic equation, calculate definite integrals, and use simplex method to solve linear programming problems (LPP). Moreover; and (10) Use relative motion, Newton's laws of motion in solving related problems (CDC, 2077).

Curriculum Development Center specify seven content domain/area of mathematics for grade XI and XII are "Algebra, Trigonometry, Analytic geometry, Vectors, Statistics and Probability, Calculus, Computational methods/Mechanics" (CDC, 2077). CDC have prescribed different teaching methodology of instruction: Inductive and deductive methods, Problem-solving approach, Case studies, Project-based learning, Question-Answer and discussion techniques, Discovery methods/ use of ICT, and Cooperative learning methods.

Internal evaluation encompasses classroom involvement, terminal examinations, and project/practical assignments (computer tasks and laboratory work) along with presentations. The evaluation scores of will be utilized to give feedback and to enhance their learning. Projects are assigned as Individual and group tasks. The criteria for internal evaluation are: Classroom participation (3), Marks from terminal examinations (6), project work/practical work (16). So the total 25 marks out of 100 marks was allocated for Internal assessment whereas rest 75 mark was allocated for External assessment which is conducted by National Examination Board (NEB).

Mathematics is the fundamental component to study engineering and further engineering career percepts. For study and a successful occupational life, mathematical foundation should be strong among the engineering graduates. Almost all subjects of bachelor of engineering courses mathematical concept are inherent so for the better output of learning the strong foundation of mathematics is essential. The result of different university bachelors level in early years are not satisfactory and particularly in mathematics and mathematical related subjects. In this context, this study aims to find out the perspectives of university professors regarding the fundamental mathematical knowledge of their bachelors level engineering students obtained from their school period and the curriculum aims to provide.

Objectives of the Study

The purpose of this study was to explore the selected mathematics professors' perceptions on relevancy of school level mathematics curriculum as the required prerequisites of bachelor level in engineering in Nepal. To achieve the objective of this study, the study was focused on the following research question: How do mathematics professor perceive the school mathematics curriculum is sufficient to provide prerequisites of bachelor's level engineering in Nepal?

Theoretical and Empirical Bases of the Study

Engineering is a highly specialized discipline that demands strong mathematical abilities. Without mathematics, people would struggle to pursue engineering careers, reducing the number of skilled individuals capable of addressing intricate engineering problems. Mathematics is not only crucial for engineering; it is essential to the discipline. Engineering would be greatly constrained in its capacity to develop safe, efficient, and creative solutions to the intricate challenges faced by engineers across different sectors without mathematics. Without mathematics, engineers would find it difficult to create efficient control systems, resulting in inefficiencies and instability within processes. Disciplines such as materials science and mechanics depend on mathematical principles to comprehend material behavior and structure design. Without mathematics, engineers would find it challenging to anticipate how materials behave and create secure and dependable structures.

There are different models for curriculum development. Tyler (1949) expressed in his book basic principles of curriculum and instruction that curriculum development needed to be treated logically and systematically. He further argued that to develop any curriculum, one should consider four basic components: objectives of the curriculum, selecting learning experiences, organizing learning experiences, and assessment and evaluation. His model has underrated by many curriculum writers and considered as rigid nature of objectives model (Acharya, 2017). Further, dynamic approach to curriculum development sees the curriculum as a continuous and developing process instead of a fixed document. This model acknowledged that the curriculum must adapt to evolving student requirements, emerging research and information, and changing societal anticipations (Fullan, 2007; Marsh & Willis, 2007). With this method, the curriculum isn't merely dictated by administrators or experts; rather, it is consistently improved and adjusted according to feedback and assessments.

A crucial aspect of the dynamic model is its focus on teamwork and collective decision-making. Educators, school leaders, learners, guardians, and community members all contribute to the development of the curriculum (Fullan, 2007; Oliva & Gordon, 2013). This cooperative approach helps guarantee that the curriculum stays pertinent and significant. The dynamic model promotes continuous professional growth for educators, enabling them to efficiently apply and modify the curriculum. In general, the dynamic model regards the curriculum as a vibrant, adaptable framework that changes to meet effectively the requirements of students and the school community.

A prevalent model for developing school curricula is the objectives-based model. This model begins by outlining particular learning goals or results that students should attain. The curriculum is subsequently structured to methodically impart the knowledge and skills required to achieve those objectives (Bloom, 1956; Tyler, 1949). This approach highlights quantifiable, behavioral objectives and often centers around getting students ready for standardized examinations and evaluations.

An alternative method is the process model, which highlights the significance of the learning journey instead of solely the end results. This framework promotes student questioning, analytical reasoning, and the cultivation of skills for lifelong learning. Following this model tends to be more adaptable and attuned to the interests and needs of students (Stenhouse, 1975; Eisner, 1994). This method might prioritize deep comprehension and the capability to apply knowledge over standardized exams. Whereas, critical pedagogy method, which considers curriculum design as a political and social endeavor. This model contests the conventional, "neutral" curriculum and aims to empower students, tackle matters of equity and social justice, and ready them to be active, engaged citizens (Freire, 2021; Apple, 2004). Curricula created with this method might incorporate various viewpoints, critical examination of power dynamics, and chances for students to engage with real-world issues.

Vertical linkage is an essential aspect of successful curriculum design, as it guarantees that learning objectives and content develop upon one another in a coherent and progressive way (Ornstein & Hunkins, 2018). By aligning the curriculum vertically through various grade levels, educators can strengthen essential concepts, skills, and knowledge, enabling students to enhance their understanding gradually (Glatthorn et al., 2018). Vertical linkage also aids in the transfer of learning since students can create significant connections between their prior knowledge and new content (Wiggins & McTighe, 2005). Additionally, a vertically-aligned curriculum offers educators a defined guide for teaching, facilitating coordination and collaboration among different grade levels (Jacobs, 2010). In general, the deliberate vertical integration of a curriculum is crucial for enhancing student learning, success, and the growth of more advanced cognitive abilities (Harden, 2001).

Methodology

The research study based on interpretive constructivism (Schwandt, 1994) was undertaken from the perspective of nominalist ontology, employing subjectivist and relativist epistemology with the objective of investigating contextual reality shaped by personal experiences and practices (Cohen et al., 2008; Denzin & Lincoln, 2018). This study's assumptions regard human knowledge as a subjective construction of meaning derived by the researcher through interpreting participants' experiences with the mathematics curriculum. This research utilized descriptive qualitative research designs with frameworks, methodologies, and approaches focused on acquiring responses to research inquiries (Creswell, 2009). This entailed gathering and analyzing data, elucidating the assumptions and outcomes, and linking their latent meanings with the current data (Bryman, 2008) to attain better precision in comprehending the theory and practice regarding the prerequisites of curriculum.

Research Participants

Six professors of bachelor level engineering colleges in Kathmandu were purposively selected as the participants in the study. The professors have been teaching mathematics for at least five years in different semesters of bachelors in engineering, and well aware about current grade XI and XII mathematics curriculum. Since Tribhuvan University and Pokhara University are the two bigger universities of Nepal in terms of enrollment of students in BE, the professors were selected for the study as research participants from those two universities.

In a qualitative study, a sample size of six is deemed adequate. Up to this point, there was sufficient qualitative data to reach saturation while developing themes (Cohen et al., 2008; Creswell, 2009). The sample professors were given pseudonyms such as Dibesh, Bishal, Shree, Puskar, Krishna, and Puspa. Their real names, university, college, and photos were not released to safeguard their identity due to ethical considerations.

Data Collection Tool and Procedure

A semi-structured interview was deemed suitable due to its adaptability and the chance to pose questions according to participants' responses. Each research participant was engaged to gain insights into their feelings, experiences, and the effects on teaching and learning mathematics at the engineering undergraduate level (Husban, 2020). A set of guidelines for the interview was created to assist in the interview process. The research instrument was made with several organized guiding questions to pose to every participant. Extra prompts were utilized taking into account the participants' perspectives and reflecting on their ongoing experiences in mathematics education (Flick, 2015). This enabled interview questions to be less structured, focusing more open and verbal formats (Cohen et al., 2008). Nevertheless, precautions were taken to avoid misleading the interviews by incorporating open, unstructured questions, allowing for the collection of the majority of necessary information from participants.

The semi-structured interviews encompassed participants' opinions, emotions, experiences, and convictions regarding prerequisites for learning mathematics (Galletta & Cross, 2013). The professors were offered a voluntary choice to take part in the study. They were briefed about the research, its objectives, and the duration needed for the interviews. Several professors voluntarily wished to participate in the study. However, purposively selection of six professors for the study who have been teaching mathematics in BE, based on the inclusion criteria set by the researcher and data saturation criteria. Each professor was interviewed approximately 25-30 minutes. The interviews were recorded, transcribed, and translated from Nepali to English for further analysis and interpretation.

Data Analysis and Interpretation

Qualitative interview data was analyzed by categorizing and interpreting ideas regarding implicit and explicit meanings within thematic frameworks (Anderson, 2007; Flick, 2015). In this study, the thematic data analysis approach was utilized to uncover the core of the experiences of the research subjects by recognizing patterns or themes in qualitative interview data (Braun & Clarke, 2006; Clarke & Braun, 2013). The researcher converted interview data into significant units according to the concepts they embodied. Subsequently, the codes were organized into significant categories by connecting them according to their meanings or concepts. The researcher assigned codes and classifications to encompass four key themes. In general, the thematic analysis aligned with qualitative research (Denzin & Lincoln, 2018) in conceptualizing meanings derived from the participants' expressions and interpreting them based on the meanings they convey (Best & Kahan, 2006; Lochmiller, 2021). Consequently, the thematic analysis was performed by delineating the primary concepts as codes and categories to identify their usefulness, adaptability, and capacity to portray and record the key themes (Braun et al., 2016) with recurring patterns (Braun & Clarke, 2006) utilizing various theoretical and epistemological backgrounds.

Maintaining Quality Standard

The study's quality standards were upheld through credibility, transferability, dependability, authenticity, and conformability (Korstjens & Moser, 2018). The credibility of this study was maintained by fostering a trustworthy atmosphere between the research participants and the researcher to gather genuine data. The credibility of the data was additionally upheld by centering the interview questions on participants' experiences regarding the prerequisites, concepts of students from various semesters of the bachelor of engineering program, and their effects on mathematics learning. The researcher made several visits to the colleges and the participants to create a relaxed atmosphere for them to engage in the interviews. Participants were first informed about the purpose of the study and that their involvement was voluntary. The ethical dimensions of the research were directed by informed consent, privacy, and data security (Jameel & Majid, 2018). Consequently, the participants were informed that their identities would be safeguarded by altering their names and not disclosing their photographs in the study reports. The power dynamics between the interviewer and the research participants had no effect. The participants were guaranteed that they could exit the study whenever they wanted without facing any penalties or repercussions.

The transferability criteria were utilized to develop themes that might clarify comparable experiences of other professors who did not participate in the study. The criteria for dependability were taken with complete accountability to accurately reflect the participants' accounts in their own words, ensuring that the themes relied entirely on what they expressed during the interviews. In this manner, the researcher reviewing the audio interviews multiple times and examining the interview transcripts along with the thematic excerpts to convey the data in the study, thereby validating the participants' perspectives in the interpretations (Denzin & Lincoln, 2018), upheld the authenticity criteria.

Results and Discussion

The prominent themes developed from the analysis of the data were *Contents Sufficiency, Sequential Consistency, Contextual Pedagogical Practice and Unfamiliarity exam system* in relation to prerequisites for the bachelor level mathematics. These themes emerged through a thematic analysis of the interview data. However, these themes not only highlight the insightful of engineering mathematics teacher on the secondary level mathematics curriculum particularly grade 11 and 12 mathematics in Nepal, but they also encompass further study works and theories related to curriculum developments. The themes are described and analyzed in the subsequent subsections.

1. Contents Sufficiency

Secondary school mathematics curriculum is generally perceived as adequate for Bachelor of Engineering prerequisites. Teachers like Professor Puspa emphasized "*the current calculus coverage is sufficient, with a suggestion to introduce introductory elements of McLaurin and Taylor series*". Similarly, Professor Krishna argued, "*the secondary school mathematics curriculum is sufficiently aligned with the prerequisites of the Bachelor of Engineering (BE) course*". He further proposed "*specific improvements such as incorporating concepts of curvature, asymptotes, and expanding conic sections to include general types, while also recommending the addition of differential equation applications and line format in 3D geometry*".

However, the curriculum's comprehensiveness varies across different educational boards. Professor Bishal highlighted that the NEB curriculum provides more comprehensive coverage compared to CBSE and Cambridge A-level mathematics, with CBSE focusing more on practical applications. He further added "*The provision of compulsory practical/project work is also helping the BE level students by providing clear concept, providing application of mathematics as well as encourage the self-learning ability of students but the implementation of prescribed practical provision has not done honestly as the intention of the NEB curriculum in most of the schools*". Despite this, there's a concern raised by Professor Puskar "*the curriculum is only sufficiently preparing students for the first semester of bachelor's studies, indicating potential gaps that need addressing in the current mathematical education framework.*"

The above narrations indicate school mathematics curriculum particularly grade 11 and 12 is adequately provides prerequisites of the Bachelor of Engineering (BE) course.

However, there is room for improvement in the content. For instance, incorporating an introductory segment on McLaurin and Taylor series for infinite series, particularly focusing on the transition from functions to series, would enhance the curriculum's relevance and depth. The secondary level mathematics curriculum has aligned with Ornstein and Hunkins (2018) that knowledge and content are well accepted integral parts of each curriculum.

2. Sequential Consistency

Most teachers agree that vertical linkage between secondary and bachelor-level mathematics courses is fundamentally sound. Professor Puskar explicitly stated that the vertical linkage is well-established, with consistent course content progression across different educational levels. The NEB curriculum, as noted by Professor Bishal, "*provides a necessary and wide range of concepts that create a solid foundation for further mathematical studies*."

However, some inconsistencies and challenges exist in the sequential arrangement of content. Professor Pushpa point out "*some vertical linkages are not properly arranged*", while Professor Bishal highlighted a critical issue "*there are some students selectively study chapters, often skipping crucial topics like calculus in grades XI and XII. This selective studying creates potential gaps in mathematical understanding, potentially compromising students' preparedness for engineering and advanced mathematical studies*". The need for a more structured and comprehensive approach to curriculum sequencing is evident from these observations.

Curriculum demonstrates good sequential consistency, as the topics covered at the secondary level align through the foundational requirements for engineering-level mathematics (Ornstein & Hunkins, 2018). Topics such as calculus are covered well, and the vertical linkage between secondary level and bachelor level mathematics is strong. The vertical linkage of curriculum is essential (Glatthorn et al., 2018), it makes new learning easier (Wiggins & McTighe, 2005) and it certain the relevancy of the curriculum (Harden, 2001). However, the escaping behavior of the students for some chapters in grades 11 and 12 made some short of lack of fundamental knowledge to study in bachelors engineering.

3. Contextual Pedagogical Practices

The current pedagogical approach in secondary mathematics education is critically examined by multiple teachers. Professor Puskar strongly criticizes the overemphasis on exam results and short-term student satisfaction, by arguing, "*Teachers prioritize simple problems and exam-oriented techniques over long-term conceptual understanding*". This sentiment is echoed by the overall pedagogical critique that advocates students are more focused on achieving results rather than developing a deep conceptual understanding of mathematical subjects.

To address these pedagogical challenges, teachers propose several innovative solutions. Professor Bisal and Professor Shree recommend implementing compulsory practical work and projects to provide clear concepts and encourage self-learning abilities. Additionally, Professor Shree suggested "*instructors should provide specific examples and utilize different techniques while teaching mathematics in various engineering faculties, potentially using tools like MATLAB and Zeo-Zebra to enhance practical understanding*". These recommendations aim to transform the pedagogical approach from result-oriented to concept-driven learning.

While the content is adequate, pedagogical practices at the secondary level need improvement. Teachers often prioritize exam-oriented techniques and simplified problem-solving to ensure immediate success, focusing on short-term results rather than fostering long-term conceptual understanding. This approach hinders students from grasping the broader implications and applications of mathematics. A shift toward conceptual and practical learning, emphasizing the real-world significance of mathematical concepts, is necessary to prepare students for advanced studies (Stenhouse, 1975; Eisner, 1994).

4. Unfamiliarity with Examination System

The examination systems at secondary and bachelor levels reveal significant disparities that challenge student progression. Professor Puskar explicitly noted the substantial differences in question patterns between these levels, which create difficulties for students transitioning to bachelor level studies. Professor Puspa also pointed out the gap of the examination systems as "*Examination system are huge different. Not the previous experience of the examination system does not support for bachelor level.*" Professor Bishal and Professor Shree further elaborated as "*BE-level exams often neglect to include a balanced mix of questions testing knowledge, comprehension, application, and higher analytical skills, and fail to progress logically from familiar to unknown concepts*".

To address these systemic challenges, teachers propose several constructive modifications. Professor Krishna highlighted the weakness in the current monitoring system, noting that "*most school students view practical work as grade-oriented rather than knowledge-driven*". Professor Puskar suggested "*by increasing the number of questions while reducing individual question weights and introducing optional 'OR' questions to provide more flexibility at the bachelor level*". The recommendations collectively aim to create a more student-friendly, comprehensive, and progressive examination system that better supports students' learning and understanding across different educational stages.

This difference causes difficulties for students transitioning to higher education (Wiggins & McTighe, 2005). To address this, the number of questions should be increased, their weightage reduced, and an "OR" choice provision should be introduced to better align with the evaluation system at the bachelor level. However, the transition between secondary and bachelor-level education is hampered by differences in evaluation systems. The experience obtained by the students regarding the examination system could not support them for undergraduate level as it is essential component for learning (Ornstein & Hunkins, 2018) .The question patterns, number of questions, and evaluation techniques in secondary education differ significantly from those at the bachelor level, making it challenging for students to adapt. Introducing a more gradual transition and harmonizing question patterns could bridge this gap.

Conclusion and Implication

Findings indicate there is not significant gaps between secondary mathematics course contents and engineering program demands. Practical aspect of the course should be priorities on project work and honestly implementation of the curriculum for betterment. The study reveals critical gaps in secondary mathematics education that demand comprehensive transformation in some aspects. Curriculum developers should redesign educational frameworks to prioritize conceptual understanding over exam-oriented learning, emphasizing practical application and vertical integration of mathematical concepts. Pedagogical approaches require radical shifts from result-focused methodologies to practice-based learning that cultivates deeper mathematical comprehension (Freire, 2021). Examination systems need fundamental restructuring to create assessment methods that evaluate analytical capabilities and conceptual understanding rather than rote memorization. Educational policymakers should emphasis on standardizing practical work guidelines, introducing interdisciplinary learning techniques, and developing flexible educational modules bridging secondary level mathematics and bachelor in engineering education. The research underscores the importance of technological incorporation, recommending tools, like MATLAB, to enhance mathematical understanding across engineering disciplines. Ultimately, the study calls for a holistic educational approach that balances theoretical knowledge with practical skills, preparing students more effectively for advanced academic and professional careers.

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