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# Flipped Learning in Mathematics and Science Education: A Systematic Review with Implications for Higher Education in Nepal

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## Abstract

Flipped learning is a learner-centered teaching strategy that reverses the conventional learning environment by delivering instructional content before class. Despite several studies on this model globally, there remains a lack of a systematic review of the studies focusing on mathematics and science higher education in Nepal. To address this gap, this study conducted a PRISMA-guided systematic review of flipped learning research published between 2015 and 2025. In this review, a thematic synthesis was employed to identify pedagogical practices, students' engagement, higher-order learning outcomes, implementation challenges, and implications for higher education transformation. For review, relevant studies were retrieved from major academic databases such as Scopus, Web of Science, ERIC, Google Scholar, and ScienceDirect. After systematic identification, screening, eligibility assessment, and qualitative synthesis, 20 peer-reviewed articles were selected for qualitative thematic meta-analysis. This study explicitly employed constructivist, cognitive load, and self-regulated learning perspectives. The findings of this study reveal that flipped learning generally enhances students' engagement, academic performance, conceptual understanding, and the development of higher-level thinking skills. Nevertheless, students' readiness, faculty workload, the digital divide, and institutional culture remain major obstacles. Finally, this study provides evidence-based insights for learner-centered pedagogy, digital equity, teacher preparation, and higher education reform in resource-constrained contexts.

**Keywords:** flipped classroom, mathematics education, science education, higher education, student engagement, systematic review

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## Introduction

Higher education systems around the world have been experiencing major challenges and changes in teaching methods due to several factors, including the rapid development of technology, the globalization of knowledge, and the increased demand for a skilled workforce for twenty-first-century workplaces. Besides imparting verbal and numerical literacy, universities, more than ever before, are under pressure to produce and develop skilled graduates with twenty-first-century competencies such as collaboration, critical thinking, innovation, and lifelong learning. In this understanding, the use of conventional and lecture-based instruction as

a primary feature of higher education has been severely criticized for encouraging passive learning and failing to promote deep cognitive engagement in learners (Nouri, 2016). Subsequently, higher education reforms across the world have emphasized learner-centered, interactive, inquiry-based and competency-oriented approaches to promote active learning and learner engagement. In this respect, learner-centered approaches mainly focus on active participation, inquiry, and knowledge construction. In this regard, flipped learning is also a learner-centered instructional strategy in which the traditional pattern of teaching-learning is reversed. The learners learn at home first through videos, podcasts, guided readings, or any

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other digital materials, and then, the classroom time is utilized for active learning activities such as group work, discussions, problem-solving activities, and exercises with guidance (Hamdan et al. 2013). Teachers conduct such interactive tasks and application-based learning to promote conceptual understanding, learner autonomy, critical thinking, engagement, and personalized learning. In this sense, flipped classrooms change the teacher's role from knowledge delivery to learning facilitation. Such a rearrangement of teaching-learning aligns with the ideas behind constructivist learning theory, which suggests that knowledge is created as a result of active involvement of learners, discussions with others, and step-monitored practices (Vygotsky, 1978). Philosophically, flipped learning is based on the constructivist paradigm that focuses on learners' active role in knowledge construction, collaborative inquiry, and reflective practices. Such learning remains contextually conditional rather than absolute. Weak digital infrastructure, large class sizes, examination-oriented systems, limited learner autonomy, insufficient teacher preparation, learners' inadequate prior knowledge, weak self-regulation, and limited academic support may be among the conditional factors.

Meta-analyses of previous studies have also shown that teaching through flipped learning strategies leads to a higher level of engagement, motivation, and academic performance in learners compared to traditional lecture-based teaching strategies (van Alten et al., 2019). For learners, flipped learning provides opportunities to study "teaching items" at their own pace at home before the class, while classroom time is fully devoted to meaningful teacher-student interactions, collaborative learning, and guided practices for effective learning outcomes. In mathematics class, the flipped learning strategy is found to be better for conceptual understanding, learner autonomy, and problem-solving skills (Karjanto & Acelajado, 2022). Similarly, the studies in science and medical fields report that the flipped classroom model contributes to better examination results, group work, and higher-level cognitive capacity (Cui et al. 2023). Furthermore, flipped learning has been identified as a transformative pedagogical innovation that integrates technology-enhanced learning with active classroom engagement.

The effectiveness of the flipped learning strategy can be further observed from various theoretical perspectives. Constructivist learning theory, for instance, emphasizes that knowledge is actively constructed through social interaction and participation. Flipped classroom strategies provide such opportunities by allocating more time for collaborative and interactive learning experiences during the class (Vygotsky, 1978). Similarly, cognitive load theory argues that students learn more effectively when they receive information for the first time at their own pace. Furthermore, it helps students reduce their unnecessary cognitive load and concentrate on classroom interaction for deeper understanding, application and further processing of the material (Sweller, 2011). In addition, self-regulated learning theory suggests

that flipping learning encourages students to plan, manage and evaluate their learning by themselves, thereby fostering metacognitive skills which are not only useful in academic settings but also in life-long learning processes (Zimmerman, 2002). Furthermore, social perspectives suggest that collaborative interaction, peer discussion and guided classroom participation in flipped learning support effective communication skills, cooperative learning, and knowledge construction. However, the adoption of flipped learning varies considerably across the global educational contexts. Several studies show that the successful implementation of this strategy depends on more factors beyond technology, such as quality of educational planning, teachers' readiness, institutional support, and student readiness (Baig & Yadegaridehkordi, 2023). In the same vein, self-regulated learning remains challenging in many developing countries due to traditionally accustomed teacher-centered and examination-driven pedagogies, limited digital literacy, digital divide and poor independent as well as self-study habits. These factors, including increased teachers' working hours and students' unwillingness to accept new learning, have challenged the effective implementation of flipped learning in higher education in developing countries like Nepal.

The adaptation of the flipped learning strategy can be investigated in the higher education system of Nepal. As in many developing countries, Nepal has witnessed a rapid expansion of university enrollment and the establishment of new universities over the last twenty years. Along with this, there has been an increasing demand for quality education, integration of technology, and employability of the graduates. Government policies have also been emphasizing digital learning, innovation, and competency-based education. However, teaching practices in many institutions also largely rely on traditional lecture-based approaches due to a lack of technology, insufficiently trained faculty and required resources, as well as disparities between urban and rural campuses (Sharma & Gautam, 2024). In addition, most of the recent studies show growing awareness of innovative teaching methods integrated with technology, such as blended learning, technology-supported teaching approaches, and so on. In this regard, the flipped learning model also employs technological integration during pre-class and even in-class sessions to enhance student engagement, collaborative learning, and problem-solving skills. However, such integration remains very fragmented and experimental rather than strategic due to the digital, infrastructural and institutional challenges. The digital divide, such as unreliable internet connections, unequal access to digital devices and the absence of institutional support, obstructs the implementation of such innovative and digital-friendly teaching methods (UNESCO, 2023). Consequently, universities still fail to guide policy formulation and practical strategies for integrating the flipped learning model into curricula. Moreover, many higher education institutions in Nepal still lack the explicit pedagogical frameworks, institutional strategies, and professional development mechanisms

required to effectively implement flipped learning in science and mathematics education. The examination-oriented teaching culture and limited digital competency among teachers and students further discourage the use of flipped learning.

Although concern towards the flipped learning model has been increasing rapidly, the research findings remain fragmented across disciplines, research methods and regional contexts. Furthermore, most of the studies on the flipped learning model are found in educational settings, but only very few are in mathematics and science education, in which students usually experience much more difficulty in conceptual learning. Not only this, very limited studies interpret global findings from perspectives of developing higher education contexts, such as in Nepal, where infrastructural, technological and pedagogical constraints discourage the use of innovative pedagogies. In addition, most of the review studies on flipped learning have been made in general education settings or technologically advanced countries. These reviews place much emphasis on students' achievement and technological integration, but rarely connect global evidence with the ongoing pedagogical transformation agenda of education in developing countries such as Nepal. Furthermore, the diversity of socio-economic, technological, cultural and institutional contexts across the globe limits the direct generalization of findings of flipped learning from one context to another. The effectiveness of flipped learning is strongly influenced by contextual realities such as technological accessibility, institutional readiness, teacher preparedness, and learner engagement.

The present review not only synthesizes recent empirical studies from 2015 to 2025, particularly related to mathematics, science and STEM higher education, but also explicitly interprets their implications for higher education reform, digital equity, teacher readiness, and competency-based pedagogy in developing countries. Unlike previous studies, this review focuses on mathematics and science higher education within under-resourced contexts and connects global evidence with practical and policy-level implications for higher education transformation in Nepal. In this respect, this review distinguishes itself from previous reviews in terms of its disciplinary focus, contextual interpretation, latest evidence base and policy-oriented perspective for higher education transformation in developing contexts like Nepal. In order to address this gap, this study presents a PRISMA-guided systematic review of published works on flipped learning in mathematics and science from 2015 to 2025.

By synthesizing global evidence and interpreting findings from developing higher education in resource-constrained perspectives, this study seeks to bridge global research to the local educational transformation. In this respect, the significance of this study is threefold: firstly, it collects all most recent studies on flipped learning in mathematics, science and STEM in higher education; secondly, it reviews the major pedagogical, technological and institutional factors that influence the flipped learning in mathematics and

science education; and thirdly, it guides for development of ongoing pedagogical reforms in Nepal based on the reviewed studies. This can be a reference for policy-makers, institutional heads, and teachers seeking innovative pedagogies. In this respect, this study contributes to policy formulation, institutional planning, digital planning, digital equity, and competency-based pedagogical transformation in Nepalese higher education along with academic scholarship on flipped learning. In this regard, this study surveys the development of flipped learning, evaluates students' engagement and academic achievements, along with facilitative and inhibitory factors for exploring the potential role of flipped learning in ongoing higher education reform in Nepal.

Various literature on flipped learning suggests that it is not just a technological innovation; it is a transformative pedagogical approach that enhances inclusive, learner-centered and competency-oriented higher education. Despite a growing number of studies on flipped learning, very few studies have been made on mathematics and science higher education in resource-constrained contexts. Such types of context-sensitive studies are required to be revisited and reviewed to get the insights for pedagogical reforms in developing countries like Nepal. Even to address this gap, this study attempts to review and critically examine global research on flipped learning to contribute to higher education in Nepal.

Furthermore, the applicability of research findings of flipped learning is confined by two major factors. First, various studies on flipped learning have been made across diverse disciplines employing different methodologies, resulting in fragmented and inconsistent findings. Second, these studies have been conducted in diverse socio-economic, technological and pedagogical contexts which cannot be directly generalized in another contexts, i.e., regions and systems. Thus, contextual understanding and interpretation of global evidence are essential before applying flipped learning in higher education systems in Nepal. In addition, very few research works have been conducted on the flipped learning model, especially in mathematics and science education, which can be generalized in resource-constrained countries such as Nepal. Unlike previous reviews on flipped learning, this review critically synthesizes empirical evidence through a context-sensitive lens. In this sense, this review not only summarizes previous findings but also contextualizes them for practical and policy-level transformation in Nepalese higher education.

To address this gap, this study presents a systematic review guided by PRISMA guidelines to synthesize global empirical findings while exploring its implications for the transformation of higher education in Nepal.

## Research Questions

This systematic review, based on the PRISMA guideline, is guided by the following four research questions:

1. How is the flipped learning model implemented in mathematics and science higher education in the global context?
2. What effects does flipped learning have on student engagement, academic achievement, and higher-order learning outcomes?
3. What factors facilitate or hinder flipped learning implementation in higher education?
4. What implications does global evidence on flipped learning hold for higher education transformation in Nepal?

## Methods

This study adopted a PRISMA-guided systematic literature review (SLR) to identify, evaluate and synthesize the global empirical evidence on flipped learning, especially in mathematics, science, and STEM higher education. This review is a transparent, replicable, and rigorous process in the identification, evaluation, and synthesis of existing research evidence (Page et al., 2021). Compared with traditional narrative reviews, the SLR approach reduces selection bias through predefined search procedures, explicit inclusion and exclusion criteria, and systematic analysis.

This thematic qualitative synthesis review design was preferred here for three reasons. Firstly, the rapid expansion of flipped learning research across various educational disciplines has created a significant body of evidence that requires systematic consolidation. Secondly, because of the different methodological traditions applied in the teaching of mathematics and science, an integrative synthesis is required to identify common patterns, converging findings and emerging trends. Thirdly, the ongoing reform initiatives in Nepalese higher education demand evidence-based pedagogical guidance derived from global research and best practices rather than isolated case studies. In addition, the review process was guided by internationally recognized systematic review principles and reporting standards as proposed by Kitchenham (2004), Snyder (2019), and PRISMA reporting standards (Page et al., 2021). These principles guide the procedures for study identification, screening, eligibility assessment, data extraction and synthesis. This qualitative analysis emphasized identifying recurring pedagogical, technological, and institutional themes influencing flipped learning implementation and outcomes.

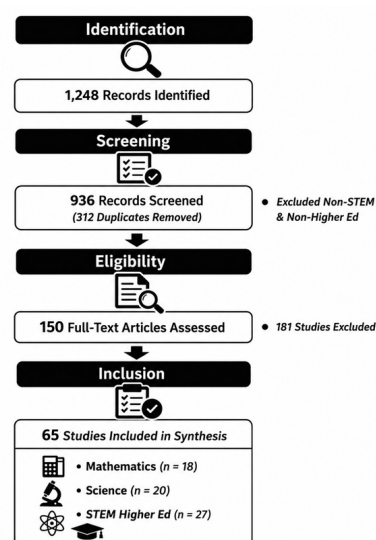
## Review and Search Strategy

To ensure methodological transparency and academic reliability, the literature search was systematically conducted across the six main academic databases, such as Scopus, Web of Science, ERIC, ScienceDirect, SpringerLink, and Google Scholar. These databases were selected because of their broad coverage of peer-reviewed educational research. Moreover, indexing quality, citation impact, and

relevance to mathematics and science higher education pedagogy were considered during the database selection. The search strings employed keywords combined with the Boolean operators to retrieve relevant studies. This included any of the “flipped learning”, “flipped classroom”, “mathematics education”, “science education”, “STEM education,” or “higher education”. The search was confined to peer-reviewed journal articles published from 2015 to 2025 in order to capture recent developments and practices in flipped learning. In addition to database searching, reference list screening and backward citation tracking were also employed to identify relevant studies that may not have been retrieved through the initial database searches. Such multi-stage search strategies enhanced the comprehensiveness and reliability of the review processes.

## Study Selection Process

The process of selecting studies was made using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure transparency, methodological rigour, and replicability (Page et al. 2021). PRISMA provides standard steps for the identification, screening, and selection of research evidence relevant to systematic reviews. To identify high-quality empirical research on flipped learning in mathematics, science, and STEM higher education, this study adopted a structured multi-stage selection procedure. Four consecutive stages, such as identification screening and final inclusion, were used in the systematic review procedures. At each stage, irrelevant, duplicate, or poor methodological studies were systematically excluded on the basis of exclusion criteria. The application of these well-established criteria at each stage ensured that only peer-reviewed, relevant, and contextually appropriate studies were included in the qualitative synthesis, thereby enhancing the credibility, trustworthiness, and accuracy of the review findings. The stages of the study selection process are illustrated in Figure 1.



**Figure 1: Study Selection Process**

Inclusion and Exclusion Criteria

Establishing and defining clear inclusion and exclusion criteria is essential for systematic reviews to ensure transparency, methodological quality, and relevance in the selection processes. This review selected 20 studies as its final corpus through rigorous PRISMA-guided screening processes on the basis of pre-determined inclusion and exclusion criteria. Regarding the inclusion criteria, the studies were included only if they focused on flipped learning or pedagogy, studies conducted on mathematics, science or STEM higher education contexts, related to empirical studies related to innovative pedagogies or practices, peer-reviewed journals published between 2015

to 2025, and available in full-text versions. For exclusions, the incomplete articles, non-peer-reviewed journals, and studies unrelated to higher education in STEM disciplines were excluded. This systematic selection process ensured methodological consistency, contextual relevance, and analytical reliability of the reviewed evidence. Setting predetermined criteria is a way to reduce selection bias and ensure that only studies aligned with the main objectives of the review are included in the final analysis. In this study, the criteria were designed to ensure the inclusion of studies that were methodologically rigorous, contextually relevant, and directly related to flipped learning in mathematics, science, and STEM education. The inclusion and exclusion criteria applied in this review are presented in Table 1.

Table 1: Inclusion and Exclusion Criteria

| Criteria Category  | Inclusion Criteria                                               | Exclusion Criteria                                                   |
|--------------------|------------------------------------------------------------------|----------------------------------------------------------------------|
| Publication Type   | Peer-reviewed journal articles                                   | Opinion papers, editorials, theses, conference abstracts, or reports |
| Publication Period | Published between 2015 and 2025                                  | Published outside the specified time range                           |
| Language           | Articles written in English                                      | Non-English publications                                             |
| Educational Field  | Mathematics, science, or STEM education                          | Studies unrelated to STEM disciplines                                |
| Educational Level  | Higher education or university contexts                          | Studies focused exclusively on K–12 education                        |
| Research Design    | Empirical studies or systematic reviews                          | Conceptual papers without empirical evidence                         |
| Pedagogical Focus  | Explicit implementation of the flipped learning pedagogy         | General blended learning without a flipped structure                 |
| Accessibility      | Full text available                                              | No full-text access                                                  |
| Outcome Reporting  | Reported measurable learning outcomes or implementation evidence | Studies lacking outcome data or implementation evidence              |

Quality Assessment

The methodological quality of the selected studies was assessed using modified criteria adapted from Kitchenham (2004), Creswell and Creswell (2018). The study was assessed across five key aspects, such as clarity of research design, methodological rigour, legitimacy of data analysis procedures, clarity of reporting, and relevance to the research questions. Each study was independently reviewed by two researchers to enhance reliability, trustworthiness, consistency, and minimize biases regarding the inclusion or exclusion. Quality standards were employed from inception to presentation.

The quality standards were maintained through strategies such as clearly defined inclusion and exclusion criteria, rigorous screening, independent assessment by multiple researchers, and development of systematic and valid review guidelines for data extraction. However, this review cannot entirely avoid subjectivity; methodological standards significantly strengthen the credibility, consistency, and reproducibility of the reviewed findings. Any dilemmas or disagreements in evaluation were resolved through discussions and consensus.

Data Extraction

A structured data extraction protocol was developed to ensure analytical consistency across studies. For each

article included in the study, the following information, such as author(s), publication year, study context, study design, participants, subject area, intervention characteristics, data collection methods, key findings and implications related to flipped learning, was systematically extracted. Data extraction was made to ensure both accuracy and completeness.

Data Synthesis and Analytical Approach

Relevant data were extracted from the selected studies for thematic synthesis employing an interpretive approach, which is suitable for integrating findings from various types of research (Snyder, 2019). Such thematic synthesis enabled us to identify common patterns and show the relationships as well as trends of the themes, considering the contextual variability of different studies. After extracting the data, the analytical procedure was conducted in three steps: initial coding of extracted findings, development of analytical themes, and generation of broader analytical themes. On the basis of such analysis, four main themes emerged from the thematic analysis of the extracted data, which served as the organizing themes for the Results and Discussion chapters.

Results

The reviewed studies were selected from diverse geographical regions such as Asia, North America, Europe,

the Middle East, Africa, and Oceania. The majority of these studies were from technologically-advanced countries such as China, the United States, Taiwan, Turkey, Spain, and Malaysia. However, the studies from South Asia and other under-resourced contexts were comparatively limited. In this regard, the findings of this study can be presented under various thematic headings as given below.

### Overview of Included Studies

The study identified 20 peer-reviewed articles published between 2015 and 2025 based on predetermined inclusion criteria. These selected studies reviewed here cover diverse geographical contexts, educational levels, and subject domains, particularly mathematics and science education. The screening procedure is outlined in the PRISMA flow diagram (Figure 1), while Table 1 presents a summary of the main features of the included studies. From this, the analysis reports that the flipped learning approach has been adopted in higher education systems. Most of the studies were from Asia (38%), North America (20%), the Middle East (10%) and Africa and Oceania (7%), particularly from

China, the United States, Turkey, Spain, Malaysia, and South Korea, as shown in Table 2. These included studies were further classified according to major disciplinary clusters. The studies on mathematics, for instance, were mainly concerned with calculus, statistics, algebra, and teacher education programs. Likewise, the studies on science were more focused on laboratory-based learning, conceptual understanding, and inquiry-based instruction. Despite the global expansion of this learning model, very few studies originated from South Asia, revealing a significant research gap that would be of interest to Nepal and other developing countries. Overall, the review shows that flipped learning has been widely implemented in all educational settings. The dominance of undergraduate-level studies reveals that flipped learning is primarily used to transform traditional teaching into foundational STEM courses, which are marked by high failure rates and difficulties in understanding concepts. Methodologically, the studies adopted very different research designs, enabling a comprehensive examination of both the learning outcomes and the implementation of flipped learning.

**Table 2.** Summary of Included Studies on Flipped Learning in Mathematics and Science Education (n = 20)

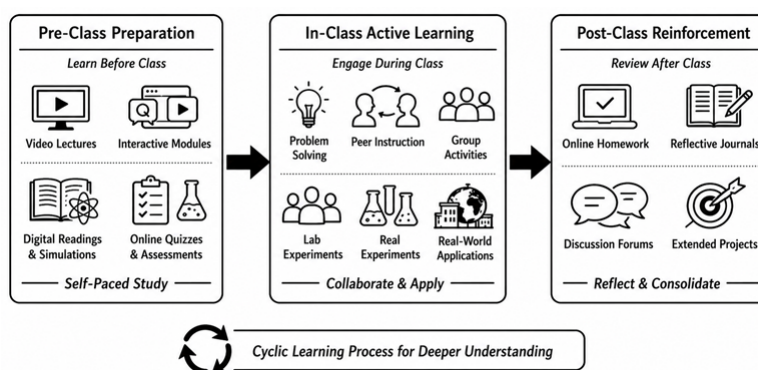
| Author(s) and Year                | Country     | Discipline            | Study Design                        | Key Findings                                                            | Challenges/Notes                                                             |
|-----------------------------------|-------------|-----------------------|-------------------------------------|-------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Abeysekera & Dawson (2015)        | Australia   | Higher Education      | Conceptual/Theoretical Paper        | Enhance motivation and reduce cognitive load when designed effectively. | Lack of empirical evidence                                                   |
| Jensen et al. (2015)              | USA         | Biology               | Quasi-experimental                  | Higher conceptual understanding                                         | Requires extensive classroom redesign and preparation time                   |
| Lage et al. (2016)                | USA         | Science               | Case Study                          | Higher student achievement                                              | Resource management issues                                                   |
| Zainuddin & Halili (2016)         | Malaya      | Multidisciplinary     | Systematic Review                   | improve motivation, engagement, and self-regulated learning.            | Need for better technological infrastructure and instructional design.       |
| Chen et al. (2017)                | USA         | Medical Science       | Systematic review                   | Better academic outcomes                                                | Time to develop digital materials; students' resistance                      |
| Lo & Hew (2017)                   | Hong Kong   | K-12 Mathematics      | Critical Review/Systematic Review   | Improves students' engagement, understanding, and learning              | Unprepared students, time-consuming, unequal access                          |
| Akçayır, G., & Akçayır, M. (2018) | Turkey      | Higher Education/STEM | Systematic Review                   | Enhances student achievement, motivation, and engagement                | Unequal student preparedness; technology access issues                       |
| Hew & Lo (2018)                   | Hong Kong   | Health/Science        | Systematic review and Meta-analysis | Mixed achievement effects                                               | Heterogeneity across studies, implementation, and inadequate technology      |
| Lundin et al. (2018)              | Sweden      | STEM/Higher Education | Systematic Review                   | Improve learning outcomes and participation in STEM courses             | Mixed evidence due to variation in design and implementation                 |
| Van Alten et al. (2019)           | Netherlands | STEM                  | Meta-analysis                       | Significant achievement gains                                           | Effective only when combined with quizzes and structured in-class activities |

|                              |            |                       |                           |                                                                                   |                                                                                             |
|------------------------------|------------|-----------------------|---------------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| Al-Samarraie et al. (2020)   | Global     | STEM                  | Systematic review         | Engagement improves with design quality                                           | Challenges include students' low motivation, technological barriers, and increased workload |
| Strelan, P. et al. (2020)    | Australia  | STEM/Higher Education | Meta-analysis             | Positive on achievement and learning outcomes                                     | Depends on various factors                                                                  |
| Bredow et al. (2021)         | USA        | Higher Education/STEM | Meta-analysis             | Positive cognitive and affective outcomes                                         | Study quality inconsistency                                                                 |
| López-Belmonte et al. (2021) | Spain      | STEM Education        | Systematic Review         | Academic achievement, motivation, participation, collaboration, and higher-order. | Depends on digital infrastructure, teacher competence, students' autonomous                 |
| Kapur et al. (2022)          | USA        | Education/STEM        | Meta-review               | Effective when integrated with productive failure and active learning             | Weak instructional design reduces effectiveness.                                            |
| Ezeh et al. (2023)           | USA        | STEM                  | Meta-analysis             | Effective in STEM learning                                                        | Depends on students' preparedness and instructors' pedagogical competence                   |
| Gong, Cai & Cheng (2024)     | China / UK | STEM Education        | Meta-analysis             | Significantly improves STEM student achievement                                   | Depends on various factors                                                                  |
| Haziki, N. H. et al. (2025)  | Malaysia   | mathematics           | Meta-analysis             | Moderate effects                                                                  | Heterogeneity in study designs                                                              |
| Li et al. (2025)             | Global     | K–12 STEM             | Three-level Meta-analysis | Positive effects on performance                                                   | Unequal access to technology and differences in students                                    |
| Czarnowske et al. (2025)     | Germany    | Higher Education/STEM | Causal ML study           | No significant improvement in exam scores; engagement improved                    | Implementation quality critical                                                             |

### Models of Flipped Learning Implementation

The review revealed that despite differences in institutional contexts, flipped learning is generally implemented through a consistent three-phase model: (1) pre-class preparation, (2) active learning during in-class time, and (3) post-class consolidation. Together, these three phases restructure the

traditional sequence of teaching methods by redesigning initial content acquisition to the post-class stage and retaining class time for higher-order, interactive learning activities. This flipped learning model reforms cognitive effort across various learning environments, enhancing deeper engagement and meaningful understanding.



**Figure 2:** Three Interconnected Phases of Flipped Learning

The three-phase activities given in Figure 2 are discussed below briefly.

**Pre-class Preparation (Before Class):** This step really differentiates flipped learning from traditional learning. Here, students engaged with the core content before class

time via recorded videos, interactive modules, digital readings, and formative assessments. Besides allowing students to learn at their own pace, this method also helps them clarify any confusion and address areas of difficulty in advance so that they can be prepared for deeper engagement and interaction in the class.

**In-class Active Learning (During Class):** In this phase, the main function of the classroom time is not one-sided lecturing but focuses on students' active and collaborative learning through various activities. These activities may include working on problems individually or in groups, peer teaching, doing experiments or simulations, participating in discussions and real-world applications. The teacher's role is to diagnose where students have got the wrong idea and guide them accordingly.

**Post-Class Reinforcement (After Class):** Ultimately, learning is effectively made through follow-up activities such as online assignments, reflective journals, discussion forums, and projects. This phase helps students get the opportunities for continuous reflection and application, fostering a spiral learning pattern which enhances long-term retention and deeper conceptual understanding. Collectively, these three stages are the typical structures for implementing flipped learning universally.

### **Role of Technology in Flipped Learning**

Across the reviewed studies, technology primarily functioned as a pedagogical enabler rather than an end in itself. Effective implementations aligned with the use of technological tools with teaching goals rather than relying on technological sophistication alone. In particular, several studies indicate that mobile-compatible and low-bandwidth resources proved to be quite effective in resource-limited settings, highlighting their relevance for higher education institutions in countries such as Nepal. Within this understanding, flipped learning can be feasible with the mobile-supported learning, downloadable offline resources, low-bandwidth instructional videos, and blended mode, even in rural as well as resource-constrained educational contexts.

### **Effects on Student Engagement**

The studies reviewed here indicate that student engagement emerged as a major outcome of flipped learning in the classrooms. By reversing the traditional pedagogical patterns from live instruction to self-paced learning outside the classrooms, in-class became more interactive and participatory, leading to increased attendance, interaction, and assignment completion. Besides, students reported that they were more responsible for their own learning, reinforced by pre-class quizzes and well-organized in-class activities. This model also fostered deeper conceptual understanding and determination in resolving complex problems through the students' engagement. For instance, exposure to teaching explanations via video repeatedly would be a strategy that helped math students understand the challenging concept better. The studies further reported that flipped learning increased learner motivation, reduced anxiety levels, and improved teacher-student relationships. In addition, flipped classrooms enhanced interactive and collaborative learning, encouraging peer support and shared understanding. In fact, the degree of students'

engagement depends on the instructional design prepared by the teacher.

### **Effects on Academic Achievement**

Academic performance was examined in 52 of the reviewed studies. The majority of these studies were experimental and quasi-experimental, which reported statistically significant improvement in students under flipped learning compared to traditional lecture-based methods. Consistently, meta-analytic evidence in STEM education indicates that active learning methods are associated with enhanced learning outcomes as opposed to passive lecture-based methods (Freeman et al. 2014). In mathematics education, substantial improvement was observed in subjects such as calculus and statistics, especially among low-achieving students.

Flipped learning emphasized deeper conceptual understanding and more meaningful learning outcomes rather than rote memorization. In a science laboratory setting, students in the flipped learning model performed improved skills in experimental design and scientific reasoning.

Furthermore, having students prepared beforehand allows the teacher to focus on inquiry and experimentation during the laboratory session. Several studies have shown that the flipped classroom model might be able to eliminate the differences in achievement levels by allowing students to work at their own pace. The students who had difficulties with the live lectures were at an advantage because they were given the chance to view the materials more than once. Despite this, the positives were only made possible through equal access to technology and support from the institution.

### **Development of Higher-Order Skills**

Beyond academic achievement, the flipped learning strategy contributes to the development of a wide range of twenty-first-century skills. Engagement in problem-based and inquiry-driven classroom activities fosters critical thinking skills, problem-solving capabilities, and evidence-based reasoning. Collaborative group work further develops communication, teamwork, and peer learning skills from their classmates as they learn from their teachers. A flipped class is a place where students are active agents of their own learning. Hence, they have to decide their time for study, monitor their progress and prepare in advance as a self-regulated learning (Zimmerman, 2002). In addition, regular interaction with digital platforms and multimedia learning resources enhances students' technological competencies along with other twenty-first century skills which are essential for personal, academic and professional contexts.

### **Student and Teacher Perceptions**

Overall, student attitude was found to be positive across all reviewed studies. One of the major advantages was the

flexibility offered by this model in which students engage with learning responsibilities and pre-class preparation at their own pace and space. However, some students resisted flipped learning at first as they had to prepare more in advance, and the students accustomed to teacher-centered systems found such transitions much harder. The perceptions of faculty members in the flipped learning model evolved over time. Initially, they were concerned about overload, particularly in creating instructional videos and later reported that their class burden was reduced, resulting in deeper engagement and meaningful interactions with students in in-class activities. Importantly, teacher training and professional development emerged as major factors that impacted teachers' willingness and ability to adopt the flipped learning model effectively.

### **Facilitators of Effective Implementation**

The synthesis of the studies identified several enabling factors regarding the effective implementation of the flipped learning model. Successful flipped classrooms aligned with learning objectives, assessments, and activities were highly emphasized. Access to reliable technology infrastructure, along with training and administrative support, played a vital role in effective and sustainable implementation. High-quality instructional materials, particularly well-designed video lectures, were found effective in supporting learning outcomes. In addition, the use of low-stakes quizzes helped students prepare for accountability and preparedness for in-class activities.

### **Challenges and Barriers**

Despite its demonstrated good results, flipped learning implementation faces several recurring challenges, such as limited access to reliable internet and digital supports in resource-constrained settings. Some students struggle with self-directed learning in the pre-class activities due to the absence of appropriate structured guidance. Teachers and learners who have been motivated by the exam-oriented teaching-learning pedagogy reported that the initial transition to the flipped learning model can be time-consuming. Furthermore, the dominance of examinations and teacher-centered lectures often hinders the adoption of flipped learning in developing country contexts such as Nepal.

### **Implications for Higher Education in Nepal**

Although empirical research on the flipped learning model in Nepal is still quite limited, insights from similar contexts can provide valuable directions. Any implementation should prioritize the context-sensitive strategies. Mobile-based learning and low-bandwidth digital resources seem the most 'doable' and promising for Nepalese universities at this time. In this respect, strengthening institutional infrastructure, providing teacher training and gradually integrating flipped learning into existing curricula are essential for sustainable adoption.

### **Synthesis of Evidence**

In general, the reviewed literature provides strong empirical evidence for the effective use of flipped learning in math and science education. The flipped model consistently encourages active learning, students' engagement, conceptual understanding, and the development of higher-order skills. However, its success is not only determined by technology alone, but it also depends on an appropriate pedagogical design, institutional readiness, and contextual adaptation. In this understanding, flipped learning is not just a teaching method but also a tool for change for a student-centered education system.

### **Discussion**

This systematic review synthesizes global empirical data to analyze flipped learning as a pedagogical change, not only a new teaching method. The findings of the reviewed studies further demonstrate that learning outcomes are better possible through the roles of teachers, students' learning strategies, and institutional culture rather than just the use of technology. For addressing the research questions, this systematic review integrates global empirical evidence on flipped learning in mathematics and science education and interprets its implications for higher education transformation, especially in developing higher education institutions, such as those in Nepal. In this regard, flipped learning is a major shift from teacher-centered pedagogy to learner-centered pedagogy. These findings from the reviewed studies present relevant frameworks, international empirical evidence, implementation contexts, and role of higher education reforms in future.

### **Flipped Learning as a Pedagogical Transformation**

The reviewed studies indicate that flipped learning reconfigures teaching and learning relationships rather than functioning as a mere technological innovation. Traditionally, students are seen just as passive recipients of knowledge in the conventional lecture-based models. The flipped learning model addresses the limitations of traditional pedagogies by relocating foundational content in the pre-class phase, thereby enabling the class time for higher-order cognitive activities. This change aligns with the constructivist learning theory, which emphasizes knowledge is actively constructed through interaction, collaboration, and problem-solving (Vygotsky, 1978). The findings from the reviewed studies suggest that flipped learning is a way to make constructivist principles work by enabling learners to explore, discuss, and apply what they have learned during face-to-face sessions.

Furthermore, the flipped learning model is the tool that transitions from present education relying on numeracy and literacy skills to competency-based education relying on knowledge of the student. This shift from literacy-based to competency-based education is gaining much more significant attention in global higher education,

especially in mathematics and science education, since these subjects require much conceptual understanding and active engagement rather than memorization. Notably, the effectiveness of flipped learning essentially depends on pedagogical design, where the technological support subordinates this pedagogy more effectively (Abeysekera & Dawson, 2015).

### **Impact on Student Engagement and Learning Processes**

One of the consistent findings across the reviewed studies is that students had much more engagement through participation. Pre-class preparation combined with in-class activities enhances behavioural, cognitive and emotional engagement. These outcomes are attributed to active learning theory. This active learning much more significantly improves students' performance in STEM education compared to traditional lectures (Freeman et al., 2014). Flipped classrooms also foster self-regulated learning through active learning and taking their own responsibility for effective learning in pre-class activities, monitoring their understanding and collaborating with peers in-class activities (Zimmerman, 2002). Such autonomous and self-regulated learning principles help students foster their interaction, engagement and problem-solving activities in-class contexts (Zimmerman, 2002). Enhancing such autonomy in learners is very important for becoming skilled and lifelong learners capable of adapting to changes in scientific and technological fields. However, improvements in engagement were not to be taken for granted. The findings of the reviewed studies demonstrate that if flipped courses were less well-designed, they sometimes resulted in students' resistance, particularly among students accustomed to passive learning. Thus, effective adoption needs gradual implementation, clear expectations, and structured accountability mechanisms such as formative assessment tools.

### **Academic Achievement and Conceptual Understanding**

The review offers strong evidence that flipped learning has a positive impact on students' academic success in mathematics and science. The findings in the reviewed studies reported better exam scores, deeper understanding of concepts, and increased abilities in solving problems in the flipped learning. Several explanatory factors can be attributed to these achievements: (1) students can learn at their own pace and revisit the complex concepts during their pre-class activities; (2) in-class activities give instant feedback and opportunities to address misconceptions; and (3) collaborative learning enhances deeper processing and knowledge internalization. In mathematics education, students benefit from repeated exposure through video content in their pre-class activities, while classroom time is devoted to problem-solving and critical thinking activities. In the same vein, the enthusiasm for science education was boosted by the acquisition of skills and increased preparedness through laboratory contexts.

### **Development of Twenty-First-Century Skills**

Besides academic performance, flipped learning also helped nurture twenty-first-century skills, such as critical thinking, collaboration, communication skills and digital literacy. These skills refer to adaptability, creativity and problem-solving required for the higher education framework. As the societal problems become much more complex in today's world, higher education institutions have to produce graduates with the capabilities of thinking and acting effectively in such situations, not only repositories of knowledge. Flipped learning involves collaboration, fostering peer learning communities. In these communities, learners articulate their reasoning, negotiate their understanding and engage in problem-solving practices that reflect the real-world personal and professional contexts. In addition, the use of digital tools enhances technological competencies aligned with your institutional goals. In this understanding, flipped learning helps the graduates enhance their competencies to address complex and complicated societal challenges.

### **Role of Technology: Enabler Rather Than Driver**

Technology integrated with pedagogy enhances effective teaching-learning activities in higher education. Even low-cost tools such as recorded lectures, open educational resources, and mobile-friendly platforms can be used in pre-class activities of the flipped model when aligned with teaching purposes. On the other hand, highly technological settings without pedagogical design result in limited changes. This finding is relevant for resource-constrained and developing contexts. Institutions need not wait for a sophisticated technological ecosystem, but well-designed low-bandwidth solutions can be equally effective.

### **Teacher Role Transformation**

Flipped learning views the roles of teachers from knowledge transmitters to facilitators, mentors, and designers of learning environments. Although teachers in the initial phase might feel the workload, they gradually experience better satisfaction with their instructions and meaningful engagement with students. Enhanced teacher-student interaction, improved responsiveness to needs, and satisfied instruction, along with better outcomes, are the major benefits of this model. In this respect, teachers' role in this learning model is much more active, dynamic and learner-centered.

### **Implementation Challenges and Institutional Barriers**

Despite the flipped learning model's benefits, it has been facing several implementation challenges for a long time. The prime issue is student readiness, as students are accustomed to lectures and may resist extra learning responsibility in pre-class activities. Without any proper guidance and structured accountability, some students may fail to engage with preparatory materials in their pre-class activities that will be preparation for in-class activities. Institutional culture also plays a major role in embracing this model. Other challenges, such as examination-driven

systems, rigid curricula, large class sizes, and limited instructional autonomy, prevent teachers from using this learning model. Digital divide creates unequal access to devices and internet connectivity, particularly in resource-constrained contexts. In this way, these challenges highlight that flipped learning needs systematic change with strategic plans.

### **Implications for Higher Education Reform in Nepal**

The findings of the reviewed studies here have significant implications for ongoing reform in higher education in Nepal. The flipped learning model has made us redefine the role of teachers from mere knowledge transmitters to creators of learning environments, mentors, and facilitators of student inquiry and engagement. Although teachers may initially experience increased overload for designing pre-class materials and activities, evidence indicates that they gradually become satisfied with their pedagogical shifts, such as their effective instructions, teacher-student interactions and collaborative outcomes in class activities.

The implications of the study regarding flipped learning are relevant in the context of Nepalese higher education, particularly in mathematics and science education. However, this model has been facing several challenges, such as large lecture classes, limited student participation, exam-oriented and memorization-based learning practices, and growing demand for digitally competent graduates. At the same time, universities are expected to produce digitally competent, creative, and employable graduates. In this regard, the flipped learning model can be an effective tool for transforming conventional teaching practices into more interactive, participatory, collaborative, student-centered, and skill-oriented approaches that align with the current reform agenda on quality enhancement, active learning and competency-based education. Pre-class content engagement and in-class problem-solving activities of the flipped learning model help students become more active in knowledge construction, critical thinking, communication, and teamwork.

A successful flipped learning model requires systematic professional development, institutional, and policy support for its effective use. University teachers may have less experience in student-centered pedagogy, digital instruction, and technology-mediated teaching practices. Thus, they need to be provided with large-scale teacher training, institutional mentoring and regular pedagogical support for effective implementation of this model. Likewise, teacher-centered instruction and examination-driven learning in the existing educational culture need gradual and context-sensitive transformation.

Furthermore, the growing use of mobile technology in Nepal supports implementing flipped learning in higher education. Mobile-supported instructional strategies such as short video lectures, downloadable learning materials, and offline-access resources can reduce the infrastructural and connectivity divide in resource-constrained contexts. It suggests that even locally available digital resources can be integrated with pedagogical reform rather than

highly sophisticated infrastructures. In this respect, the flipped learning model might encourage teachers in their professional development for student-centered pedagogy and the use of digital platforms for educational purposes.

In this respect, the findings imply that flipped learning can enhance the transformative pedagogical approach for higher education reform in Nepal by fostering active learning, digital integration, collaborative knowledge construction, and development of twenty-first-century skills for academic and professional success.

## **Conclusion**

This systematic review of 20 studies (2015-2025) synthesizes evidence on flipped learning in mathematics and science and offers its potential as a tool for higher education transformation in Nepal. The findings show that flipped learning is a potentially effective, student-centered approach that not only increases students' engagement and academic achievement but also enhances their conceptual mastery and encourages higher-order thinking. Flipped learning, which converts the traditional content delivery into a teacher-led online mode and reserves the face-to-face time for students' active involvement, cooperative work, and problem-solving, eliminates the drawbacks of traditional lecture-based teaching and facilitates the growth of critical thinking, communication, collaboration, and self-learning skills, which are very much needed in the 21st-century. Properly executed, the flipped classroom concept does not rely solely on technology but very much depends on well-planned, purposeful instructional design, the educational institutional backing, and the instructor preparation. Student resistance to compliance, increased preparation workload, inequality of access to resources, and traditional forms of student evaluation are some of the issues that call for well-thought-out strategies and gradual change.

In Nepal, flipped classrooms that take into account local conditions, for example, by using low-bandwidth and mobile-supported methods, offer realistic and scalable ways for changing STEM education. Overall, flipped learning is more than just a teaching method; it acts as a springboard for changes in higher education, capable of not only enhancing the quality of STEM education and promoting students' active participation but also of bringing Nepalese universities in line with worldwide educational movements. There is a need for more data-driven research in Nepal in order to fine-tune locally to ensure sustainable implementation. In this respect, this study theoretically contributes to the growing literature on flipped learning, aligning the constructivist learning theory, self-regulated learning theory, and cognitive load theory into a context-sensitive pedagogical framework for higher education transformation. Conceptually, this study presents an interconnected model linking technological accessibility, pedagogical design, institutional readiness, learner self-regulation and academic achievement within the flipped learning settings. From the pedagogical perspective, this study suggests that effective flipped learning demands gradual curriculum redesign, structured pre-class

engagement, interactive in-class activities and institutional support mechanisms adapted to resource-constrained contexts. For future research, this study recommends longitudinal case studies, mixed methods research, bibliometric analysis, and computational learning analysis to examine the long-term effectiveness, sustainability, and contextual adaptability of learning in South Asian higher education systems, particularly in Nepal.

## Implications

Based on the reviewed evidence, this study contributes to the literature by emphasizing flipped learning in mathematics and science education and interpreting implications in the context of developing higher education contexts, particularly in Nepal. Most of the previous studies have often emphasized technological aspects or general higher education trends; however, this study focuses on the pedagogical dimension of the flipped learning model. Furthermore, this study demonstrates how the flipped classroom method can be a means of transforming education even in non-technologically advanced contexts. Besides the line of reasoning that is typically followed, this review helps the reader to have a unified understanding of the present situation as well as the future directions of flipped learning in higher education. This review provides an overview of the research aspects of articles published from 2015 to 2025, and offers researchers a comprehensive reference and guides future research in this field.

Based on the reviewed evidence, this study presents a unified conceptual relationship among technological accessibility, pedagogical design, institutional support, learner self-regulation, engagement, and academic achievement. In this respect, the framework suggests that the effectiveness of flipped learning is possible through the interaction of these interdependent variables rather than through technology alone.

Despite the benefits, flipped learning is not universally successful in all contexts. The evidence from the reviewed studies shows that students' resistance, unequal participation, cognitive overload during pre-class preparation, difficulties among learners lacking self-regulated learning skills, unequal digital access, limited teacher preparedness, and institutional constraints significantly reduce the effectiveness of flipped learning in resource-constrained settings. Furthermore, theoretical lenses such as constructive learning theory, cognitive load theory, and self-regulated learning theory support flipped learning.

## Limitations

Although this review adhered to systematic procedures, it has several limitations. Variations in study designs, measurement tools, and contextual factors limited direct comparisons across studies. It was confined to a qualitative thematic synthesis review rather than a statistical meta-analysis for contextual and interpretive understanding of the flipped learning practices. The majority of studies from

technically developed regions may affect the generalizability of findings in resource-constrained higher education contexts, such as in Nepal. In addition, a publication bias might have resulted in a predominance of positive findings. Future investigations, thus, should shed light on higher education in South Asia and Nepal in order to enhance the contextual relevance.

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## Authorship

Dr. Kunwar conceptualised and supervised the entire work; Mr. Acharya contributed to drafting and content development; and Mr. Umanath Lamsal assisted with editing, formatting, and finalisation of the manuscript. All authors reviewed and approved the final version.

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